Impact of frozen storage on oxidation changes of some components in goose meat

M. Wereńska,[1] A. Okruszek, G. Haraf, J. Wołoszyn, and Z. Goluch

Department of Food Technology and Nutrition, Wroclaw University of Economics and Business, Wroclaw 53-345, Poland

ABSTRACT The objective of this study was to investigate the oxidation activity and lipid oxidation changes in breast (**BM**) and leg (**LM**) muscles from 17-wk-old female White Kołuda geese packaged in a vacuum, and stored in freezing conditions at −20°C. The geese were fed ad libitum during the experimental period (up to 17 wk) on the same complete feed. The samples of LM (n = 18) and BM (n = 18) from the right carcass were stored for 30, 90, 80, 270, and 365 d. Lipid oxidation was described by determining changes in: TBARS value expressing the amount of malondialdehyde (**MDA**), total antioxidant capacity (**TAC**) measured by DPPH and ABTS methods and total reduction potential (**TRP**) measured by FRAP method. Moreover, total heam pigments pigment (**THP**), relative concentration of myoglobin (**Mb**), oxymyoglobin (**MbO_2**), and metmyoglobin (**MMb**) were determined in this study. Time of storage affected the TAC, TRP, TBARS, and the color stability of BM and LM. The THP concentration and Mb proportion decrease gradually during the 365 d of frozen storage, while the relative concentration of MMb increase in BM and LM. It was noted that the shares of MMb in both analyzed types of muscles stored for 365 d did not exceed 0.4. This value is considered to be the limit, after which the meat takes on an intense gray-brown color not accepted by the consumer. The oxidation processes occurring during frozen storage caused an increase of TBARS and a decrease of $DPPH^{\bullet}$, $ABTS^{\bullet+}$, FRAP values in both kinds of muscles. The amounts of TBARS during frozen storage of muscles did not exceed 2.0 mg MDA/kg of meat. A higher value of TBARS than 2.0 causes a lack of acceptance by consumers of the flavor profile. Based on the results concerning changes in the heam pigments, as well as changes related to the oxidation of lipids, we cannot unequivocally state in which types of muscles the changes had a more intense course.

Key words: goose, frozen storage, heam pigments, TBARS, antioxidant potential

2022 Poultry Science 101:101517
https://doi.org/10.1016/j.psj.2021.101517

INTRODUCTION

After years of development, Poland's goose industry ranks high in terms of importance among the countries of Central and Eastern Europe with regard to raising geese and market output, and plays an indispensable role in the domestic and European waterfowl industry. According to statistics, the total goose production in Poland was 1.026 thousand carcasses and it was about 20,000 tons of geese meat (GUS, 2020). For many years, the main species used to produce goose meat in Poland has been the White Kołuda goose, which comprises up to 95% of the total commercial production; the remaining 5% of the domestic geese population are regional, native varieties, which are valuable material, especially for home farming (Łagowska and Bombik, 2016; Haraf et al., 2018). About 95% of the goose meat produced in Poland is exported, mainly to European Union countries, of which Germany is its largest recipient (Adamski et al., 2016). In Poland and many other countries in Europe, geese have been slaughtered seasonally from early spring to late autumn. In order to ensure the supply of goose meat outside the goose slaughter season, the meat is subjected to freezing and storage in freezing conditions. The purpose of storing meat in freezing conditions is primarily to inhibit catabolic processes that negatively affect its quality characteristics. Lipids contained in goose meat are one of the least stable ingredients. During meat storage, including freezing, they are exposed to a number of physicochemical and biochemical changes (Soyer et al., 2010; Arshad et al., 2013; Muela et al., 2015). Changes occurring in meat during freezing storage may also be caused by exogenous factors, among others: oxygen contained in atmospheric air, temperature and storage time, as well as the

Received February 25, 2021.
Accepted September 26, 2021.

[1]Corresponding author: monika.werenska@ue.wroc.pl

presence of some heavy metals (Min et al., 2008; Soyer et al., 2010; Utrera and Estevez, 2013). Lipids contained in meat also undergo oxidative processes due to the activity of endogenous factors, that is, tissue enzymes and microbial origin. During frozen storage of meat, hydrolysis of ester bonds between the glycerol molecule and fatty acids occurs, as well as oxidation of fatty acids. These processes take place through chemical reactions or as a result of the action of endogenous enzymes contained in muscle tissue (Leygonie et al., 2012; Contini et al., 2014). Reactions that occur in lipids without enzymes are referred to as oxidation. Oxidation processes of meat lipids during freezing storage are difficult to inhibit because even a small amount of their products easily reacts with other components, which results in the formation of chemically unstable primary products, that is, peroxides. In turn, as a result of secondary oxidative transformations, reactive hydroperoxides and other oxidation products, among others, aldehydes (including malondialdehyde, 4-hydroxy-trans-nonenal, hepta-2,4-dienal, hydroxyketanal) and hydrocarbons − ethane and pentane as well as ketones are formed (Nowak et al., 2015; Schaur et al., 2015). These processes often limit or even prevent further storage of raw meat, and consequently its technological and culinary use. The secondary products of lipid oxidation contribute to the occurrence of an unpleasant, rancid taste and smell of meat, as well as the deterioration of its color, including an increase in the proportion of metmyoglobin (Faustman et al., 2010; Ayala et al., 2014; Amaral et al., 2018).

The aim of the study was to define: the color changes by determining the concentration of THP, and the share of Mb, MbO_2, MMb; indicators of oxidative changes such as $DPPH^{\bullet}$, $ABTS^{\bullet+}$, FRAP, and 2-thiobarbituric acid reactive substances (**TBARS**) in BM and LM of Kołuda white geese depending on the freezing storage time (30, 90, 180, 270, and 365 d at −20°C).

MATERIALS AND METHODS

Meat Samples

The experimental material consisted of breast muscle (**BM**) (n = 108) and leg (thigh) muscles (**LM**) (n = 108) from 17-wk-old female White Kołuda geese (W 31), which are called "Polish oat geese". The geese were reared in the same industrial farm and fed on the same complete concentrated diet (Wołoszyn et al., 2020). The birds were slaughtered in a poultry slaughter plant according to Polish poultry industry regulations. The carcasses were bled, scalded (approximately 1 min, at approximately 63°C), plucked, and eviscerated. The eviscerated carcasses were placed immediately inside a refrigerator at 4°C for 24 h. After that, the breast and leg muscles were cut out from the right side of the carcass, and then individually packed in a head shrink bag Supravis SHRINK BAG P. The average weight for BM (with skin and subcutaneous fat) was 495 g ± 20 g, and for LM, it was (with skin and subcutaneous fat) 425 g ± 18 g. The packed muscles were frozen in an air tunnel at −20°C, measured at their geometric center. Then, the muscles were placed in a freezer cabinet (HSA29530N, Beko, Warszawa, Poland) and stored for 30, 90, 180, 270, and 365 d at a temperature of −20°C (±1°C). Each time, 18 BM and 18 LM were investigated. Thirty-six (18 breasts + 18 legs) fresh muscles (24 h after slaughter at +4°C) were used for the control (C) group, and the results obtained for this group were taken as initial values.

Sample Preparation

In order to determine the concentration of THP, the share of myo-, oxy-, and metmyoglobin from the frozen breast and legs muscles on their cross-section, 5 g of the sample were cut out in lobes 1-mm thick.

To analyze TBARS, $DPPH^{\bullet}$, $ABTS^{\bullet+}$ FRAP, the BM and LM were thawed in a refrigerated cabinet for 24 h at +4°C (LG, M600, Seoul, South Korea). Next, the skin and subcutaneous fat from the muscles were separated. Each breast and leg muscle (from the right side) was chopped (mesh diameter of 2 mm) in an electric bowl chopper (model MM/1000/887, Zelmer, Rzeszów, Poland).

To determinate the $DPPH^{\bullet}$, $ABTS^{\bullet+}$ and FRAP (QUENCHER method), the chopped muscles were lyophilized in a laboratory lyophilizer (Alpha 1-2 LD plus, Martin Christ GmbH, Osterode am Harz, Germany). The freeze-drying process was conducted by treating goose meat at −80°C for 24 h, followed by drying at a pressure of 0.02 mbar for 48 h.

Heam Pigment Analysis

The total heam pigments (**THP**) were determined according to the method described by Warris in Pikul's modified (Pikul, 1993). The absorbance of the pigment in phosphate buffer solution was measured at 572, 565, 545, and 525 nm in a spectrophotometer Specord 210 (Analytic Jena AG, Jena, Germany). The THP concentration and relative concentration of: myoglobin (**Mb**), oxymyoglobin (**MbO_2**), and metmyoglobin (**MMb**), were calculated according to the equations given by (Krzywicki, 1982).

Total Antioxidant Capacity

The total antioxidant capacity (**TAC**) of geese muscle was determined based on the QUENCHER method (Serpen et al., 2012). The method consisted of measuring the absorbance of the sample with the addition of $DPPH^{\bullet}$ free radical solutions (DPPH method) and with $ABTS^{\bullet+}$ radical cation (ABTS method). It was weighed into a centrifuge tube: 10 mg of meat powder (lyophilizate) diluted at a ratio of 1:5 (w/w) with cellulose. The reaction was started after the addition of 10 mL of $ABTS^{\bullet+}$ and $DPPH^{\bullet}$ working solution. The tubes were shaken vigorously for 1 min and placed on an orbital shaker in the dark. The mixture was shaken at 400 rpm

at room temperature on the orbital shaker model SW 22 (Julabo GmbH, Seelbach, Germany).

The DPPH$^{\bullet}$ free radical solution was prepared according to the procedure described by (Williams-Brand et al., 1995). The stock solution of DPPH$^{\bullet}$ was prepared before work by dissolving 40 mg of DPPH$^{\bullet}$ in 100 mL of ethanol. The solution of DPPH$^{\bullet}$ had an absorbance of 0.750 (±0.02) at 525 nm.

The ABTS$^{\bullet+}$ cation radical solution was prepared based on the method described by (Re et al., 1999). ABTS$^{\bullet+}$ was produced by reacting the ABTS stock solution with 2.45 mmol potassium persulfate and kept in the dark at room temperature (18 ± 1°C) for 16 h before use. Before analysis, the ABTS$^{\bullet+}$ solution was diluted with redistilled water to an absorbance of 0.700 (±0.02) at 734 nm.

The results of TAC were expressed in mmol trolox ((±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) equivalent (TE)/1 kg of dm (dry mass) of meat.

Total Reduction Potential

The total reduction potential (**TRP**) of geese muscle was determined by the QUENCHER method given by Serpen et al. (2012). The FRAP stock solution was prepared before work according to the procedure given by (Benzie and Strain, 1996). The results of the TRP were expressed in mmol trolox ((±)-6-hydroxy-2,5,7,8-tetramethylchromane-2-carboxylic acid) equivalent (TE)/1 kg of dm of meat.

TBARS Assay

The TBARS include lipid hydroperoxides and aldehydes. The TBARS procedure was performed as described by Salih et al. (1987) with Pikul's modification (Pikul, 1993). Ten grams of ground sample (breast and leg muscles) were homogenized in 35 mL of perchloric acid in a homogenizer (T 25, Ika Ultra-Turrax Corp., Staufen, Germany) at 4,000 rpm for 10 min. The reagent BHT (2,6-bis (1,1-dimethylethyl)-4-methylphenol) was added prior to homogenization. The BHT had been previously dissolved in ethanol. The homogenized sample was filtered through Whatman number 1 filter paper into a 50 mL volumetric flask. The filtrate (5 mL) was mixed with 0.02 M 2-thiobarbituric acid (5 mL) in capped test tubes. The tubes were incubated in boiling water for 1 h and then chilled at room temperature. The absorbance was measured at 532 nm with the use of a spectrophotometer (Specord 210, Analytic Jena AG, Jena, Germany) against a blank containing 5 mL of perchloric acid and 5 mL of 0.02 M TBA solution. The constant 6.2 was used to calculate the TBARS value as recommended by Krzywicki (1982). The TBARS was expressed as milligrams MDA/kg of meat.

Statistical Analysis

The data were analyzed as a completely randomized design using a two-way ANOVA concerning the kind of muscles (breast and leg) and time its frozen storage (30, 90, 180, 270, and 360 d) as a factorial design (2 × 5), according to the following linear model: $Y_{ij} = \mu + A_i + B_j + (AB)_{ij} + e_{ij}$, where Y_{ij} = value of trait (the dependent variable); μ = overall mean; A_j = effect of kind of muscle; B_j = effect of time frozen storage of muscles; (AB) = interaction and e_{ij} = random observation error, using Statistica 13.3 software (StatSoft Inc.). The statistical significance of the differences between the averages of the groups was calculated using Tukey's test and was at a level of $P \leq 0.05$. The Tables present the average values and their standard deviations.

RESULTS AND DISCUSSION

The freezing storage time affected the changes of heam pigments in both types of muscles. It was shown that the breast muscles stored for 180 d and the leg muscles stored for 270 d were characterized by significantly lower ($P \leq 0.05$) THP (0.26 and 0.14 mg/g muscle tissue respectively) compared to the 30th and 90th d (for breast muscles) and to the 30th, 90th, 180th d (for leg muscles) (Table 1). The decrease in the THP content in meat with the extension of its freezing storage time probably may be related to the progressive degradation processes of myoglobin and its derivatives. Renerre (1999), also suggested the reaction of their breakdown products with secondary lipid oxidation products, including MDA. Significant differences ($P \leq$

Table 1. THP (mg/g of muscle tissue) content and share of Mb, MbO_2, MMb in BM and LM of White Koluda® geese.

			Time of freezing storage (d)				
			30	90	180	270	365
Parameters	Typeof muscle	Control group C	n = 18				
Total heam pigment	BM	$^{x}3.45^{a} \pm 0.25$	$^{x}3.43^{a} \pm 0.24$	$^{x}3.29^{ab} \pm 0.16$	$^{x}3.10^{b} \pm 0.35$	$^{x}3.06^{b} \pm 0.19$	$^{x}3.01^{b} \pm 0.15$
THP	LM	$^{y}2.93^{a} \pm 0.21$	$^{y}2.59^{b} \pm 0.33$	$^{y}2.33^{bc} \pm 0.28$	$^{y}2.31^{bc} \pm 0.16$	$^{y}2.27^{c} \pm 0.26$	$^{y}2.24^{c} \pm 0.17$
Myoglobin	BM	0.31 ± 0.03	0.32 ± 0.03	0.31 ± 0.03	0.32 ± 0.03	0.33 ± 0.03	0.33 ± 0.03
Mb	LM	0.34 ± 0.03	0.34 ± 0.03	0.35 ± 0.04	0.33 ± 0.03	0.33 ± 0.03	0.35 ± 0.03
Oxymyoglobin	BM	$0.38^{a} \pm 0.03$	$0.37^{a} \pm 0.03$	$0.36^{a} \pm 0.03$	$0.32^{b} \pm 0.03$	$0.27^{c} \pm 0.02$	$0.26^{c} \pm 0.03$
MbO_2	LM	$0.38^{a} \pm 0.05$	$0.36^{ab} \pm 0.03$	$0.33^{bc} \pm 0.03$	$0.31^{cd} \pm 0.03$	$0.27^{de} \pm 0.03$	$0.25^{e} \pm 0.03$
Metmyoglobin	BM	$0.27^{c} \pm 0.02$	$0.26^{c} \pm 0.03$	$0.28^{c} \pm 0.03$	$0.32^{b} \pm 0.03$	$0.35^{a} \pm 0.04$	$^{x}0.38^{a} \pm 0.03$
MMb	LM	$0.24^{d} \pm 0.04$	$0.25^{cd} \pm 0.03$	$0.28^{bc} \pm 0.03$	$0.31^{b} \pm 0.03$	$0.35^{a} \pm 0.03$	$^{y}0.35^{a} \pm 0.03$

[a-e]Different letters in row mean statistically significant differences between group average, including storage time ($P \leq 0.05$).
[x-y]Different letters in columns mean statistically significant differences between the group average, including type of muscle ($P \leq 0.05$).

0.05) in THP were also confirmed between the types of muscles in each of the analyzed periods of their freeze storage. It was shown that THP in BM was higher by 0.96 and 0.84 mg/g of muscle tissue on the 90th and 30th d, respectively, by 0.79 mg/g of muscle tissue on the 180th and 270th d, and by 0.77 mg/g of muscle tissue on the 365th d of their freeze storage than in LM (Table 1). The differences in THP in the analyzed muscle types may result from the different activity of the respiratory enzymes contained in the muscles and from the different ability of oxygen diffusion into the muscle tissue, which has a direct impact on the rate and intensity of color change during storage in freezing conditions (Ramanathan and Mancini, 2018). Moreover, higher THP in BM, compared to LM, may be associated with, among others, the in vivo activity of these muscles and the share of white and red muscle fibers (Purohit et al., 2015; Listrat et al., 2016). Except for the THP content, the muscle color of slaughter animals is also influenced by the mutual participation of their components, that is, myoglobin, oxymyoglobin and metmyoglobin (Wu et al., 2020).

The proportions of Mb, MbO_2, and MMb in the THP determined in the C group (BM and LM) were similar, and the differences between the average groups were not significant (Table 1). The Mb share in the control group (0.31-BM; stated in our study) was similar to data presented previously by (Haraf et al., 2009) for duck breast meat. In turn, the MbO_2 proportions obtained by (Haraf et al., 2009) in the examined raw material were higher in breast and leg muscles, and MMb lower in breast and leg muscles than their proportion in the analyzed muscles (Table 1). It was shown that the Mb content in the BM and LM was similar during their freezing storage, and the differences between the average groups were not confirmed statistically. It was also found that the MbO_2 share in both analyzed types of muscles decreased, and MMb increased, along with the extension of their storage time in freezing conditions (Table 1). The significant ($P \leq 0.05$) decreases of MbO_2 and increase of the MMb relative concentration occurred on the 180th d (BM) and on the 90th d of freezing storage (LM). In subsequent analyzed periods of storage of both types of muscles (i.e., the 270th and 365th d), the changes in the shares of MbO_2 and MMb were much smaller, and the differences were not significant (Table 1). It should be noted that the shares of MMb in both analyzed types of muscles stored in freezing conditions for 270 and 365 d did not exceed 0.4. This value is considered to be the limit, above which the meat takes on an intense gray-brown color not accepted by the consumer (Kim et al., 2011; Jeantet et al., 2016). An increase of the MMb content in the muscles of slaughter animals during their storage may be related to the progressive processes of lipid oxidation, which may be directly linked to the oxidation of heam pigments contained in them (Fernández-López et al., 2008; Wideman et al., 2016). It should be noted that this causal relationship has not been fully clarified. It is not known whether lipid oxidation affects the oxidation of heam pigments or vice versa because the meat has an endogenous enzymatic reduction system that contributes to the reduction of MMb to MbO_2 (Faustman et al., 2010a; Alonso et al., 2016; Neethling et al., 2017). The changes of the Mb proportion in both types of muscles determined in our own research differ from the results published by other authors. Alonso et al. (2016) found a significant increase in the share of Mb in chicken breast muscles and in pig meat stored for 8 wk and 24 mo at −18°C and −20°C. However, Brewer and Wu (1993) indicated a significant decrease in the Mb proportion in beef meat stored for 52 wk at −18°C. Brewer and Wu (1993) and Alonso et al. (2016) stated a decrease of MbO_2 and an increase in the MMb share in beef and pork stored for 52 and 104 wk under freezing conditions. The relative changes in the share of MbO_2 and MMb in THP in goose muscles during their freezing storage are consistent with the data presented by these authors. The MMb proportion in BM and LM in the analyzed periods of freezing storage was similar and the differences were not statistically significant. In our work, there was no effect of the muscle type on changes in Mb and MbO_2 share during storage in freezing conditions. However, a higher ($P \leq 0.05$) proportion of MMb in BM was noted on the 365th d of storage (0.38) compared to LM (0.35) (Table 1).

The different mechanisms of activity of antioxidant compounds contained in raw meat causes, that several analytical methods are usually used to measure their activity. These methods are based on a variety of chemical reactions and quantify the ability of different substances to neutralize free radicals and other compounds involved in oxidative processes (Elias et al., 2008; Serpen et al., 2012; Ortuño et al., 2016).

It was found that the TAC and TRP determined in C (BM and LM) were similar, and the differences between their average values were not significant (Table 2). The

Table 2. $DPPH^{\bullet}$ $ABTS^{\bullet+}$ and FRAP value (mmol TE/ kg dm) of BM and leg LM of White Kołuda® geese.

Parameters	Type of muscle	Control group C	Time of storage (d)				
			30	90	180	270	365
			n = 18				
$DPPH^{\bullet}$	BM	$23.74^{a} \pm 2.68$	$20.57^{b} \pm 1.81$	$20.50^{b} \pm 1.39$	$19.29^{b} \pm 1.08$	$18.57^{bc} \pm 1.11$	$^{y}17.11^{c} \pm 0.46$
	LM	$24.54^{a} \pm 2.33$	$21.86^{b} \pm 1.38$	$20.71^{bc} \pm 0.85$	$19.55^{c} \pm 0.32$	$19.05^{c} \pm 1.22$	$^{x}18.48^{c} \pm 0.91$
$ABTS^{\bullet+}$	BM	$40.12^{a} \pm 0.53$	$37.98^{b} \pm 1.87$	$^{y}37.53^{bc} \pm 0.73$	$^{y}36.64^{c} \pm 0.51$	$^{y}35.51^{d} \pm 0.98$	$^{y}34.19^{e} \pm 0.20$
	LM	$39.31^{a} \pm 0.58$	$38.50^{a} \pm 0.63$	$^{x}39.06^{a} \pm 1.12$	$^{x}38.40^{ab} \pm 0.81$	$^{x}37.53^{b} \pm 1.02$	$^{x}37.33^{b} \pm 0.86$
FRAP	BM	$23.68^{a} \pm 1.26$	$^{x}23.19^{ab} \pm 2.12$	$^{x}21.97^{b} \pm 0.78$	$19.50^{c} \pm 1.16$	$13.28^{d} \pm 0.83$	$11.78^{e} \pm 0.54$
	LM	$22.39^{a} \pm 1.07$	$^{y}20.36^{b} \pm 1.36$	$^{y}20.20^{b} \pm 1.05$	$18.85^{c} \pm 0.50$	$14.32^{d} \pm 1.38$	$12.36^{e} \pm 0.35$

[a-e]Different letters in row mean statistically significant differences between group average, including storage time ($P \leq 0.05$).
[x-y]Different letters in columns mean statistically significant differences between the group average, including muscle type ($P \leq 0.05$).

TAC in both types of muscles was similar, and the TRP was lower than the results obtained by Serpen et al. (2012) for chicken, beef, and pork meat. This study showed that the TAC and TRP in both types of muscles decreased along with the extension of their storage time in freezing conditions (Table 2). In the case of BM, statistically significant ($P \leq 0.05$) differences in the DPPH values occurred only between the 180th and 365th d (1.46 mmol TE/kg dm), and in the case of the LM, between the 30th and 180th d of freezing storage (2.31 mmol TE/kg dm) (Table 2). The analysis of the TAC of muscles performed using the ABTS method showed that BM stored for 30 and 90 d and LM for 30, 90, and 180 d in freezing conditions were characterized by a significantly greater ability to quench the $ABTS^{+\bullet}$ compared to other analyzed storage periods (Table 2).

It was also shown that the TAC determining the degree of reduction of Fe^{3+} to Fe^{2+} (FRAP test) in both types of muscles, as well as their antioxidant properties determined using the DPPH and ABTS methods, decreased with longer freezing storage time. This means that, despite the use of freezing temperature, oxidation processes occurring in the meat raw material were not inhibited but only slowed down. The BM and LM stored for 30 and 90 d were characterized by a significantly higher ability to reduce Fe^{3+} to Fe^{2+}, compared to other studied storage periods (Table 2). The results obtained in our own research, showing changes in the extinction of $DPPH^{\bullet}$ radicals by the autogenous muscle antioxidant system during freezing storage, are consistent with the results presented by (Fasseas et al., 2008; Min et al., 2008; Jung et al., 2010; Singh et al., 2014). These authors also found a significant decrease in the TAC (determined using the DPPH method) of chicken meat as well as beef and pork during their refrigerated and freezing storage. Min et al. (2008) stated that it is closely related to the progressive catabolic processes of antioxidant compounds contained in meat, especially carnosine and anserine. The results of the total antioxidant activity of BM and LM investigated geese determined by the ABTS method are similar to those obtained by Jung et al. (2010) for chicken meat stored in freezer and by Jang et al. (2008), and Singh et al. (2014) for chicken muscles, storage in a refrigerator at 4°C. These authors stated a decrease in the antioxidant potential of broiler chicken muscles along with the extension of their time of storage. According to Tabart et al. (2009), this may be the result of progressive changes in the activity of chemical compounds contained in raw meat material. Qwele et al. (2013), Pradhan et al. (2000), Sreelatha and Padma (2009) suggested that the key factors that influence meat antioxidant potential during storage under refrigeration and freezing conditions are: the degree of degradation of organic compounds from the group of retinoids and tocopherols and tocotrienols, as well as enzymes, mainly superoxide dismutase, glutathione peroxidase and catalase and thioalcohols, forming the so-called endogenous meat antioxidant system. In the case of TRP (FRAP test), the obtained results are similar to those presented by Min et al. (2008) for chicken meat, pork tenderloin and beef stored in refrigerated conditions. The TAC analysis of muscles using the DPPH method showed that the biologically active ingredients contained in the BM were characterized by a lower ability to quench $DPPH^{\bullet}$ radicals compared to the LM throughout the entire freezing storage period. However, a statistically significant difference was confirmed only on the 365th d of storage − 17.11 and 18.48 mmol TE/kg dm, respectively (Table 2). It was established that the ability to quench the $ABTS^{+\bullet}$ cation-radical was dependent on the type of muscle, and LM were significantly higher antioxidant potentials on the 90th, 180th, 270th, and 365th day of storage in freezing conditions, compared to for BM (1.53; 1.76; 2.02, and 3.14 mmol TE/kg dm, respectively). The analysis of changes in the TAC values, determined using the FRAP method, showed that the BM were characterized by a higher reduction potential than the LM. The significant ($P \leq 0.05$) differences between the average values of TAC were confirmed on the 30th and 90th d of freezing storage (2.83 and 1.77 mmol TE/kg dm, respectively; Table 2).

Oxidation processes occurring in raw meat during refrigerated and frozen storage have an impact on its deterioration and shorten the shelf life for culinary and technological use. The consequence of the oxidation of meat ingredients is, among others, a change in its aroma and taste, particularly due to the formation of malondialdehyde (Faustman et al., 2010; Fereidoon and Ying, 2010; Soyer et al., 2010). The average contents of malondialdehyde determined in fresh (control C) BM and LM (24 h stored at +4°C) were similar and amounted to 0.36 and 0.44 mg MDA/kg of meat, respectively (Figure 1). These values were higher than the results obtained by Ali et al. (2007), Min et al. (2008), Selani et al. (2011), Freitas et al. (2015), Śmiecińska et al. (2015), Wei et al. (2017) in chicken and turkey meat. Whereas, the TBARS calculated by Leygonie et al. (2012) and Karwowska et al. (2017) for White Kołuda goose muscles and refrigerated ostrich meat was higher (by 0.71 −0.86 mg MDA/kg meat and 1.36 mg MDA/kg meat, respectively) than the values obtained in our research. The amounts of malondialdehyde determined in both types of goose muscles increased with the extension of the freezing storage time. The BM and LM stored for 270 and 365 d were characterized by higher TBARS than the ones stored for 180, 90, and 30 d. It can be stated that in the final storage period (i.e., on the 270th and 365th d) of both types of muscles, the rate of formation of secondary lipid oxidation products slowed down. It is worth emphasizing that the amount of lipid oxidation products that reacted with 2-thiobarbituric acid during frozen storage of muscles did not exceed 2.0 mg MDA/kg meat (Figure 1). This value is considered borderline, and its increase above 2.0 causes a lack of acceptance by consumers of the flavor profile of stored raw meat (Campo et al., 2006; Łopacka and Lipińska, 2015; Skałecki et al., 2015). As in our research, Karwowska et al. (2017) found a significantly higher content of malondialdehyde in the breast and leg muscles of the White Kołuda goose (by 0.52 and 0.16 mg MDA/kg of meat) on the 180th day of their freezing storage, compared

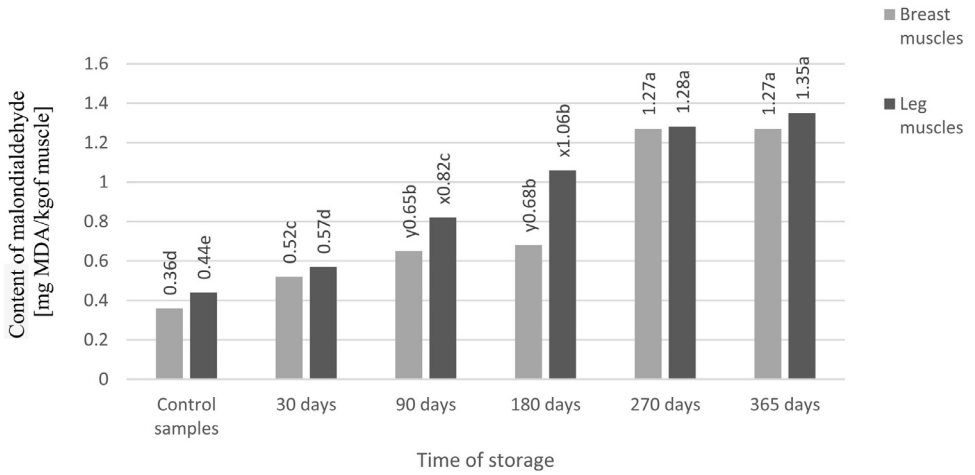

Figure 1. Mean values of malondialdehyde (mg MDA/kg of muscle) in BM and LM of White Kołuda® geese. a-e – Different letters mean statistically significant differences between group average, including storage time ($P \leq 0.05$); x-y – Different letters mean statistically significant differences between the group average, including muscle type ($P \leq 0.05$).

to the control sample(muscles 3 d chilled storage - at 4°C). Coetzee and Hoffman (2001), Tang et al. (2002), Soyer et al. (2010), and Selani et al. (2011) showed that the content of secondary lipid oxidation products, expressed as TBARS, increased in broiler chicken meat during frozen storage. Coetzee and Hoffman (2001) and Karwowska et al. (2017) suggest that this relationship could be caused by the different rates of formation of secondary lipid oxidation products in the raw meat, resulting from chemical reactions between MDA and its proteins. The products of these reactions include protein-lipid complexes that are involved in the mechanisms of the degradation of exogenous amino acids, thus contributing to the reduction of the nutritional value of meat.

The type of muscle had a significant effect on the value of the TBARS, too (Figure 1). The LM, compared to BM, were characterized by a higher ($P \leq 0.05$) content of malondialdehyde on the 90th and 180th d of storage (by: 0.17 and 0.38 mg MDA/kg of meat, respectively). During the remaining periods, the differences in the TBARS value in BM and LM were lower and not significant (Figure 1). Likewise, Karwowska et al. (2017) stated the effect of the types of muscles of White Kołuda geese on changes in the TBARS value during freezing storage. In contrast to our study, these authors showed that breast muscles were characterized by a higher content of MDA (by 0.43 mg/kg of meat) than the leg muscles on the 180th d of freezing storage time. According to them, this may be explained, among others, by a higher fat content and endogenous prooxidants as well as heam iron content in breast muscles.

CONCLUSIONS

The THP content and the MbO_2 share decreased whereas MMb increased in both types of muscles during frozen storage time. The obtained data indicate the progressing oxidation processes of MbO_2, which leads to an increase in the relative content of MMb. The proportion of MMb was below 0.4 in both types of muscles during all storage time, which means that the color of the tested material can be accepted by the consumer. Storage of meat in freezing conditions decreased the TAC and TRP and increased the TBARS of both types of muscles. The antioxidant stability measured using the DPPH method decreased on the 180th (LM) and on the 365th day of storage (BM), too. However, antioxidant stability measured using the ABTS method decreased in the case of BM from the 180th, and in the case of LM from the 270th d of storage.

The highest increase in the content of MDA in BM occurred between 180 and 270 d of freezer storage (by 163.9%), while the content of MDA in LM increased (by 53.8% on average) in subsequent storage periods, that is, from the 30th to the 270th d. The formation of secondary oxidation products of lipids reactive with 2-thiobarbituric acid in goose meat varied depending on the kinds of muscle and time of freezing storage.

DISCLOSURES

The authors declare no conflicts of interest

REFERENCES

Adamski, M., J. Kucharska-Gaca, J. Kuźniacka, E. Kowalska, and R. Czarnecki. 2016. Wpływ wybranych czynników na wydajność rzeźną i jakość mięsa gęsiego. Zywn. Nauk. Technol. Jakosc/Food. Sci. Technol. Qual. 5:33–44.

Ali, M. S., G. H. Kang, H. S. Yang, J. Y. Jeong, Y. H. Hwang, G. B. Park, and S. T. Joo. 2007. A comparison of meat characteristics between duck and chicken breast. Asian-Australasian J. Anim. Sci. 20:1002–1006.

Alonso, V., E. Muela, J. Tenas, J. B. Calanche, P. Roncalés, and J. A. Beltrán. 2016. Changes in physicochemical properties and fatty acid composition of pork following long-term frozen storage. Eur. Food Res. Technol. 242:2119–2127.

Amaral, A. B., M. V. Da Solva, and S. C. D. S. Lannes. 2018. Lipid oxidation in meat: mechanisms and protective factors - a review. Food Sci. Technol. 38:1–15.

Arshad, M. S., F. M. Anjum, M. I. Khan, M. Shahid, S. Akhtar, and M. Sohaib. 2013. Wheat germ oil enrichment in broiler feed with α-lipoic acid to enhance the antioxidant potential and lipid stability of meat. Lipids Health Dis. 12:1–14.

Ayala, A., M. F. Muñoz, and S. Argüelles. 2014. Lipid peroxidation: production, metabolism, and signaling mechanisms of malondialdehyde and 4-hydroxy-2-nonenal. Oxid. Med. Cell. Longev. 1–31.

Benzie, I. F. F., and J. J. Strain. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Anal. Biochem. 239:70–76.

Brewer, M. S., and S. Y. Wu. 1993. Display, packaging, and meat block location effects on color and lipid oxidation of frozen lean ground beef. J. Food Sci. 58:1219–1236.

Campo, M. M., G. R. Nute, S. I. Hughes, M. Enser, J. D. Wood, and R. I. Richardson. 2006. Flavour perception of oxidation in beef. Meat Sci. 72:303–311.

Coetzee, G. J. M., and L. C. Hoffman. 2001. Effect of dietary vitamin E on the performance of broilers and quality of broiler meat during refrigerated and frozen storage. South Afr. J. Anim. Sci. 31:158–172.

Contini, C., R. Álvarez, M. O'Sullivan, D. P. Dowling, S. Óg Gargan, and F. J. Monahan. 2014. Effect of an active packaging with citrus extract on lipid oxidation and sensory quality of cooked turkey meat. Meat Sci. 96:1171–1176.

Elias, R. J., S. S. Kellerby, and E. A. Decker. 2008. Antioxidant activity of proteins and peptides. Crit. Rev. Food Sci. Nutr. 48:430–441.

Fasseas, M. K., K. C. Mountzouris, P. A. Tarantilis, M. Polissiou, and G. Zervas. 2008. Antioxidant activity in meat treated with oregano and sage essential oils. Food Chem. 106:1188–1194.

Faustman, C., Q. Sun, R. Mancini, and S. P. Suman. 2010. Myoglobin and lipid oxidation interactions: mechanistic bases and control. Meat Sci. 86:86–94.

Fereidoon, S., and Z. Ying. 2010. Lipid oxidation and improving the oxidative stability. Chem. Soc. Rev.. 39:4067–4079.

Fernández-López, J., E. Sayas-Barberá, T. Muñoz, E. Sendra, C. Navarro, and J. A. Pérez-Alvarez. 2008. Effect of packaging conditions on shelf-life of ostrich steaks. Meat Sci. 78:143–152.

Freitas, E. R., A. Da Silva Borges, A. L. F. Pereira, V. K. G. Abreu, M. T. S. Trevisan, and P. H. Watanabe. 2015. Effect of dietary ethanol extracts of mango (Mangifera indica L.) on lipid oxidation and the color of chicken meat during frozen storage. Poult. Sci. 94:2989–2995.

GUS. 2020. Mały Rocznik Statystyczny Polski 2020. 151. https://stat.gov.pl/obszary-tematyczne/roczniki-statystyczne/roczniki-statystyczne/maly-rocznik-statystyczny-polski-2020,1,22.html. Accessed Jan. 2021.

Haraf, G., J. Książkiewicz, J. Wołoszyn, and A. Okruszek. 2009. Characteristic of meat colour of different duck populations. Arch. Tierzucht. 52:527–537.

Haraf, G., J. Wołoszyn, A. Okruszek, A. Orkusz, and M. Wereńska. 2018. Protein- und lipidgehalt des brustmuskels von vier verschiedenen, polnischen gänsegenotypen. Eur. Poult. Sci. 82:1–11.

Jang, A., X. D. Liu, M. H. Shin, B. D. Lee, S. K. Lee, J. H. Lee, and C. Jo. 2008. Antioxidative potential of raw breast meat from broiler chicks fed a dietary medicinal herb extract mix. Poult. Sci. 87:2382–2389.

Jeantet, R., T. Croguennec, P. Schuck, and G. Brule. 2016. Handbook of Food Science and Technology 3: Food Biochemistry and Technology. Jeantet R., Croguennec T., Schuck P., Brule G., eds. Wiley, Hoboken, NJ.

Jung, S., J. H. Choe, B. Kim, H. Yun, Z. A. Kruk, and C. Jo. 2010. Effect of dietary mixture of gallic acid and linoleic acid on antioxidative potential and quality of breast meat from broilers. Meat Sci. 86:520–526.

Karwowska, M., M. Grabowicz, J. Stadnik, P. Szterk, Z. Bernacki, and Z. J. Dolatowski. 2017. The effect of corn or beet pulp silage supplemented diet on production parameters, oxidative stability of muscles and fatty acid composition of abdominal fat in geese. Ann. Anim. Sci. 17:887–902.

Kim, Y. H. B., M. Frandsen, and K. Rosenvold. 2011. Effect of ageing prior to freezing on colour stability of ovine longissimus muscle. Meat Sci. 88:332–337.

Krzywicki, K. 1982. The determination of haem pigments in meat. Meat Sci. 7:29–36.

Łagowska, K., and E. Bombik. 2016. Gęsina wraca na nasze stoły. Pol. Drobiar. 10:2–5.

Leygonie, C., T. J. Britz, and L. C. Hoffman. 2012. Impact of freezing and thawing on the quality of meat. Rev. Meat Sci. 91:93–98.

Listrat, A., B. Lebret, I. Louveau, T. Astruc, M. Bonnet, L. Lefaucheur, B. Picard, and J. Bugeon. 2016. How muscle structure and composition influence meat and flesh quality. Sci. World J. 1–14.

Łopacka, J., and A. Lipińska. 2015. Zmiany oksydacyjne zachodzące w czasie przechowywania mięsa wołowego w modyfikowanej atmosferze gazów oraz obróbki termicznej i ich potencjalne skutki zdrowotne. Probl. Hig. i Epidemiol. 96:719–726.

Min, B. R., K. C. Nam, J. C. Cordray, and D. U. Ahn. 2008. Factors affecting oxidative stability of pork, beef, and chicken meat. Iowa State Univ. Anim. Ind. Rep. 654:1–5.

Muela, E., P. Monge, C. Sañudo, M. M. Campo, and J. A. Beltrán. 2015. Meat quality of lamb frozen stored up to 21 months: instrumental analyses on thawed meat during display. Meat Sci. 102:35–40.

Neethling, N. E., S. P. Suman, G. O. Sigge, L. C. Hoffman, and M. C. Hunt. 2017. Exogenous and endogenous factors influencing color of fresh meat from ungulates. Meat Muscle Biol. 1:253–275.

Nowak, I., M. Dąbrowska, and A. Zielińska. 2015. Produkty utleniania lipidów jako potencjalny problem zdrowotny oraz analityczny. Chemik 69:89–94.

Ortuño, J., R. Serrano, M. J. Jordán, and S. Bañón. 2016. Relationship between antioxidant status and oxidative stability in lamb meat reinforced with dietary rosemary diterpenes. Food Chem. 190:1056–1063.

Pikul, J. 1993. Ocena technologiczna surowców i produktów przemysłu drobiarskiego. Wydawnictwo Akad. Rolniczej w Poznaniu. Poznań. 23–53.

Pradhan, A. A., K. S. Rhee, and P. Hernández. 2000. Stability of catalase and its potential role in lipid oxidation in meat. Meat Sci. 54:385–390.

Purohit, A., R. Singh, W. Kerr, and A. Mohan. 2015. Effects of heme and nonheme iron on meat quality characteristics during retail display and storage. J. Food Meas. Charact. 9:175–185.

Qwele, K., A. Hugo, S. O. Oyedemi, B. Moyo, P. J. Masika, and V. Muchenje. 2013. Chemical composition, fatty acid content and antioxidant potential of meat from goats supplemented with Moringa (Moringa oleifera) leaves, sunflower cake and grass hay. Meat Sci. 93:455–462.

Ramanathan, R., and R. A. Mancini. 2018. Role of mitochondria in beef color: a review. Meat Muscle Biol. 2:1–12.

Re, R., N. Pellegrini, A. Proteggente, A. Pannala, M. Yang, and C. Rice-Evans. 1999. Antioxidant activity applying an improved ABTS radical cation decolorization assay. Free Radic. Biol. Med. 26:1231–1237.

Renerre, M. 1999. Biochemical basis of fresh meat colour. Pages 344−351 in proceeding of 45th ICoMST.

Salih, A. M., D. M. Smith, J. F. Price, and L. E. Dawson. 1987. Modified extraction 2-thiobarbituric acid method for measuring lipid oxida-tion in poultry. Poult. Sci. 66:1483.

Schaur, R. J., W. Siems, N. Bresgen, and P. M. Eckl. 2015. 4-Hydroxy-nonenal—a bioactive lipid peroxidation product. Biomolecules 5:2247–2337.

Selani, M. M., C. J. Contreras-Castillo, L. D. Shirahigue, C. R. Gallo, M. Plata-Oviedo, and N. D. Montes-Villanueva. 2011. Wine industry residues extracts as natural antioxidants in raw and cooked chicken meat during frozen storage. Meat Sci. 88:397–403.

Serpen, A., V. Gökmen, and V. Fogliano. 2012. Total antioxidant capacities of raw and cooked meats. Meat Sci. 90:60–65.

Singh, P., J. Sahoo, M. K. Chatli, and A. K. Biswas. 2014. Shelf life evaluation of raw chicken meat emulsion incorporated with clove powder, ginger and garlic paste as natural preservatives at refrigerated storage (4 ± 1°C). Int. Food Res. J. 21:1363–1373.

Skałecki, P., M. Florek, A. Staszowska, and A. Kaliniak. 2015. Wartość użytkowa i jakość filetów ryb karpiowatych (Cyprinidae) utrzymywanych w polikulturze. Zywn. Nauk. Technol. Jakosc/ Food. Sci. Technol. Qual. 22:75–88.

Śmiecińska, K., N. Hnatyk, T. Daszkiewicz, D. Kubiak, and P. Matusevičius. 2015. The effect of frozen storage on the quality of vacuum-packaged Turkey meat. Vet. ir Zootech. 71:61–66.

Soyer, A., B. Özalp, Ü. Dalmiş, and V. Bilgin. 2010. Effects of freezing temperature and duration of frozen storage on lipid and protein oxidation in chicken meat. Food Chem. 120:1025–1030.

Sreelatha, S., and P. R. Padma. 2009. Antioxidant activity and total phenolic content of Moringa oleifera leaves in two stages of maturity. Plant Foods Hum. Nutr. 64:303–311.

Tabart, J., C. Kevers, J. Pincemail, J. O. Defraigne, and J. Dommes. 2009. Comparative antioxidant capacities of phenolic compounds measured by various tests. Food Chem. 113:1226–1233.

Tang, S. Z., J. P. Kerry, D. Sheehan, and D. J. Buckley. 2002. Antioxidative mechanisms of tea catechins in chicken meat systems. Food Chem. 76:45–51.

Utrera, M., and M. Estevez. 2013. Oxidative damage to poultry, pork, and beef during frozen storage through the analysis of novel protein oxidation markers. J. Agric. Food Chem. 61:7987–7993.

Wei, R., P. Wang, M. Han, T. Chen, X. Xu, and G. Zhou. 2017. Effect of freezing on electrical properties and quality of thawed chicken breast meat. Asian-Australas. J. Anim. Sci. 30:569–575.

Wideman, N., C. A. O'Bryan, and P. G. Crandall. 2016. Factors affecting poultry meat colour and consumer preferences - a review. Worlds Poult. Sci. J. 72:353–366.

Williams-Brand, W., M. E. Cuvelier, and C. Berset. 1995. Use of a free radical method to evaluate antioxidant activity. LWT - Food Sci. Technol. 30:25–30.

Wołoszyn, J., M. Wereńska, Z. Goluch, G. Haraf, A. Okruszek, M. Teleszko, and B. Król. 2020. The selected goose meat quality traits in relation to various types of heat treatment. Poult. Sci. 99:7214–7224.

Wu, S., J. Han, R. Liang, P. Dong, L. Zhu, D. L. Hopkins, Y. Zhang, and X. Luo. 2020. Investigation of muscle-specific beef color stability at different ultimate pHs. Asian-Australas. J. Anim. Sci. 33:1999–2007.