

THE EFFECTS OF FREEZING AND STORAGE TIME ON THE
QUALITY OF REINDEER MEAT

By

George A. Aguiar, B.S.

A Project Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER of NATURAL RESOURCES MANAGEMENT AND GEOGRAPHY

University of Alaska Fairbanks

August 2017

APPROVED:

Gregory L. Finstad, Committee Chair

Peter J. Bechtel, Committee Member

Eva Wiklund, Committee Member

Meriam Karlsson, Chair

Department of Agriculture and Horticulture

School of Natural Resources and Extension

Abstract

Restaurants, wholesalers and retailers of fresh meat require a year round consistent supply of uniform quality product to sustain demand and justify niche market costs such as advertisement and stocking product. Frozen reindeer meat could be stored, short or long term to increase availability provided there are no adverse effects of freezing. No studies to date have evaluated the effects of freezing and storage time on reindeer meat quality.

Nine reindeer steers (castrated bulls; age 2.5 years) were fed a balanced milled ration at the University of Alaska Fairbanks (UAF) Reindeer Research Program (RRP) facility at the Agricultural Forestry Experiment Station (AFES). In February, animals were transported to a USDA approved meat processing facility for slaughter where both striploins (*M. longissimus dorsi*) were removed from the carcasses. The striploin samples were allocated to four subsamples consisting of fresh (control), freshly frozen, 6 month frozen and 12 month frozen treatment groups to determine if freezing and frozen storage of reindeer meat for up to one year effects meat quality. All samples underwent shear force measurement, water holding capacity (WHC) determination, proximate analysis, sensory evaluation, TBARS (rancidity) and fatty acid methyl ester profile (FAMES) analysis. Meat was sampled after 6 months of frozen storage for amino acid and mineral analysis.

Shear force values were not significantly different amongst treatment groups fresh to 12 month ($P=0.992$). Purge and cooking loss variation were significant between fresh and 12 months ($P = 1e-05, 1e-04$). There was no significant difference from fresh to 12 month in moisture, ash and protein content while lipid content variation was significantly different ($P = 0.99, 1.00, 1.00$ and $< 1e-6$ respectively). Tenderness and juiciness attributes were not significantly different among treatment groups fresh and 12 month ($P=0.91$ and $P=0.53$); however, an off flavor attribute was significantly different ($P=0.005$) amongst treatment groups suggesting that off flavor diminishes with freezing. While not detected in sensory evaluation, mean TBARS (rancidity) values increased significantly ($P = <.1e-04$) between fresh and 12 months. Characterization of reindeer muscle indicated that the amino acid profile and selected mineral were consistent with that of a high quality nutritional meat product. Omega 3 fatty acid (W3), Omega 6 fatty acid (W6), Monounsaturated fatty acid (MUFA), Polyunsaturated fatty acid (PUFA), the ratio between Omega 3 and Omega 6 (W3/W6) and the ratio between PUFA and

MUFA (PS) were not significantly different while Saturated fatty acid (SAFA) was significantly different amongst treatments groups from fresh to 12 months. ($P = 0.35, 1.00, 0.96, 0.12, 1.00, 0.14$ and 0.03).

Results of this study suggest reindeer meat can be frozen for up to a year without compromising quality. This could facilitate the marketing flexibility for the reindeer industry to be able to provide a consistent supply of product year round to niche restaurants and wholesalers while commanding a premium price.

| Table of Contents | Page |
|----------------------------|-------------|
| Abstract..... | 2 |
| Background..... | 5 |
| Introduction | 8 |
| Materials and Methods..... | 9 |
| Results..... | 13 |
| Discussion..... | 20 |
| Conclusions..... | 22 |
| Acknowledgements..... | 22 |
| References..... | 23 |

Background

Reindeer Meat Production in Alaska

In 1892 reindeer were introduced to Alaska from Siberia by Reverend Sheldon Jackson to provide a food supply for the Native people of the Seward Peninsula in Western Alaska and potentially a way of life (Stern et al., 1980). By 1902 the Russian Imperial Government prohibited any further exports and the expansion of reindeer in Alaska would only come by means of natural growth (Christie et al., 2009). The imported reindeer consisted primarily of Chukotka stock along with reindeer from the Tungus of eastern Siberia (Ellana and Sherrod., 2004). The Chukotka breed has a higher muscle to bone ratio while the Tungus is a bigger breed. Both characteristics have significant implication for meat production, pertaining to either commercial or subsistence while utilizing rangeland.

Throughout history, the advancement of domestication of grazing animals has been to provide power, a protein source, and economic gain from the utilization of vegetation (Stern et al., 1980). Alaska's grazing and forage crop base could provide opportunity for potential economic growth (Wiklund et al., 2008). Purchasing feed is a major cost to any animal production operation that is behind fence. The concentrate, which usually consists of cereal grain and supplemental protein and minerals, is costly in Alaska and the amount fed will influence profitability of a reindeer operation (Finstad and Aguiar., 2007). The Seward Peninsula is comprised of approximately 6,070,300 hectares of excellent rangeland characterized by many preferred reindeer forages. The Peninsula is designated for reindeer grazing and capable of producing large quantities of reindeer meat.

With an abundance of forage and limited predation, the imported reindeer thrived and reproduced in their new environment.

By 1916, over 1,200 Eskimo owned herds had emerged (Stern et al., 1980). By the 1920's more than 500,000 reindeer existed in Alaska spreading from Barrow to the Aleutian Islands (Stern et al., 1980). Deteriorating rangeland and conflicts between herders became issues and the local market, along with the profits of reindeer herding were declining (Stern et al., 1980). From 1920 through 1929 the Lomen family had a large enterprise distributing meat throughout the United States which came to an end with the Great Depression and the reindeer meat industry would take several steps back (Stern et al., 1980). In 1941 the Bureau of Indian

Affairs began a program to revitalize the industry and improve reindeer management by establishing 17 new herds under private ownership. The requirement of developing a grazing management plan in accordance with the Natural Resource Conservation Service allowed access to a grazing permit (NRCS, 1953, 1954). In 1971 the Reindeer Herder's Association was formed as a political organization to facilitate involvement with government organizations and promote the reindeer industry (Bader and Finstad, 2001). Meat production had been steadily rising from 1960 to 1968 with the exception of one year. In 1970 herd owners were receiving on average 50 cents a lb. for reindeer meat. By 1977 the price had increased to 85 cents a lb. (Stern et al., 1980). Beginning in the 70's, reindeer herding has been a significant economic factor on the Seward Peninsula incorporating the harvest of velvet antler and meat (Carlson, 2005). The reindeer industry has and will continue to face challenges associated with their remote location such as the distance animals are from markets, transportation costs and lack of infrastructure (Christie et al., 2009). Migrating caribou became a significant problem in the early 90's and wiped out whole herds of reindeer by comingling with them and leading them off of the ranges when deciding to continue on with their migration.

Amongst all of the challenges there are now approximately 10-15 thousand reindeer on the Seward Peninsula. There are approximately another 5 thousand animals on the Pribilof Islands, Aleutian Chain, Nunivak Island and the interior of Alaska collectively. The Alaskan reindeer meat industry has produced meat for subsistence and local use and has historically been an important export commodity (Stern et al., 1980). Reindeer meat production dropped from 342,727 kg of dressed reindeer meat in 1968 (Stern et al., 1980) down to 95,455 kg of reindeer meat produced in 2010 (USDA., 2011). Many herders believe that the development of the reindeer industry lies within the production and sale of meat (Finstad et al., 2006).

Meat Quality

Meat is able to provide many nutrients such as protein, vitamins and fat as part of a balanced diet with the overall quality being determined by the meat attributes (Akhtar et al., 2013). Quality of beef is highly dependent upon tenderness, juiciness and flavor with tenderness being the most important to many consumers (Lagerstedt et al., 2008). Appearance and odor are also important characteristics.

The postmortem decline in pH value of meat is an integral component of determining meat quality aspects and variable from animal to animal (Aberle et al., 2001). Normal muscle pH is characterized by approximately 7.4 in living muscle which gradually decreases after exsanguination to 5.6 – 5.7 in about 6 to 8 hours and after 24 hrs. reaches ultimate pH of 5.3 – 5.7 as a result of an accumulation of lactic acid in the muscle (Aberle et al., 2001). Meat pH values are directly correlated to the levels of muscle energy (glycogen) at the time of slaughter (Gill and Newton, 1981). If the glycogen stores in the muscles are low, meat pH will be elevated. Environmental factors such as stress, cold and heat, along with poor physiological body condition of the animal can interfere with the muscle glycogen content and therefore also with normal meat pH decline and ultimate pH causing undesirable meat quality aspects. If pH declines too rapidly while a carcass does not adequately drop in temperature, proteins are denatured, a loss of water and protein binding capacity occur and muscle coloration fades; all of which are undesirable meat quality characteristics that will be expressed in meat by means of paleness and a very low water holding capacity (Aberle et al., 2001). If pH maintains a high level not consistent with normal muscle to meat conversion, naturally occurring water is tightly bound to proteins (Aberle et al., 2001). The negative effects are dark, dry and firm meat with a sticky texture.

The main purpose of chilling meat soon after slaughter is to inhibit or drastically slow down microbiological growth and to limit effect on quality (Aidani et al., 2014). Temperature is important as meat may attain a low pH of 5.2 to 5.4 without undergoing excessive protein denaturation if properly and adequately chilled (Aberle et al., 2001). Freezing meat is a practice used to extend shelf life (Leygonie et al., 2012). Freezing preserves meat quality as it results in fewer changes in organoleptic and qualitative properties than other methods. Some nutritive value is lost in thawing due to drip or purge however nutrients are not rendered indigestible or damaged during the freezing process. Fresh meat refers to meat that has undergone chemical and physical changes that occur after slaughter however has not been further processed by value added methods such as freezing, curing, smoking and other means (Hedrick et al., 1994). “The properties of fresh meat dictate its usefulness to the merchandiser, its appeal to the purchaser or consumer, and it’s adaptability for further processing. Of particular importance are water-holding capacity, color, structure, firmness and texture (Hedrick et al., 1994).”

When discussing taste or flavor, the measurement of lipid oxidation through the detection of TBARS can quantify rancidity. The disadvantage of using TBARS method is that hexanal and other breakdown products do not contribute to flavor. When using organoleptic assessment via sensory analysis, it is possible to quantify an attribute such as off flavor with the use of a trained panel. This more closely mimics the consumers and their sensitivity to the oxidation that is taking place within a meat product (Tarladgis et al., 1960).

Water holding capacity (WHC) refers to the ability of meat to maintain water during the application of outside forces, usually associated some type of processing such as heating, grinding or pressing. It is not unusual for some moisture to be lost during processing as it is in the free form. Many other physical properties of raw meat (color, texture, firmness) and cooked meat (tenderness and juiciness) are often partially dependent on WHC (Hedrick et al., 1994). WHC can be directly quantified by measuring drip loss or purge in a frozen cut of meat after it has been thawed or measuring cooking loss in a cut of meat after it has been cooked to determine how much moisture was lost. WHC can also be indirectly quantified by means of sensory analysis utilizing a trained sensory panel to analyze the juiciness attribute. WHC is not only important when discussing palatability, but also the ability for meat to maintain water soluble nutritive components that can be lost during drip or cooking loss.

The tenderness of a meat product is a result of a complex combination of factors regarding palatability and has been researched more than any other palatability trait (Aberle et al., 2001). Tenderness refers to how much pressure it takes to cut through a piece of meat. Tenderness, texture and properties of intramuscular connective tissue correlate with the maturity of an animal and are often times mentioned together (Kolczac et al., 2005). The correlation can cause variability when determining measurements. Tenderness can be measured by mechanical means of the Warner-Bratzler to determine shear force by measuring kg/cm². In addition, sensory analysis using a trained panel and/or consumer tests can add valuable information when evaluating meat tenderness.

Introduction

Restaurants, wholesalers and retailers of fresh meat require a year round consistent supply of uniform quality product to sustain demand and justify niche market costs such as advertisement and stocking product.

The majority of current reindeer meat production in Alaska is on the Seward Peninsula (Finstad, 2006-2007) where environmental conditions, infrastructure limitations and body condition of the reindeer result in inconsistent supply of fresh meat.

A quality, frozen, meat product could benefit expansion of the industry by making meat more readily and consistently available to both local and distant markets. Advantages of a frozen meat product include increased storage time and flexibility in distribution, logistics for processors and restaurants along with increased inventory (Wheeler et al., 1990).

The overall aim of this study was to investigate the nutritional profile of reindeer meat and the effects of freezing and storage time on these qualities by measuring various attributes using chemical, mechanical and sensory methods over a one year time period. Other important objectives were:

- To determine existing amino acid and mineral profile.
- To compare the sensory characteristics, shear force, water holding capacity determination (WHC) and cooking loss and evaluate rancidity (TBARS) of fresh reindeer meat and frozen meat stored for up to one year.
- To determine the proximate analysis (protein, fat, moisture, ash) and fatty acid profiles of fresh and frozen reindeer meat.

Materials and Methods

Animals

Nine reindeer (*Rangifer tarandus tarandus*) steers (castrated bulls), all thirty months of age were fed a balanced milled ration consisting primarily of barley (*Hordeum vulgare*), smooth brome grass (*Bromus inermis*) hay, oats (*Avena sativa*) and fish meal at the University of Alaska Fairbanks (UAF) Reindeer Research Program (RRP) facility. The main composition of the feed mixture is described in Finstad et al., 2007.

In February of 2010 the reindeer were transported for about two hours (158 km) to a USDA approved facility (Delta Meat and Sausage Co., Delta Junction, Alaska). Animals were shot in the head with a 22-caliber rifle and exsanguinated. USDA inspected slaughter procedures were followed. Carcasses were weighed prior to being moved into a chiller kept at +2 °C. Temperature and pH was measured in *M. longissimus dorsi* (LD; at the last rib) of all animals at

15 min, 1, 2, 3, and 72 hours *post mortem*. Final temperature and ultimate pH values were measured in both LDs from all carcasses at approximately 72 h *post mortem*.

At three days post mortem the LD's were boned out from the carcasses and excised into 4 pieces which were randomly allocated to 4 treatments: fresh (control), freshly frozen, 6 month frozen and 12 month frozen. Subsamples from each replicate were allocated for sensory analysis, shear force measurements, TBARS (rancidity), proximate, amino acid, fatty acid and water holding capacity (WHC) analysis. All samples were vacuum packaged in 4mm freezer bags. Fresh (control) samples were chilled to +3 °C for immediate analysis. The freshly frozen samples were frozen to -20 °C and thawed overnight to +3 °C for immediate analysis. Samples for storage were frozen to -20 °C, stored for 6 months and 12 months and then removed from the freezer and thawed overnight to +3 °C for analysis.

Temperature and pH measurements

Meat pH was measured with an Orion, pH meter (model 290 A, Boston, MA, USA) with attached Orion Kniphe® electrode (Beverly, MA, USA) in the LD at the last rib. Calibrating the meter was done with buffers of pH 7.0 and 4.0 (Thermo Orion, Beverly MA, USA) at room temperature (20 °C).

Temperature was measured with a digital thermometer (Conmark, DT 300, Beaverton, OR, USA). The pH meter was adjusted for muscle temperature at each measurement.

Tenderness, purge and cooking loss

Reindeer meat subsamples were thawed then cooked to an end temperature of 75° C in a water bath (Isotemp 220, Fisher Scientific, USA). Internal meat temperature was monitored with copper-constantan thermocouples (Type T, Omega Engineering, Stamford, CT, USA) and a scanning digital thermometer (Model 692-0000, Barnant Co., Barington, IL, USA). Subsamples were weighed, cooked and allowed to cool to 25 °C before being weighed again to determine cooking loss. Cooking loss for 6 month time period samples were not determined. Five cores with a 1.5 cm diameter were removed parallel to the muscle fiber configuration and sheared using a TAXT Plus texture analyzer (Texture Technologies, NY, USA) instrument and a Warner-Bratzler blade attachment. Tenderness values were registered as maximum shear force (peak height) set with a 10kg load scale and a 200 mm per minute drive chart drive and

crosshead speed. Mean values were calculated. Purge (in this study a combination of drip and thaw loss) was measured by removing subsamples from the freezer and thawing overnight in a chiller to +3°C. Subsample was removed from 4mm freezer bags, any surplus drip on the meat was removed using a paper towel, and weighed. Previous weight of bag and subsample minus sample determined purge value. Purge weight was expressed as a proportion (%) of the original weight of meat packed.

Proximate analysis

Moisture content was determined gravimetrically on triplicate 3-g samples dried for 24 h at 103 °C (AOAC 952.08, 1990). Percent lipid values were determined by extraction of dried samples on a Soxtec 2043 (Foss, Eden Prairie, MN, USA) using methylene chloride (Fisher Scientific, Pittsburgh, PA, USA) as the extraction solvent. After extraction the solvent was removed by evaporation and the sample weighted (AOAC, 1990; method 948.16). Protein was measured by analyzing for the nitrogen content using an Elementar Rapid NIII analyzer (Elementar Americas Inc., Mt. Laurel, NJ, USA) with WINRAPID™ software (Elementar Americas, Inc.) to calculate protein values using the percent nitrogen times 6.25. Calibration was based on l-aspartic acid (Aldrich, St. Louis, MO, USA) as outlined in manual 12.00–5001 (Elementar Analysensysteme GmbH., 2004). Ash content was estimated by incinerating approximately 4 g of sample into a muffle furnace (Lindberg Blue M, Thermo Scientific Inc.) at 550°C for 6 h (AOAC, 1990; method 938.08).

Sensory evaluation

A panel of six members was selected and trained at the Department of Animal Sciences, University of Illinois, U.S.A. Reindeer samples were cut into 2.54 cm thick steaks against the grain of the muscle. Meat was cooked to an internal temperature of 70 °C being turned at approximately 35 °C on a Farberware Open Hearth Grill. Samples were cut and served to the taste panelists two at a time. The panel evaluated four to five samples per session during a total of four sessions for juiciness, tenderness and off flavor using a 15cm anchored unstructured line scale (0 = extremely tough, extremely dry, no off flavor; 15=extremely tender, extremely juicy, and extremely intense off-flavor) (Holmer et al., 2008).

Amino Acids and Mineral Analysis

Reindeer meat samples (LD, n=4) of approximately 5 g were collected from the samples stored in the freezer for 6 months and freeze dried for general amino acid analysis. Samples were sent to AAA Service Laboratory Inc., Boring, OR for amino acid analysis.

Samples were hydrolyzed with 6N HCl and 2 % phenol at 110 °C for 22 h. Amino acids were quantified using the Beckman 6300 analyzer with post column ninhydrin derivatization. Tryptophan and cysteine content were not determined.

Meat samples (LD, n=4) of approximately 5 g were collected from the samples stored in the freezer for 6 months and freeze dried for general mineral analysis. Samples were sent to the Palmer Research Center (Palmer, AK) of the University of Alaska Fairbanks School of Natural Resources and Agricultural Sciences for mineral analysis. Samples were ashed overnight at 550 °C and ashing residues were digested overnight in aqueous solution containing 10% (v/v) hydrochloric acid and 10% (v/v) nitric acid. Digested solutions were diluted as needed and analyzed for Ca, Fe, K, Mg, Mn, P, S and Zn by inductively coupled plasma optical emission spectroscopy on a Perkin Elmer Optima 3000 Radial ICP-OES (Perkin Elmer, Boston, Mass. U.S.A).

Fatty Acid Methyl Ester Profile

Fatty acid methyl esters (FAMES) were prepared using the method described by Maxwell and Marmer (1983). The FAME profile was analyzed on a gas chromatography coupled to a flame ionization detector (7890A, Agilent Technologies Inc.) as described by Oliveria and Bechtel (2005) with modification. Separation was made on a FAMEWAXTM (30 m X 0.32 mm i.d., 0.25 µm film) capillary column (Agilent Technologies Inc.). Helium gas was the carrier at a constant flow rate of 2 ml/min. The inlet and detector temperatures were 250 and 280 °C, respectively. The temperature program was as follows: initial temperature = 90 °C with 8 min hold; increased to 175 °C at 10 °C/min with 10 min hold; then increased to 190 °C at 4 °C/min with 10 min hold; then increased to 210 °C at 5 °C/min with 5 min hold and then increased to 250 °C at 20 °C/min with 8 min hold. Standards used for identification of peaks were: Supelco 37, Bacterial Acid Methyl Esters Mix, Marine Oil #1 and Marine Oil #3 (Supelco, Bellefonte, PA, USA).

Rancidity/ Thiobarbituric acid reactive substances (TBARS)

A 5 g (wet weight) sample was mixed with 10 mL of 10% (w/v) trichloroacetic acid (TCA), and the mixture was homogenized for 90 sec. After centrifugation at 3800 rpm for 15 min, 2 mL of supernatant was mixed with 2 mL of TBA solution (20.8 mM). The mixture was then heated in a dry bath for 20 min at 94°C, giving a transparent pink solution. The content of thiobarbituric acid reactive substances was obtained by reading the absorbance at 532 nm on a Spectrometer. Results were expressed as µg malondialdehyde (MDA) per g of wet sample.

Statistical Analysis

Analysis of Variance (ANOVA) incorporating a repeated measures mixed effects model using the statistical analysis program R (R core team, 2013) was used to evaluate the effects of differences in freezing and time on meat quality attributes and characteristics across the sample group of animals. Statistical significance was $P \leq 0.05$. A principle component analysis using the statistical analysis program R (R core team, 2013) was used to examine individual fatty acids and since no significant groupings were observed a linear mixed effects model was used to evaluate the summary of FAMES.

Results

Carcass characteristics, temperature, and pH measurements

Live weight in reindeer, carcass weight and dressing percentage ($n=9$) was 118 ± 2.72 kg, 66.12 ± 2.09 kg and 56% respectively. The pH and temperature decline in the reindeer carcasses ($n=9$) is shown in figure 1.

Tenderness, purge and cooking loss

Shear force values were not significantly different amongst treatment groups fresh to 12 month ($P=0.992$). Shear force variation was significant between fresh and 6 months ($P=0.05$). Purge variation was significant between fresh and freshly frozen ($P = 1e-05$), fresh and 6 months ($P = 1e-05$), fresh and 12 months ($P = 1e-05$), freshly frozen and 6 months ($P = 1e-05$), and freshly

frozen and 12 months ($P = 1e-05$). Cooking loss was significant between fresh and freshly frozen ($P=0.006$) and fresh and 12 month ($P=1e-04$) (Table 1).

Proximate Analysis

There was no significant difference from fresh to 12 month in moisture, ash and protein content while lipid content variation was significantly different ($P = 0.99, 1.00, 1.00$ and $< 1e-6$ respectively) (Table 2). Moisture variation was significant between fresh and freshly frozen ($P=0.001$), freshly frozen and six months ($P=0.001$), and freshly frozen and 12 months ($P=0.001$). Ash variation was significant between fresh and 6 months ($P=1e-06$), freshly frozen and 6 months ($P=1.28e-06$) and 6 months and 12 months ($P=1e-06$). Lipid variation was significant between fresh and 6 months ($P=1e-06$), freshly frozen and six months ($P=1e-06$) and freshly frozen and 12 months ($P=1e-06$). Protein variation was significant between fresh and freshly frozen ($P=0.001$), freshly frozen and six months ($P=0.002$) and freshly frozen and 12 months ($P=0.001$).

Sensory evaluation

Tenderness and juiciness attributes were not significantly different among treatment groups fresh and 12 month ($P=0.91$ and $P=0.53$) however an off flavor attribute was significantly different ($P=0.005$) amongst treatment groups suggesting that off flavor diminishes with freezing.

Sensory attribute tenderness variation was significant between fresh and freshly frozen ($P=0.02$) while off flavor variation was significant between fresh and freshly frozen ($P=0.001$), fresh and 6 months ($P=0.001$), and fresh and 12 months ($P=0.007$) (Table 1).

Amino Acids and Mineral Analysis

Characterization of reindeer muscle indicated that the amino acid profile and selected mineral were consistent with that of a high quality nutritional meat product. The amino acid and mineral analysis of reindeer meat samples ($n= 4$) is presented in Tables 4 and 5.

Fatty Acid Methyl Ester Profile and rancidity (TBARS)

Analysis of the FAMES values indicated small decreases in the content of polyunsaturated fatty acids (PUFAs) with storage time and increased in saturated (SAFA) and monounsaturated

(MUFA) FAMES (Table 3). Omega 3 fatty acid (W3), Omega 6 fatty acid (W6), MUFA, PUFA, the ratio between Omega 3 and Omega 6 (W3/W6) and the ratio between PUFA and MUFA (PS) were not significantly different while SAFA was significantly different amongst treatments groups from fresh to 12 months. ($P=0.35, 1.00, 0.96, 0.12, 1.00, 0.14$ and 0.03). Omega 6 Fatty acid (W6) variation was significant between freshly frozen and six months ($P=0.029$) and freshly frozen and 12 months ($P=0.042$) while PUFA variation was significant between freshly frozen and 6 months ($P=0.031$) and SAFA variation was significant between fresh and 6 months ($P=0.042$). Fatty acid PS variation was also significant between freshly frozen and 6 months ($P=0.0310$).

While not detected in sensory evaluation, mean TBARS (rancidity) values increased significantly ($P = <.1e-04$) between fresh and 12 months, freshly frozen and 12 months ($P = <.1e-04$) and 6 months and 12 months ($P = <.1e-04$) (Table 3).

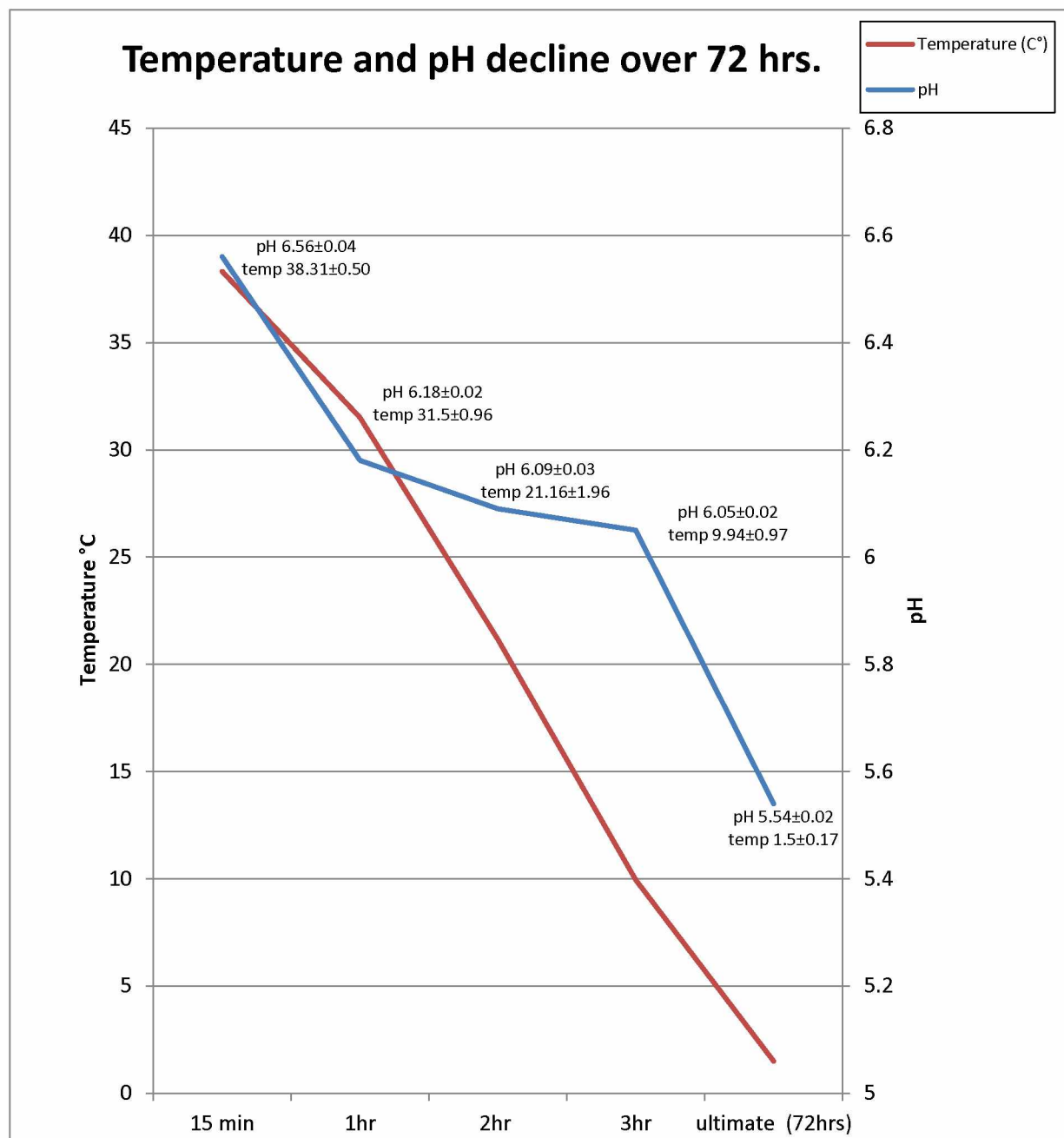


Fig. 1. Temperature and pH decline in *M. longissimus* from reindeer ($n = 9$) at 15 min., 1h, 2h, 3h and at 72h post mortem (means \pm S.E.).

Table 1. Sensory Analysis, cooking loss, purge and shear force of *M. longissimus* in four different freezing and storage treatments; fresh, freshly frozen, six months and 12 months included in this study (means± S.E.)

| | Fresh (n=9) | Freshly Frozen (n=9) | 6 months (n=9) | 12 months (n=9) |
|--|---------------------------|----------------------------|--------------------------|---------------------------|
| juiciness | 8.79 ±0.24 ^a | 8.84 ±0.30 ^a | 8.76 ±0.21 ^a | 9.26 ±0.28 ^a |
| tenderness | 8.67 ±0.62 ^a | 10.23±0.48 ^b | 9.76 ±0.33 ^{ab} | 9.02 ±0.41 ^{ab} |
| off flavor | 0.83 ±0.20 ^a | 0.15 ±0.05 ^b | 0.00 ±0.00 ^{bc} | 0.35 ±0.09 ^{bd} |
| Purge % | 3.63 ±0.62 ^a | 6.65 ±0.60 ^b | 9.49 ±1.13 ^c | 10.05 ±0.92 ^{cd} |
| cook loss % | 23.36 ± 0.79 ^a | 20.48 ±0.46 ^{bc} | NA | 19.01 ±0.62 ^c |
| Warner- Bratzler Shear Force (kg) | 4.83 ±0.46 ^a | 4.56 ±0.39 ^{ab} | 3.75 ± 0.20 ^b | 4.71 ±0.49 ^{ab} |

Means with different superscripts (^{abc}) within the same row are significantly different (P<.05) amongst treatment groups
Juiciness, tenderness and off flavor measured on a 15 cm anchored unstructured line. NA is not analyzed.

Table 2. Proximate Analysis of *M. longissimus* in reindeer from four different freezing and storage treatments; fresh, freshly frozen, six months and 12 months (means± S.E.)

| | Fresh (n=9) | Freshly Frozen (n=9) | 6 months (n=9) | 12 months (n=9) |
|--------------|--------------------------|--------------------------|-------------------------|-------------------------|
| Moisture (%) | 71.8 ±0.32 ^{ab} | 73.02 ±0.30 ^c | 71.3 ±0.34 ^a | 71.9 ±0.38 ^b |
| Ash (%) | 1.09 ±0.06 ^a | 1.11 ±0.01 ^a | 1.39 ±0.06 ^b | 1.09 ±0.02 ^a |
| Lipid (%) | 5.66 ±0.40 ^a | 5.8 ±0.38 ^a | 2.1 ±0.47 ^b | 2.11 ±0.32 ^b |
| Protein (%) | 24.0 ±0.17 ^a | 23.0 ±0.13 ^b | 23.8 ±0.18 ^a | 24.0 ±0.29 ^a |

Means with different superscripts (^{abc}) within a row are significantly different (P<0.05) amongst treatment groups.

Table 3. Mean values and standard errors for FAMES (expressed as percent of total FAMES measured) and Mean Oxidative Rancidity (TBARS; expressed in percentage as μg malondialdehyde (MDA) per g of wet sample) (means \pm S.E.) of raw *M. longissimus* in reindeer from four different freezing and storage treatments; fresh, freshly frozen, six months and 12 months included in the study.

| | Fresh (n=9) | Freshly Frozen (n=9) | 6 months (n=9) | 12 months (n=9) |
|-----------------------|--------------------------------|--------------------------------|-------------------------------|-------------------------------|
| 14:00 | 0.83 \pm 0.03 | 0.95 \pm 0.06 | 1.08 \pm 0.08 | 1.11 \pm 0.08 |
| 16:00 | 24.45 \pm 0.67 | 25.50 \pm 0.80 | 27.58 \pm 0.86 | 27.65 \pm 0.63 |
| 16:1n7 | 0.94 \pm 0.07 | 0.97 \pm 0.05 | 1.27 \pm 0.06 | 1.06 \pm 0.06 |
| 18:00 | 21.62 \pm 0.39 | 21.58 \pm 0.32 | 22.16 \pm 0.40 | 22.18 \pm 0.37 |
| 18:1n9c | 33.92 \pm 1.22 | 33.62 \pm 0.98 | 34.98 \pm 0.55 | 34.53 \pm 0.60 |
| 18:1n7c | 1.95 \pm 0.12 | 1.97 \pm 0.09 | 2.11 \pm 0.08 | 1.79 \pm 0.05 |
| 18:2n6c | 7.93 \pm 1.06 | 8.01 \pm 1.11 | 5.33 \pm 0.56 | 5.40 \pm 0.47 |
| 20:4n6 | 1.75 \pm 0.35 | 1.75 \pm 0.37 | 0.82 \pm 0.16 | 0.92 \pm 0.14 |
| w3 tot | 1.25 \pm 0.22 ^a | 1.16 \pm 0.25 ^a | 0.62 \pm 0.17 ^a | 0.80 \pm 0.10 ^a |
| w6 tot | 10.59 \pm 1.49 ^{ab} | 10.52 \pm 1.57 ^a | 6.62 \pm 0.83 ^b | 6.81 \pm 0.67 ^b |
| SAFA | 47.52 \pm 1.05 ^a | 48.89 \pm 1.14 ^{ab} | 51.71 \pm 1.21 ^b | 51.83 \pm 0.98 ^b |
| MUFA | 37.66 \pm 1.27 ^a | 37.36 \pm 1.06 ^a | 39.42 \pm 0.58 ^a | 38.27 \pm 0.57 ^a |
| PUFA | 11.84 \pm 1.71 ^{ab} | 11.68 \pm 1.80 ^a | 7.24 \pm 0.97 ^b | 7.61 \pm 0.76 ^{ab} |
| tot identified | 97.02 \pm 0.30 | 97.91 \pm 0.16 | 98.39 \pm 0.40 | 97.70 \pm 0.18 |
| w3/w6 | 0.11 \pm 0.01 ^a | 0.11 \pm 0.01 ^a | 0.08 \pm 0.02 ^a | 0.12 \pm 0.01 ^a |
| P/S | 0.32 \pm 0.06 ^{ab} | 0.32 \pm 0.06 ^a | 0.18 \pm 0.03 ^b | 0.20 \pm 0.02 ^{ab} |
| TBARS | 0.65 \pm 0.03 ^a | 0.58 \pm 0.04 ^a | 0.50 \pm 0.08 ^a | 1.50 \pm 0.16 ^b |

Means with different superscripts (^{abc}) within the same row are significantly different ($P < 0.05$) amongst treatment contrasts.

Table 4. Mean values and standard errors for amino acids (% of total identified on a wet basis) of reindeer meat.

| amino acid | Reindeer Meat (<i>n</i> = 4) | |
|---------------------|-------------------------------|-------|
| Aspartic acid (ASP) | 10.72 | ±0.02 |
| Threonine (THR) | 5.05 | ±0.01 |
| Serine (SER) | 4.08 | ±0.01 |
| Glutamic acid (GLU) | 15.80 | ±0.01 |
| Proline (PRO) | 3.91 | ±0.02 |
| Glycine (GLY) | 4.21 | ±0.05 |
| Alanine (ALA) | 6.10 | ±0.01 |
| Valine (VAL) | 5.80 | ±0.01 |
| Methionine (MET) | 0.69 | ±0.01 |
| Isoleucine (ILE) | 5.37 | ±0.03 |
| Leucine (LEU) | 9.67 | ±0.03 |
| Tyrosine (TYR) | 3.98 | ±0.02 |
| Phenylalanine (PHE) | 2.09 | ±0.06 |
| Histidine (HIS) | 4.57 | ±0.02 |
| Lysine (LYS) | 10.69 | ±0.02 |
| Arginine (ARG) | 7.27 | ±0.02 |

Table 5. Mean values and standard errors for mineral composition of reindeer meat on a dry weight basis.

| minerals | Reindeer meat (<i>n</i> =4) | | |
|---------------|------------------------------|---|------|
| Phosphorous % | 0.56 | ± | 0.02 |
| Potassium % | 0.99 | ± | 0.03 |
| Calcium % | 0.01 | ± | 0.00 |
| Magnesium % | 0.09 | ± | 0.00 |
| Sulfur % | 0.72 | ± | 0.03 |
| Zinc ppm | 117.25 | ± | 6.17 |
| Manganese ppm | 1 | ± | 0.00 |
| Iron ppm | 144.25 | ± | 9.57 |

Discussion

Alaskan reindeer were selected for characteristics pertaining to meat animals. They are stockier and heavier with a higher muscle to bone ratio than other subspecies and have been harvested for meat since being imported into Alaska in 1892. Although from older and larger animals, similar dressed carcass percentages along with ultimate pH values were reported by Wiklund et al. (2008) to those of the present study.

Storing beef frozen has been utilized to address market issues (Vieira et al., 2009). Frozen meat can be negatively affected by freezing rate, storage time, and conditions of storage time (Aberle et al., 2001). However, the effect of freezing on reindeer meat quality is unknown.

Lagerstedt et al (2008) reported that drip loss was higher for frozen meat than aged meat. Negative implications of freezing may include both chemical and mechanical damage. Ice crystallization damages muscle fibers and can denature proteins (Lawrie, 1998). The freezing rate that determines the ice crystal size can affect degree of mechanical damage (George, 1997). Slow freezing allows for large extracellular masses of ice crystals to form in the meat which will be loss as drip during thawing (Aberle et al., 2001). It would be expected that purge values would be significant as the physical changes occurring in muscle tissue from freezing and thawing causes muscle cells to rupture and fluids to be lost (Leygonie et al., 2012). In addition, it could be anticipated that cook loss would be significant as physical damage amongst muscle cells during cooking allows for moisture loss. During freezing and thawing of meat, dehydration causes the loss of the ability to hold and retain water, while the denaturation of myofibrillar proteins may be the reason for higher cooking losses in meat that has been frozen (Kolczak et al., 2005). In a study done on frozen beef for a storage time of 0, 30, 75 and 90 days, Vieira et al. (2009) reported reduced WHC and mentions vacuum packaging as an included variable that may be the cause of higher drip loss. Statistical difference in the reduction in WHC of fresh meat was evident after 90 days (Vieira et al., 2009).

Lipid content dropped from 5% to 2% when comparing fresh and freshly frozen samples with the ones stored for six and 12 months, which in itself would not necessarily decrease quality or market value. Protein, ash and moisture values were not significantly different between treatment groups. The reason for the large variation in lipid content among treatment groups is

unknown. It is possible that the variability of lipid content within muscle tissue in combination with technical challenges during sample preparation and analysis could explain the significant difference.

The sensory panel detected a significant difference in the off flavor attribute over the one year time period. The sensory scores for off flavor were lower for samples stored for 12 months compared with fresh samples. This observation might be related to drip/purge loss and a result of off flavor compounds which were soluble in the purge (drip + thaw loss) and therefore disappeared from the thawed meat.

The amino acid and mineral profile was consistent with the nutrients that would be expected to be found in reindeer meat.

The increase in SAFAs over a once year time period could be explained by rancidification of PUFAs thus increasing the percentage of SAFAs. Although the amount of SAFA is higher and statistically significant after the storage periods (six and 12 months), the biological significance is not a factor in the quality of reindeer meat and how it affects shelf life and marketability. The values are too small and would be undetectable to a person's pallet. Rancidity (TBARS) was significantly highest in samples stored for 12 months, however the sensory panel detected no such differences in rancidity (TBARS) or off flavor among treatments. A similar study states that no significance was detected in rancidity values of beef after a much shorter storage time of 90 days (Vieira et al, 2009).

Most attributes that the present study examined were not significantly different when comparing fresh meat and meat stored frozen for 12 months. Throughout the fresh, freshly frozen, 6 month and 12 month time period, the study demonstrated significant differences in random treatment variations, however any significant differences between treatment group variations outside of the fresh to 12 month time period are irrelevant when marketing reindeer meat as having a 12 month shelf life as a frozen product. If reindeer meat quality is not significantly different from a fresh product when stored for 12 months then it does not really matter what happens in between and could allow reindeer meat to fulfill the demand throughout a 12 month time period without compromising quality.

The ability to freeze reindeer meat for storage and shipping without negatively impacting quality could provide many options and opportunities for furthering economic development for the reindeer industry in remote rural Alaska. As most reindeer producers in Alaska are off of the

road system with little to no access to infrastructure and immediate mode of transportation to markets, a method of product distribution without compensating quality would be invaluable to the industry by ways of market potential and higher profits. A better understanding of freezing effects on reindeer meat quality could give reindeer producers, processors, distributors and consumers the information needed to more confidently and accurately market and distribute reindeer meat to distant markets without compromising product quality.

Conclusions

Results of this study suggest reindeer meat can be frozen for up to a year without compromising quality and consumer. This could facilitate the marketing flexibility for the reindeer industry to be able to provide a consistent supply of product to niche restaurants and wholesalers while charging a premium price.

Acknowledgements

The authors wish to thank all members of the Reindeer Research Program (RRP), School of Natural Resources and Agricultural Sciences, University of Alaska Fairbanks for their assistance pertaining to the care of the animals along with collection of samples. We also thank Jeannie Pinkleman, owner of Delta Meat and Sausage Co., and her staff for use of the facility and skilled labor required for our sample collection. We acknowledge the staff from the department of Animal Sciences at the University of Illinois, U.S.A. in their part with the sensory evaluation. We also thank Randy Peterson and John Harley for their contribution towards the statistical analysis of the data. Financial support for this project was provided by the United States Department of Agriculture (USDA) Hatch Formula Funding accession no. 224658 and by the Reindeer Research Program, University of Alaska Fairbanks (State of Alaska General Research Fund).

References

- Aberle E.D., J.C. Forrest, D.E. Gerrard and E.W. Mills. (2001). Principles of Meat Science Fourth Edition. Iowa: Kendall/Hunt Publishing Company.
- Aidani, E., B. Aghamohammadi, M. Akbarian, A. Morshedi, M. Hadidi, N. Ghasemkhani and A. Akbarian. 2014. Effect of chilling, freezing and thawing on meat quality: a review. *Int. J. Biosci.* 4(3): 159-169.
- Akhtar, S., M.I. Khan and F. Faiz. 2013. Effect of Thawing on Frozen Meat Quality: A comprehensive Review. *Pak. J. Food Sci.* 23(4): 198-211.
- AOAC, Method 952.08. 1990. Official Methods of Analysis, 15th ed. Association of Official Analytical Chemists, Arlington, VA, USA.
- Bader, H.R., and G.L. Finstad. 2001. Conflicts between livestock and wildlife: An analysis of legal liabilities arising from reindeer and caribou competition on the Seward Peninsula of Western Alaska. *Environ. Law* 31: 549–580.
- Carlson, S.M. 2005. Economic impact of reindeer–caribou interactions on the Seward Peninsula. Masters thesis, University of Alaska Fairbanks, Fairbanks, Alaska, USA.
- Christie, A. and G.L. Finstad. 2009. Reindeer in the “Great Land”: Alaska’s Red Meat Industry. *J. Ag Food Info* 10: 354-373.
- Ellanna, L. J. and G. K. Sherrod 2004. From Hunters to Herders. The Transformation of Earth, Society and Heaven Among the Inupiat of Beringia. Fairbanks, Alaska: Department of Anthropology, University of Alaska Fairbanks Publication.
- Finstad, G.L., K.K. Kielland and W.S. Schneider. 2006. Reindeer herding in transition: Historical and modern day challenges for Alaskan reindeer herders. *Nomad. People.* 10: 31–49.
- Finstad, G. 2006-2007. *Reindeer in Alaska: Under New Management.* *Agroborealis* 38 (2), 22-28. or <https://www.uaf.edu/files/snre/Agro%2038-2.pdf>
- Finstad, G. and G. Aguiar. 2007. Biomass Production, Nutritional Characteristics and effect on reindeer (*Rangifer tarandus tarandus*) of Two Pasture Grasses: Kentucky Nugget Bluegrass (*Poa pratensis*) and Smooth Brome Grass (*Bromus Inermis*). A.A.A.S. Symposium. Anchorage, Alaska.

- Finstad, G., E. Wiklund, K. Long, P.J. Rincker, A.C.M. Oliveira and P.J. Bechtel. 2007. Feeding soy or fish meal to Alaskan reindeer (*Rangifer tarandus tarandus*) – effects of animal performance and meat quality. *Rangifer*. 27(1): 59-75.
- George, R.M. 1997. Freezing Systems. Quality in Frozen Food. Ed. Erickson, M.C. & Hung, Y.C. New York: Chapman and Hall.
- Gill, C. O. and Newton, K. G. 1981. Microbiology of DFD beef. – In: Hood, D. E. & Tarrant, P. V. (eds.). The problem of Dark-Cutting in beef. Martinus Nijhoff, Den Haag, pp. 305-327.
- Hedrick, H.B., E.D. Aberle, J.C. Forrest, M.D. Judge and R.A. Merckle. (1994). Principles of Meat Science Third Edition. Iowa: Kendall/Hunt Publishing Company.
- Holmer S.F., L.W. Kutzler, F.K. McKeith and J. Killefer. 2008. Sodium citrate as a replacement for sodium chloride in a brine solution when evaluated in cows of a different backfat thickness. *Meat Sci*. 81: 349-356.
- Kolczak, T., K. Palka. and J. Lacki. 2005. Water retention, shear force and texture parameters of cattle psoas and semitendinosus muscles unfrozen and frozen during post-mortem ageing: *Pol. J. Food Nutr. Sci*; Vol. 14/55 No. 1: 17-26.
or <https://www.cabdirect.org/cabdirect/FullTextPDF/2007/20073139040.pdf>
- Lagerstedt Å, Enfält L., Johansson L. and Lundström, K. 2008. Effect of freezing on sensory quality, shear force and water loss in beef (*M. longissimus dorsi*) *Meat Sci*. 80: 457-461.
- Lawrie, R.A. (1998). Lawrie's Meat Science Sixth Edition. England: Woodhead Publishing Limited.
- Leygonie, C., Britz T.J. and Hoffman, L.C. 2012. Impact of freezing and thawing on the quality of meat: Review. *J. Meat Sci*; 91, Issue 2: 93 – 98.
or <http://www.sciencedirect.com/science/article/pii/S0309174012000149>
- Maxwell, R.J. and W.N. Marmer. 1983. Fatty acid analysis: Phospholipid rich samples. *Lipids* 18: 453-459.
- NRCS (Natural Resource Conservation Service), United States Department of Agriculture. 1953. Comptroller General's Opinion B-115665 of 1 Oct. 1953, 33CG:133.
- NRCS (Natural Resource Conservation Service), United States Department of Agriculture. 1954. Amendment No. 4, Title 9, Administrative Regulations, 17 May 1954.
- Oliveira, A. C. M. and Bechtel, P. J. (2005). Lipid composition of Alaskan pink salmon (*Oncorhynchus gorbuscha*) and Alaska Walleye Pollock (*Theragra chalcogramma*) by-products. *Journal of Aquatic Food Product Technology*, 14, 73–91.

R Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.
or <http://www.R-project.org/>.

Stern, R. O., Arobio, E. L., Naylor, L.L. and Thomas, W.C. 1980. Eskimos, Reindeer and Land. Agricultural and Forestry Experimental Station, University of Alaska Fairbanks. Bulletin 59. 205pp.

Tarladgis, B.G., B.M. Watts, M.T. Younathan and L. Dugan. 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. Journal of the American Oil Chemist's Society 37, 44-48

United States Department of Agriculture. (2011). Alaska Agricultural Statistics 2011. or https://www.nass.usda.gov/Statistics_by_State/Alaska/Publications/Annual_Statistical_Bulletin/annual2011.pdf

Vieira, C., M.T. Diaz, B. Martinez and M.D. García-Cachán. 2009. Effect of frozen storage conditions (temperature and length of storage) on microbiological and sensory quality of rustic crossbred beef at different states of ageing. Meat Sci. 83(3): 398-404.

Wheeler, T.L., R.K. Miller, J.W. Savell and H.R. Cross. 1990. Palatability of Chilled and Frozen Beef Steaks. J. Food Sci; 55, Issue 2: 301.

Wiklund, E., G. Finstad, L. Johansson, G. Aguiar and P.J. Bechtel. 2008. Carcass composition and yield of Alaskan reindeer (*Rangifer tarandus tarandus*) steers and effects of electrical stimulation applied during field slaughter on meat quality. Meat Sci. 78: 185-193.

Wiklund, E., M. Farouk and G. Finstad. 2014. Venison: Meat from red deer (*Cervus elaphus*) and reindeer (*Rangifer tarandus tarandus*). Animal Frontiers; 4: 55-61.