Physicochemical and microbiological analysis of goose meat

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Abstract

Temperature plays a crucial role in the storage of meat. Low temperature effectively slows down the growth rate of microorganisms and enzymatic activity that causes meat spoilage. Frozen storage of meat allows consumers to choose meat's date of consumption during storage without losing its sensory quality. This work is committed to the effects of freezing and refrigeration on quality and safety of food. The study aims to determine whether different frozen storage temperatures and duration affect the quality of raw goose meat and its processing characteristics after thawing. This information could be a valuable contribution to the scientific literature concerning storage of meat. The focus was on goose meat and sausages. The meat was frozen in three independent runs for 3 and 6 months at -20°C and -70°C. The thawed meat was subjected to physicochemical and microbiological analyses and then turned into raw sausages. Frozen meat sausages showed significantly higher thiobarbituric acid (TBA) values after 2 and 4 weeks of the experiment, compared to the control group. Frozen storage also reduced the growth of *Pseudomonas* spp. and *Enterobacteriaceae* for all storage temperatures. Findings of the present study could be used to preserve quality and taste of products during meat processing.

Keywords: goose meat; quality; storage temperature; exudative losses; TBA-active products; microbiological analysis

Introduction

Temperature is a crucial component in meat storage. For instance, low temperatures affect the slowing down of meat spoilage by preventing the growth of microorganisms and enzyme activity (Raveendran *et al.*, 2018). One of the most popular methods for meat preservation is freezing (Zhou *et al.*, 2010). It represents an effective means to maintain quality of meat and extend its shelf life, especially during long-distance transportation. For this reason, most categories of meat in international trade are in frozen form (Ravuvu *et al.*, 2021). Moreover, consumers also prefer keeping products in a frozen state at home. The reason behind this is convenience—supply of frozen products enables consumers to choose what and when to consume without worrying about the product losing its qualities (Smith *et al.*, 2021).

The main disadvantages of freezing meat are growth of ice crystals, weight loss, protein degradation, changes in texture, and discoloration. These difficulties eventually affect the quality of meat. The damaging factors may include wrong storage temperature and fluctuations in temperature, inadequate packaging, and high humidity level (Lanari and Zaritzky, 1991). During frozen storage, fluctuations in temperature occur because of freezing and

thawing, for example, opening freezer door and defrosting at home (Zhou *et al.*, 2010). A typical family opens and closes the fridge door for several times a day, thus causing fluctuations inside the refrigerator cabinet (Liu *et al.*, 2004). Meantime, any increase in the temperature of frozen meat during defrosting speeds up its deterioration (Cai *et al.*, 2019).

The freezing and thawing rates are not controlled at home. Therefore, storing meat and meat products in household refrigerators and freezers is a challenge to maintain quality of meat. Thus, the present work investigates the effect of different frozen storage regimes on the quality of poultry (goose) meat and meat products to establish the best storage option.

As a method of food preservation, freezing originated a long time ago. It worked well in cold areas where people could successfully freeze food to prolong its shelf life. Although this method requires strict temperature control, it is hard to maintain a stable temperature in the meat processing industry. Preserving food through freezing became popular in the mid-20th century (Nowak and Jakubczyk, 2020). In the beginning, there were no guidelines for freezing and storing frozen food products because producers froze a wide variety of foods without considering freezing time and storage temperature. Ultimately, it resulted in a public aversion to frozen foods that were contaminated with mould or had rancid flavors (Garnier *et al.*, 2017). This demonstrated the importance to select a suitable storage temperature for meat and meat products.

Meat contains 20–22% protein and 60–75% water (Wu *et al.*, 2020). Consequently, the interaction between these two components is crucial for maintaining muscle structure. Meat proteins encompass three categories: myofibrillar, sarcoplasmic, and matrix proteins (Leygonie and Hoffman, 2020). Myofibrillar proteins are the most abundantly determined components in meat, accounting to 45–55% of total proteins. They are responsible for meat's appearance and its sensory quality, tenderness, and water retention capacity (Roberts *et al.*, 2020). The prolonged frozen storage, however, changes myofibrillar proteins because of formation of ice crystals and volume expansion (Abraha *et al.*, 2018). These changes involve, among other things, surface hydrophobicity and sulfhydryl content (Zhang and Ertbjerg, 2019). The effects of storage temperature and duration on the physicochemical properties of myofibrillar proteins need more attention.

Over the past century, different research studies have conducted extended shelf-life tests for most food categories, including beef and poultry (Zhou *et al.*, 2010). The extensive research evolved into a series of publications dedicated to temperature resistance and storage duration (Choi *et al.*, 2018). Some experimental studies revealed the unpredictable effects of temperature fluctuations. However, they were not without critical analysis.

Food handling and refrigeration technologies have been evolving since the 1950s (Tassou *et al.*, 2010). Today, producers face the challenge of sustainable food supply, which gave them an impetus to lower their energy consumption. Storing large quantities of meat and other food products in the cold is an energy-intensive activity, accounting for 60–70% consumption of refrigeration energy. Bondoc (2014, 2016a, 2016b, 2016c, 2016d), Bondoc and Șindilar (2002), Botzen *et al.* (2021); Crețu *et al.* (2016), and Sovacool *et al.* (2021) suggested that increasing storage temperature by at least 1°C changed the situation for better results. Other researchers, however, warned that it would reduce the shelf life of frozen products. The optimal storage temperature is linked to the practical shelf life, the period for which quality of the product is maintained at its standard level (Torres-Sánchez *et al.*, 2020). The ideal temperature for storing most frozen foods is -18°C (US Food and Drug Administration [FDA], 2021). It allows maintaining a high level of quality at a lower cost.

Freezing prolongs shelf life, but it is not an absolute preservation method. The freezing process includes three stages: cooling the product to its initial freezing point, removing phase transition heat, and cooling the product until thermal equilibrium with the surroundings (Fadiji *et al.*, 2021). During the pre-cooling stage, the level of water with a high concentration of salts and other soluble materials decreases with decrease in product temperature. The partial pressure of water at this freezing stage is reported to drop exponentially with decreasing temperature, followed by an increase in the concentration of solutes (Yoon *et al.*, 1998). This change is associated with water activity and explains why the microbial activity stops at temperatures below -10°C (Bogosian and Bourneuf, 2001; Șindilar *et al.*, 2001). The fraction of unfrozen water contributes to many deteriorating chemical reactions. Hence, storage at -10°C is improbable, but it is possible to keep products frozen at temperatures above the current -18°C standard.

Goose meat is known for its nutritional value, good taste, and rich chemical composition. It is a source of proteins, vitamins, and minerals, such as iron, zinc, and calcium, and cleanses the accumulated radionuclides and toxins. Goose meat without skin contains about 180 calories per 100 grams. The fat content of goose meat has virtually no cholesterols. Previous research has thrown light on the physicochemical and microbiological properties of goose meat after slaughter (Crețu *et al.*, 2016; Ni *et al.*, 2022), but the effect of elevated storage temperatures on product quality is not studied yet.

As mentioned earlier, storing meat and meat products is a challenge to maintain meat quality because of uncontrolled freeze–thaw cycles. As far as the present authors acknowledge, only a few studies have examined the effect of frozen storage on the technological properties of goose meat (Fu *et al.*, 2022; Wereńska *et al.*, 2022). Hence, the present study examined how different frozen storage temperatures and durations affect the quality of goose meat after thawing. Following were the objectives of the study: to conduct a physicochemical and microbiological analyses of raw goose meat; review different freezing methods and frozen storage modes; determine the physicochemical and microbiological profiles of goose meat sausages; and evaluate the quality of goose meat using biochemical analysis under different conditions of both storage temperature and duration.

Materials and Methods

Materials

Research was conducted at the Department of Food Technology and Safety, Kazakh National Agrarian Research University, Almaty, Kazakhstan. Both pectoralis major muscles were sampled from every six male geese (Anser Services, Virginia, US) slaughtered in a conventional slaughterhouse. All birds were from the same flock. The mean age of the geese was 24 weeks. Six pectoral muscles from six birds were used for the experiment. The average weight of the breast muscles with skin and subcutaneous fat was 5.2–7.6 kg. The total weight of the chest muscles was 42 kg. The vacuum method of packing in a plastic bag was used (a plastic bag tightly adheres to the muscles because of the removal of air by vacuum).

The carcasses were cooled down to 4°C before being transported to the laboratory. All the procedures (maintenance, slaughtering, and transportation) followed the European Community Council Directive 98/58/EC (European Commission, 1998).

During the slaughter procedure, the following characteristics were determined: slaughter weight, breast weight, and breast meat yield. The yield of breast meat or breast ratio was calculated as the percentage of slaughter weight (Ran *et al.*, 2021). All muscles were divided into the following five experimental groups:

1. Meat, frozen storage for 3 months at -20°C (3/-20°C)
2. Meat, frozen storage for 3 months at -70°C (3/-70°C)
3. Meat, frozen storage 6 months at -20°C (6/-20°C)
4. Meat, frozen storage for 6 months at -70°C (6/-70°C)
5. Meat, no frozen storage (control group) (storage conditions of the control group: 4°C).

All samples were frozen at suitable temperatures using Bitzer SE freezers (*Sindelfingen,* Germany). The experiments were performed in three independent repeats. Sausages were made from goose meat under different storage conditions, according to the experimental groups.

Physical, biochemical, and microbiological analyses of raw goose meat and sausages

In this study, goose meat and sausages made from it underwent physical, biochemical, and microbiological analyses. The respective procedures are described below.

Each goose's muscle attached to the sternum was cut into three sections (2-cm thick) for replicate analysis. Each section underwent grinding in liquid nitrogen, using homogenizer for Eppendorf microtube® and phosphate buffer pH 7.4, after which the material was disintegrated on UZDN-2T (U-Ross Pribor LLC., Moscow). The homogenates were centrifuged at 3,000 g for 10 min on a Heraeus Biofuge Stratos centrifuge (Thermo Scientific, USA). The concentration of thiobarbituric acid (TBA)-active products was determined using the standard method described by Gavrilov *et al.* (1987). The total antioxidant capacity of samples was assessed by the method reported by Serpen *et al.* (2012). The mean percentage of different redox forms of myoglobin was calculated according to the system reported by Richards (2013).

After the samples were stored in Eppendorf microtubes® for 3 and 6 months at -20°C and -70°C, respectively, they were thawed and analyzed to identify thawing loss, pH-value, color, and microbiological changes (*Enterobacteriaceae*, *Pseudomonas* spp., and the total plate count).

For microbiological analysis, samples were placed in sterile bags and 225-mL sterile physiological solution (0.85% NaCl) was added. After homogenization in Lab Stomacher Blender 400-BA 7021 (Seward, West Sussex, UK), the corresponding dilutions were distributed on the dishes with selective agar. Then the samples were homogenized under aseptic conditions in a quarter concentrated Ringer's solution (Oxoid) for 2 min in LAB Blender 400 (PBI, Italy) at room temperature. Decimal dilutions were prepared, and aliquots of 0.1 mL of the corresponding dilutions were distributed in three replicates on the following media: violet red bile glucose agar (VRBGA; Oxoid, UK) for *Enterobacteriaceae* incubated at 30°C for 24–48 h, and agar with selective cetrimide–fucidin–cephaloridine additive (Oxoid) for *Pseudomonas* incubated at 30°C for 48 h. The results were calculated as the average of three replicates. Bacterial cultures for

microbiological analysis were grown on meat-peptone agar (MPA) for 10 h at 28°C.

Relative drip loss was calculated as the percentage difference between carcass weight at 24 h and 72 h. Sausage products from goose muscles were produced according to a technological process comprising the following operations: reception and separation of raw materials; deboning and veining of meat; salting; grinding and making minced meat; injection; and cooking. Type of sausages: boiled; ingredients: 1-kg ground goose breast fillet without bones and skin, 0.5-kg pork with 20% fat, 75-g chopped garlic, 50-g coarsely ground black pepper, 35-mL water, 18-g red pepper, 35-g mustard seeds, and 30-g salt. Sausages were packed in vacuum. The samples were stored at a temperature of about 4°C for 28 days.

Cooking loss was calculated as the percentage difference between the weight of raw sausage and its weight after cooking. The percentage of storage loss was determined as initial product weight minus its weight after 1, 2, 3, and 4 weeks of storage. Color parameters (lightness, redness, and yellowness) of meat samples were measured before freezing and immediately after thawing. Color parameters of raw sausages were determined after 1, 2, 3, and 4 weeks of storage. All examinations were conducted with a colorimeter (Pocket Colorimeter II, Germany). The pH values of samples were measured using a pH meter with a 9625-10D electrode (HORIBA LAQUA-PH1500-SR, Japan). Water activity was determined in triplicate with a cryometer (Kriometer AWK-20, NAGY, Germany). The results were averaged and used for further statistical analysis. Moisture, protein, and fat content of sausages were determined according to official methods of analysis (AOAC International; Latimer, 2016).

Statistical analysis

The results were analyzed using the Multivariate Analysis of Variance in Microsoft Excel and Statistica 10 (de Smith, 2018). The experiments were repeated for six times. The differences were considered significant at $P \leq 0.05$ according to Student's *t*-test.

Results

Physical, biochemical, and microbiological characteristics of meat within 24 h after slaughter

The physical characteristics of goose meat determined during the slaughter procedure are depicted in Figure 1. The breast meat yield averaged 40.5% during the three repeats with six goose carcasses. The slaughter weight ranged from 15.1 to 16.7 kg and the breast weight ranged from 5.2 to 7.6 kg.

The mean drip loss of frozen samples was 0.8%. The mean cooking loss was 18.6%. The shear force result was 15.9 N. The thawed samples had the following color values: lightness, 49.7; redness, 4.9; and yellowness, 2.1. The mean pH value was 6.0. The average microbiological indicators of meat within 24 h after slaughter are

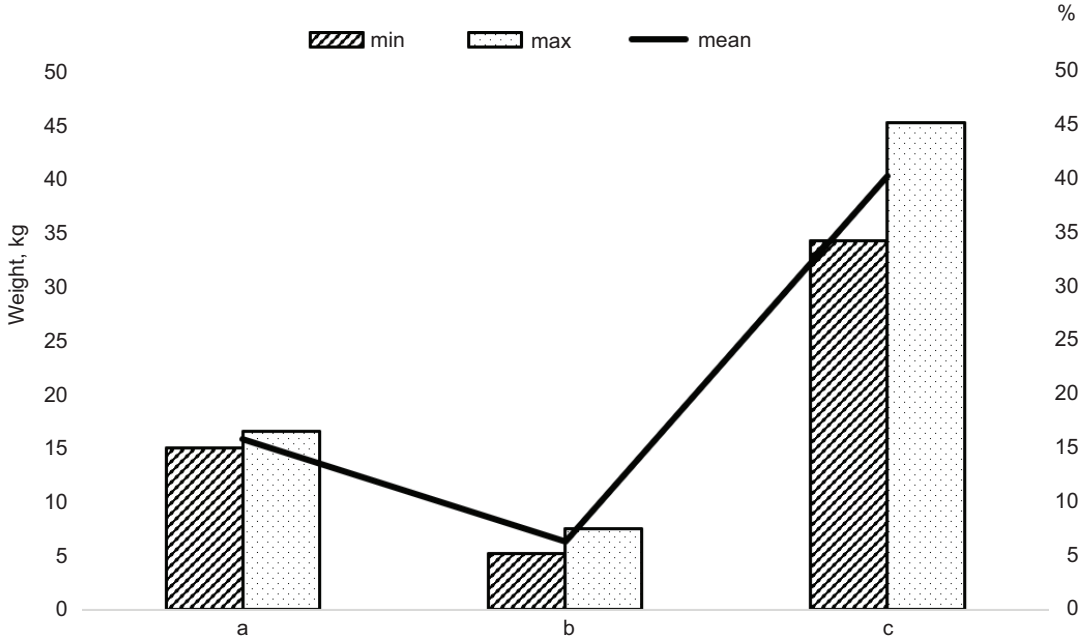

Figure 1. Physical characteristics of goose meat: (a) slaughter weight, in kg; (b) breast weight, in kg; (c) breast ratio, % (*min: minimum value, max: maximum value, mean: average of the sample).

given. The microbiological analysis revealed that the total plate count (it refers to the number of bacteria) of samples ranged from 7.2 log colony-forming unit per gram (CFU/g) to 7.6 log CFU/g. While the total counts of *Pseudomonas* spp. were between 4.0 log CFU/g and 4.4 log CFU/g, the mean count of *Enterobacteriaceae* was 3.2 log CFU/g.

Results from the pre-processing analysis of fresh and frozen-thawed goose meat

A significant influence of time on the parameters of thaw loss and yellowness was discovered. Thaw loss and yellowness values were additionally influenced by the freezing temperature, while interaction effects were obtained only for thaw loss results. In addition, malondialdehyde is one of the typical end products of lipid peroxidation, which indicates the degree of lipid oxidation in food products. In the present study, the amount of malondialdehyde in studied and control variants was insignificant (Table 1).

Frozen meat samples demonstrated significantly higher thawing loss values than the control ones. In addition, 3/-70°C samples had lower thawing loss values ($P < 0.05$) compared to 3/-20°C samples. There were no significant temperature-related differences between samples stored for varying periods. The control meat samples had significantly lower values of yellowness compared to 3/-20°C samples, whereas other treatment groups were comparable.

The relative content of oxymyoglobin in samples stored frozen for 6 months was lower than in the control group ($P < 0.05$) whereas the relative amount of metmyoglobin was significantly higher, compared to frozen samples stored for 3 months. In contrast to metmyoglobin results, the oxymyoglobin content of 3/–20°C and 3/–70°C samples was comparable to other groups. Storage duration and storage temperature had no significant effect on the content of TBA-active products and antioxidant capacity of samples, both separately and in combination (Table 1).

There were no significant differences in total plate counts with respect to storage temperature and duration. The growth rates of *Pseudomonas* spp. ($P < 0.05$) were lower than in the control group during the 6-month frozen storage, regardless of the storage temperature. Since during the study, the results of determining total microorganisms did not show significant differences in terms of storage time or storage temperature of meat products, Figure 2 shows the growth of cultures of *Pseudomona*s spp. in (a) the control group and (b) after freezing the meat samples for 6 months.

The same result could be obtained for *Enterobacteriaceae*. The only exception is that samples kept in 3-month storage also showed a substantial reduction of bacterial growth, compared to the control group samples.

Results from the analysis of raw fermented sausages

Raw sausages lost 19.3–22.7% of weight during the first week of storage. By the end of the fourth week, the weight loss was 36.2–38%. After 2 weeks, sausages made from 6/–20°C and 6/–70°C meat samples showed significantly higher storage losses, compared to those from 3/-20°C and 3/–70°C samples. No storage losses were observed for other storage periods.

The mean pH value was 6.0±0.30. The water activity was 0.86±0.03. Freeze–thaw treatment did not affect these parameters. Regardless of the storage temperature, meat sausages frozen for 3 months showed higher

Table 1. Some physicochemical characteristics of goose meat stored in different frozen storage conditions.

	Control	3/–20°C	3/–70°C	6/–20°C	6/–70°C
pH	5.9±0.09	6.0±0.2	6.1±0.1	6.0±0.1	6.0±0.2
Lightness	49.4±1.2	52.1±2.8	54.6±0.7	53.3±2.0	51.1±1.7
Redness	5.1±1.2	4.9±1.4	6.0±0.9	4.8±0.7	5.9±0.9
Yellowness	1.7*±0.3	3.9*±0.8	3.0*±0.4	2.9*±0.7	2.8*±0.6
Oxymyoglobin (%)	30.3*±0.5	22.8*±3.9	27.8*±1.8	19.9*±2.5	24.7*±4.0
Metmyoglobin (%)	50.1*±0.5	56.4*±4.1	48.8*±2.9	58.7*±3.1	57.2*±3.8
TBA-value (µg malondialdehyde per gram of meat)	0.06±0.02	0.12±0.07	0.07±0.04	0.09±0.03	0.08±0.04
Total antioxidant capacity (µM trolox equivalent per gram of meat)	5.1±0.6	4.8±0.4	4.9±1.3	5.4±0.6	5.9± 0.6

*Differences are statistically significant at $P \leq 0.05$. 3/-20°C and 3/-70°C: 3 months of storage at -20°C and -70°C, respectively. 6/–20°C and 6/–70°C: 6 months of storage at –20°C and –70 °C, respectively.

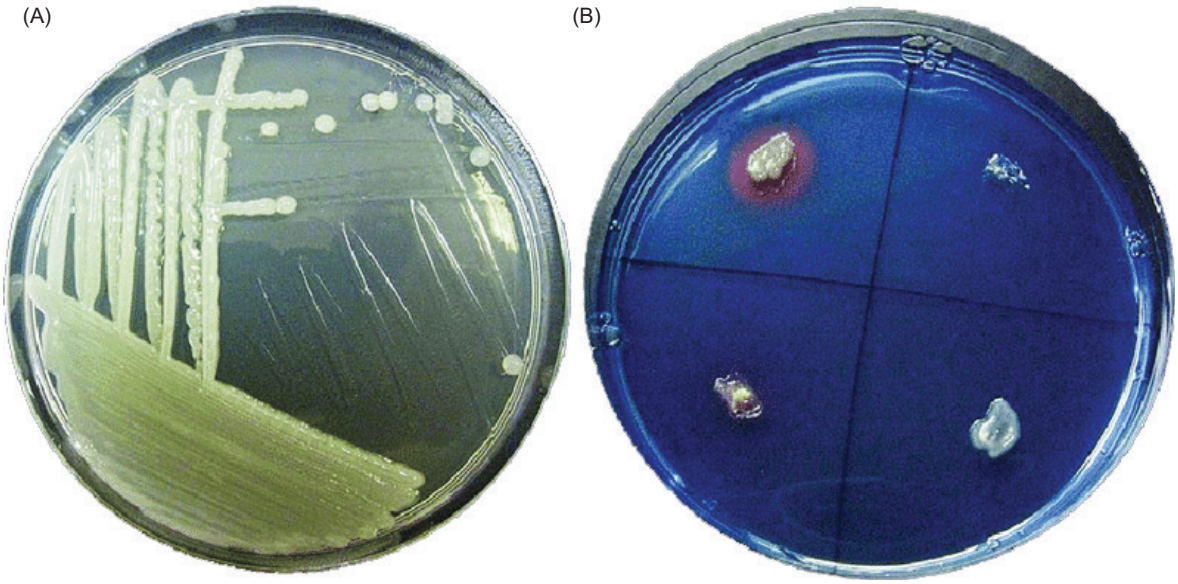

Figure 2. ***Pseudomonas*** **spp. (A) growing in the control group samples, and (B) stored frozen for 6 months.**

lightness values on the day of production than sausages from fresh meat. This effect could not be detected during further storage. Sausages stored at -70°C showed higher redness values on the day of production ($P < 0.05$) than those stored at -20°C. Yellowness values were comparable between the experimental groups at all points.

Results of the chemical analysis of sausages for moisture, protein, and fat content are presented in Table 2. Since the raw materials and recipe were the same for all variants, the only difference was the duration and temperature conditions of meat storage; hence, these compositional parameters of nutritional value did not differ sharply. However, it is important to note that at a temperature of -70°C and for 6-month storage, a slightly higher moisture content and a lower level of protein and fat content were discovered.

Sausages from frozen-thawed meat had significantly lower TBA values after 2 and 4 weeks of storage. Sausages from meat samples stored for 6 months had higher antioxidant capacity ($P < 0.05$) than those from meat samples stored frozen for 3 months at all points. Results of the control sausages in the second week were comparable with those of 3/-20°C and 3/-70°C sausages.

The freeze–thaw treatment did not affect the total plate counts of sausages. Mean *Pseudomonas* spp. counts ranged from 2.0 log CFU/g to 3.1 log CFU/g. Initially, 6/-20°C and 6/-70°C sausages had significantly higher *Pseudomonas* spp. counts, compared to those produced from meat kept in storage for 3 months. However, there were no significant differences, compared to the control group. At other test points, the concentration of *Pseudomonas* spp. was below the detection limit (1.8 log CFU/g). Frozen storage had a substantial effect on the growth of *Enterobacteriaceae*. Sausages from frozen meat had lower *Enterobacteriaceae* count (approximately 0.7±0.2 log CFU/g) than those from fresh meat (2.0±0.7 log CFU/g).

Thus, different analyses are presented because the following results are indicated in the specified sections, namely: meat parameters within 24 h after slaughter; parameters of goose meat before processing (fresh and frozen-thawed); and analysis of raw fermented sausages.

Table 2. Results of chemical analysis of goose meat sausages.

	Control	3/-20°C	3/-70°C	6/-20°C	6/-70°C
Water	63.5±0.04	64.2±0.03	64.9±0.06	64.4±0.04	65.1±0.09
Proteins	21.6±0.09	20.2±0.05	19.6±1.2	19.1±0.05	18.5±0.04
Fats	4.2±0.08	4.0±0.09	3.9±0.5	3.7±1.02	3.4±0.03

3/-20°C and 3/-70°C: 3 months of storage at -20°C and -70°C, respectively. 6/-20°C and 6/-70°C: 6 months of storage at -20°C and -70°C, respectively.

Discussion

The physicochemical parameters (Tables 1 and 2, and Figure 1) discovered after slaughter were generally consistent with those in other publications concerning poultry meat (Ab Aziz *et al.*, 2020; da Silva-Buzanello *et al.*, 2018; Milicevic *et al.*, 2015). Solé *et al.* (2016), for example, determined an average slaughter weight of 5.3 kg whereas the breast muscle weight averaged 22.18%. The microbiological findings were consistent with the results obtained by Kaban *et al.* (2020). Hence, the meat samples used in the freezing experiment could be considered representative examples.

The water-holding capacity of meat is a term often used to describe molecules that are able to trap water physically in a manner that prevents exudation. This ability of meat can be measured by determining drip loss, thawing loss, and cooking loss. The present results established that freezing significantly affected the amount of exudative loss and, consequently, the water-holding capacity of goose meat. The exudative loss could increase due to formation of ice crystals (Leygonie and Hoffman, 2020). Higher freezing temperatures lead to slower freezing values (Choi *et al.*, 2018), resulting in large intercellular crystals whereas fast freezing values at low freezing temperatures lead to a multitude of small intracellular ice crystals in muscle tissues (Choi *et al.*, 2018; Dawson *et al.*, 2018). This process destroys the muscle tissue structure and leads to quality loss, such as increased exudation (Leygonie and Hoffman, 2020). Denaturation of proteins during freezing results in a decrease in their water-holding capacity (Abraha *et al.*, 2018; Zhang and Ertbjerg, 2019). Roberts *et al.* (2020) described that fluid in muscles is usually bound within and between myofibrils. The present results show that frozen goose meat has higher exudative losses than unfrozen meat and are therefore consistent with results of previous studies (Baéza *et al.*, in press). Goose meat stored at -70°C had less fluid loss after thawing than samples stored at -20°C. This was probably due to reduced structural changes caused by formation of ice crystals. Abraha *et al.* (2018) also found that temperature was critical for ice crystallization; hence, it also affected meat quality (Wu *et al.*, 2021). The lower the freezing temperature, the higher the proportion of frozen water (Choi *et al.*, 2018).

There was no difference in pH values between fresh and frozen goose meat samples. No significant changes were observed in lightness and redness after freezing; the values of yellowness, however, increased (Table 2). According to Testa *et al.* (2021), meat color is one of the most important factors affecting consumer purchasing behavior as an indicator of meat freshness. Meat color stability is mainly determined by the amount of myoglobin, its redox status, and formation of ice crystals (Wu *et al.*, 2020). Oxyhemoglobin makes the product appear bright red, while metmyoglobin is associated with pale appearance (Testa *et al.*, 2021).

There was no significant difference in TBA values and total antioxidant capacity of the experimental groups. Lipid oxidation also occurred in meat samples (Domínguez *et al.*, 2019; Echegaray *et al.*, 2021), which, according to Huang and Ahn (2019), is the primary factor that degrades meat quality. The reason behind this process is an imbalance between pro-oxidant factors and antioxidant capacity. However, TBA values in the present study differ from those in other studies, where frozen meat had higher levels of lipid re-oxidation than fresh meat (Hematyar *et al.*, 2021; Rahman *et al.*, 2015).

The main mechanisms of meat spoilage include autolytic/oxidative processes and microbial growth (Tavares *et al.*, 2021). The variety of spoilage microorganisms that grows on meat depends on different factors (Rawat, 2015), such as raising, feeding, and slaughter of animals, meat cutting and packaging, transportation, and storage, as well as on consumer handling. The spoilage of meat and meat products is also determined by original bacterial flora (Rawat, 2015). Even so, *Pseudomonas* spp. is among the most crucial groups of meat bacteria (Heir *et al.*, 2021). Microbiological findings of this study (Figure 2) demonstrated that freezing suppressed the growth of *Pseudomonas* spp. and *Enterobacteriaceae*, although the freezing procedure did not significantly affected the total microbial biomass.

For technological reasons, sausages are often made from frozen meat to prevent excessive heating during the manufacturing process (Domínguez *et al.*, 2019). Frozen process, however, affects the quality of the product. Thus, the present study analyzed the effect of frozen storage duration and temperature on the technological properties of meat used in the production of raw sausages. According to Roberts *et al.* (2020), freezing induces protein insolubility and alters the myofibrillar microstructure of meat. However, the present results showed no significant differences in the shelf life ($P > 0.05$) of control samples and those frozen and stored for up to 6 months, indicating no impact on water activity. After 2 weeks, samples stored for 6 months showed higher storage loss than those stored for 3 months. However, these values should not be overestimated, as this difference was found only in the second week. The present findings also showed that lipid oxidation was reduced through freezing. However, no study has analyzed this parameter in relation to frozen raw meat.

The future research must use the results of this study to improve meat processing technology and develop an effective freezing regime for retaining the quality and taste properties of meat.

Conclusions

This study examined the effect of frozen storage on the quality and safety of meat and meat products, in particular goose meat and sausages produced from it. The study found that goose meat frozen stored for up to 6 months at -20°C and -70°C had little effect on the technological properties of raw sausages. The weight loss of sausages ranged from 19.3 to 22.7% after 1 week of storage and was 36.2 to 38% after 4 weeks.

Considering TBA values and antioxidant properties, it was assumed that freezing did not affect the taste of goose meat. Sausages produced from frozen meat stored for 6 months showed higher antioxidant capacity ($P < 0.05$) than those stored for 3 months at all points. The results of the control sausages were comparable with those of 3/-20°C and 3/-70°C sausages in the second week. The total plate counts of meat products did not differ significantly with respect to storage duration and temperature. Freezing reduced the growth of *Pseudomonas* spp. in meat stored for 6 months, compared to controls ($P < 0.05$). The storage temperature had no effect on this process. Hence, freezing contributes to the microbiological safety of meat and meat products. Therefore, the results of this study could help optimize the meat processing technology and develop an effective freezing regime for retaining the quality and taste properties of meat.

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Conflict of interest

The authors declared that there was no conflict of interest related to this study.

Availability of data and material

Data are available on request.

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