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Antioxidant and other quality properties of reindeer muscle from two different Norwegian regions

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ABSTRACT

The effects of origin, gender, age, and muscle type on chemical composition, colour, antioxidant status and sensory profile of reindeer muscles *Longissimus dorsi* (LD) and *Semimembranosus* (SM) from two production regions were investigated. For some variables, the comparison between reindeer and beef muscles was also included. Muscles from North Norway (NN) were darker and contained more myoglobin and moisture, and less protein and fat than muscles from Mid Norway (MN). Oxygen radical absorbance capacity (ORAC) was significantly higher in these muscles while the levels of antioxidant enzymes were significantly lower in contrast to MN muscles. Relative to male reindeer, muscles from females contained significantly more total phenols and showed higher antiradical power (ARP). Carcass weight and the sensory attributes colour, sharp and bitter flavour had higher scores for older animals. Considerable differences between LD and SM were revealed in sensory assessment. In comparison to beef reindeer meat was darker, had more myoglobin, total phenols, antioxidant enzymes, and higher ARP and ORAC values.

1. Introduction

Reindeer (*Rangifer tarandus tarandus*) are well adapted to a climate characterised by low temperatures and snow during a major part of the year. The production of reindeer is the most important source of income for Sami people and it is an essential part of their life and culture. Reindeer meat is a natural product, associated with Norwegian tradition, and a large part of the Norwegian population consumes reindeer at special occasions such as weddings, baptisms and confirmations (Kjuus, Svennerud, Skøyen, Bergset, & Borgen, 2006).

Reindeer husbandry is mainly based on the utilisation of native pastures, which give the reindeers the necessary nutrients. During the summer, reindeers graze on protein-rich food such as grass, herbs and fungi in the mountains and forest. In the autumn and in the winter they shift to a diet consisting mainly of energy-rich lichens and dwarf shrubs. Reindeer meat produced in extensive systems has potential to become an attractive product for the health oriented consumers on account of its low fat content with a high ratio of polyunsaturated fatty acids (Sampels, Wiklund, & Pickova, 2006; Wiklund, Pickova, Sampels, & Lundstrom, 2001) and most likely a high antioxidant potential (Sampels, Pickova, & Wiklund, 2004). Natural grazing is also an important contributor to the development of various "wild" flavours, specific for reindeer meat (Wiklund, Johansson, & Malmfors, 2003; Wiklund, Malmfors, Lundström, & Rehbinder, 1996; Wiklund, Nilsson, & Åhman, 2000).

Grazing animals provide meat of long shelf live (oxidative stability) presumably due to their diet consisting mainly of plant material with a high content of antioxidants (Descalzo & Sancho, 2008; Gatellier, Mercier, & Renerre, 2004). These bioactive substances may affect the shelf life and the flavour of meat by the reduction and partial inhibition of the oxidation of unsaturated fats. The muscle has a natural defence mechanism against oxidative stress due to non-enzymatic water and lipid soluble compounds like vitamin E, vitamin C, carotenoids, ubiquinols, polyphenols, cellular thiols, and enzymes like superoxide dismutase (SOD), catalase (CAT) and glutathione peroxidase (GPx). Together, enzymatic and non-enzymatic systems serve to retard oxidation or prevent accumulation of lipid oxidation products (Chan & Decker, 1994; Decker & Xu, 1998; Gatellier et al., 2004; Halliwell, Murcia, Chirico, & Aruoma, 1995; Terevinto, Ramos, Castroman, Cabrera, & Saadoun, 2010). Antioxidant enzymes constitute an intracellular barrier against free radicals. In skeletal muscles the most important enzymes are catalase (CAT), superoxide dismutase (SOD) and glutathione peroxidase (GPx). SOD is an important antioxidant defence in nearly all cells exposed to oxygen and catalyses the dismutation of superoxide into oxygen and hydrogen peroxide while CAT and GPx catalyse the dismutation of hydrogen peroxide into water and oxygen. GPx can additionally decompose lipoperoxides formed during lipid oxidation (Chan & Decker, 1994; Decker & Xu,

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1998; Gatellier et al., 2004). Antioxidant enzymes can be used as a good indicator of the oxidative status of muscle tissue. Antioxidant enzyme activities differ between meats from different species and muscle types (Pradhan, Rhee, & Hernandez, 2000). Antioxidant activity in muscle varies depending on cell anoxia and depletion of nutrients after bleeding. Antioxidants in the diet strengthen the immune systems, prevent cancer and heart disease, and reduce the ageing process and the development of serious diseases. This protection has been explained by the capacity of these antioxidants to scavenge free radicals responsible for the oxidative damage of lipids, proteins and nucleic acids (Aruoma, 1998).

Measurements of antioxidant capacities in food have increased considerably in recent years. Although the studies have focused on vegetables, fruit and spices, some research has been conducted to investigate antioxidant activities in beef (Descalzo et al., 2007; Descalzo & Sancho, 2008; Gatellier et al., 2004; Pradhan et al., 2000). Several methods such as antioxidant enzyme assay, oxygen radical absorbance capacity (ORAC), 2, 2-diphenyl-1-picrylhydrazyl radical scavenging capacity assay (DPPH) have been used to determine antioxidant activities. The ORAC assay is widely used because of the automated procedure and the application of a biologically relevant radical source i.e. peroxyl radical (Davalos, Gomez-Cordoves, & Bartolome, 2004; Huang, Qu, & Prior, 2005). The DPPH assay is simple and has been applied to determine the free radical scavenging capacities of food antioxidants (Brand-Williams, Cuvelier, & Berset, 1995).

There is limited research on antioxidant accumulation, status and their synergies in muscle, including reindeer muscle. As far as we are aware no data is available on the activity of antioxidant enzymes in reindeer. Information on factors influencing the activity of these enzymes and the antioxidant capacity of meat is also incomplete.

The objectives of the present study were to get information about reindeer muscle and meat quality from the chemical composition, colour, antioxidant activity and sensory profile. In addition, for some of the variables comparison of reindeer to beef muscle was included.

2. Materials and methods

2.1. Raw materials

Reindeer samples were collected from two reindeer slaughterhouses, one in North Norway (Kautokeino) and one in Mid Norway (Røros) in the autumn (October–November). Eighteen carcasses were selected with nine reindeers from each region represented by four female and five males. The reindeer were divided in two age groups according to the adopted custom in Norway. The young animal's group (under 1.5 years) included the calves and animals that overwintered once, while the remaining animals that overwintered twice or more belonged to the adult group (over 1.5 years). Slaughtered, dressed carcasses were hung at +2° for 4 days before selection. The criteria for selection of the carcasses at the slaughterhouses were pH<6.0 for LD (*M. Longissimus dorsi*) and slaughter weight >19.0 kg. *M. Semimembranosus* (SM) and *M. Longissimus dorsi* (LD) (at 2.0 to 2.5 °C) were removed from the right and left side of the carcasses by a professional cutter. Muscles were vacuum packaged separately, labelled, put in polystyrene boxes and transported to Nofima mat AS either by air or in a refrigerated truck. The samples were on arrival placed at +4 °C ± 1.0 °C and stored for 3 days before being distributed to various analyses and frozen at −40 °C. In total, 36 samples derived from eighteen animals were analysed in terms of chemical composition, colour, antioxidant status and sensory profile. Beef LDs from 8 NRF (Norwegian Red) young bulls (450 kg live weight) slaughtered at a commercial slaughterhouse (HedOpp, Norway), aged for 7 days at 4 °C and frozen at −40 °C were used for comparison.

2.2. Meat quality assessments

Meat samples were thawed at 1–2 °C overnight and the following measurements made in duplicate.

2.2.1. pH

Determination of pH directly in meat cuts was carried out with a Beckman 31 pH meter with an insertion electrode Zerolyt (Mettler-Toledo AG, Switzerland).

2.2.2. Proximate analysis

The muscle samples were analysed by "AnalyCen" laboratory (Moss, Norway). Water, fat and protein were determined according to routine methods (NMKL 23 1991; EU DIR 98/64 m; EU DIR 93/28 m), respectively.

2.2.3. Colour measurement

An automatic Minolta Chroma Meter CR-300 with 8 mm measuring cell and light source (D65) determined L* (lightness), a* (redness) and b*(yellowness) after 30 min blooming. Five measurements from the meat surface were averaged. Chroma (saturation) was calculated as $(a^{*2}+b^{*2})^{1/2}$ (Wyszecki & Stiles, 1982).

2.2.4. Myoglobin

Myoglobin was extracted from raw muscle samples in cold (1 °C) 0.04 M phosphate buffer, pH 6.8 (Warriss, 1979). Total myoglobin was calculated based on the absorbances of a clarified extract at 525 (isobestic point) and 700 nm (Krzywicki, 1979) using the Ultraspec 3000 (Pharmacia Biotech, Cambridge, UK). Total myoglobin (Mb) was calculated using the following formula:

$$\mathrm{Mb(mg/g)} = (\mathrm{A525}-\mathrm{A700}) \times 2.303 \times \text{dilution factor};$$

where

$$\mathrm{Mb} = \mathrm{deoxyMb} + \mathrm{MbO_2} + \mathrm{MetMb}.$$

2.3. Antioxidant status of the meat

Methods for assessing the antioxidant activity included the use of the free radical DPPH (2, 2-diphenyl-1-picrylhydrazyl), the Oxygen Radical Absorbance Capacity assay (ORAC) and indirect methods, level of total phenols and antioxidant enzyme assay.

2.3.1. Antiradical power (ARP)

The antioxidant activity of muscle was determined by using 2.2-diphenyl-1-picrylhydrazyl (DPPH•) as described by Brand-Williams et al. (1995) with some modifications. DPPH• (25 mg/L) and meat samples were dissolved in absolute ethanol (AE) instead of methanol. Muscle samples (2.5 g) were homogenised with 10 mL of AE (30 s, 8200 rpm) and centrifuged (20 min, 20,650×*g*, 4 °C). The filtrated supernatants at three concentrations were mixed with DPPH• solution, covered and incubated in the dark, at ~20 °C. The reduction in the DPPH• was measured from the absorbance at 515 nm on the Ultraspec 3000 against a blank (AE and DPPH•), after 60, 90 and 120 min of incubation. Absorbance of a blank sample containing 0.8 mL absolute ethanol and 3.2 mL DPPH solution was defined as 100%. The percentage of remaining DPPH• was used to calculate the amount of sample required to decrease the initial DPPH• concentration by 50% (EC50). The antiradical power (ARP) is given as the reciprocal of EC50, in units of mg of DPPH• per gram meat.

Total phenols were determined using the Folin–Ciocalteu procedure (Waterhouse, 2002). Muscle samples (5.0 g) were homogenised with 50 mL methanol (60 s, 8200 rpm) and centrifuged (20 min, 20,650×*g*, 4 °C). To the filtered supernatants (0.2 mL) 1.0 mL Folin–

Ciocalteu's reagent (1:10 v/v, with water) and 0.8 mL Na_2CO_3 (7.5% w/v) were added. After incubation for 2 h (~20 °C) in the dark, the absorbance was measured at 765 nm on the Ultraspec 3000. Gallic acid was used as standard. Total phenol content was expressed as Gallic acid equivalents (GAE) in mg 100 g^{-1} muscle.

Oxygen radical absorbance capacity (ORAC) assay was performed as described by Davalos et al. (2004) with some adjustments. A 1.0 g muscle was homogenised with 9 mL of phosphate buffer (75 mM, pH 7.4), three times for 15 s (8200 rpm) on ice. After centrifugation at 0 °C for 10 min at 39,200×*g* the supernatants were appropriately diluted with 75 mM potassium phosphate buffer (pH 7.4) using an automated liquid handling system (Biomek 2000 Workstation, Beckman Coulter, Inc., Fullerton, CA,USA). Sample (20 μL) was added to a black 96-well microplate (96F, Nunc, Rochester, NY, USA). Fluorescein (120 μL, 70nM final conc.) was added as the fluorescent substrate, and the samples were incubated in a FLUOstar OPTIMA 96-well plate reader (BMG LABTECH, Offenburg, Germany) at 37 °C for 10 min prior to addition of pre-warmed AAPH (60 μL, 24 mM final conc.) — 2,2′-azobis(2–23 amidinopropane)dihydrochloride — as the source for peroxyl radicals delivered by the integrated pump. The ORAC assays were carried out in duplicate at 37 °C with four dilutions per sample with Trolox (20 μL, 2 μM final conc.) as the control standard and phosphate buffer as blank. Fluorescence readings (excitation at 485 nm and emission at 520 nm) were carried out through the bottom of the wells every 3 min until the signal was less than 5% of the initial reading. All fluorescence measurements were expressed relative to the initial readings. The final ORAC values were calculated using the differences in areas under the fluorescein decay curves between the blank and sample (net area). Antioxidant capacity was expressed as μmol Trolox equivalents (TE) per gram muscle (μmol TE g^{-1} muscle).

2.3.2. Assays of antioxidant enzyme activities

After partial thawing, the samples were chopped with knife and kept on ice. Muscle (2.5 g) was homogenised with 10 mL of phosphate buffer (50 mM, pH 7.0) for 30 s (8,200 rpm) and centrifuged at 4 °C for 20 min at 10,600×*g*. The same filtrated supernatant was used to determine CAT, SOD and GPx activities.

Catalase (CAT) activity was determined by measuring the spectrophotometric decrease in H_2O_2 concentrations according to the method developed by Aebi (1984) and modified by Mei, Crum, and Decker (1994). The supernatant (0.1 mL) reacted at room temperature (22 °C) with 2.9 mL of 11 mM H_2O_2 in phosphate buffer and the decomposition rate of the substrate (H_2O_2) was monitored at 240 nm on the Ultraspec 3000 during the initial 60 s. The activity was calculated using the molar extinction coefficient of H_2O_2 (39.4 M^{-1} cm^{-1}) and results expressed as μmol of decomposed H_2O_2 per minute per gram of muscle i.e. U g^{-1} meat.

Superoxide dismutase (SOD) activity was measured using the superoxide dismutase kit (Ransod, Cat. No SD 125, Randox Laboratories Ltd. Antrim, UK) which is based on the method developed by Woolliams, Wiener, Anderson, and Mc Muray (1983). This method employs the reaction between xanthine and xanthine oxidase (XOD) to generate superoxide radicals (O_2^{-}•) that react with 2-(4-iodophenyl)-3-(4-nitrophenol)-5-phenyltetrazolium chloride (INT) to form a red formazan dye. The SOD present in the sample competes with INT for superoxide radicals and therefore inhibits the production of the formazan dye. The superoxide dismutase activity was measured by the degree of inhibition of this reaction at 505 nm on the Ultraspec 3000 for 3 min. One unit of SOD (U), from the standard curve, was defined as the amount of the enzyme required for 50% inhibition of INT reduction. Results were expressed in units of SOD g^{-1} muscle.

Glutathione peroxidase (GPx) activity was performed using Ransel reagents (Randox-cat no: RS-505 — Randox Laboratories Ltd. Antrim, UK) based on the method of Paglia and Valentine (1967). GPx catalyses the oxidation of glutathione (GSH) by cumene hydroperoxide. In the presence of glutathione reductase and nicotinamide adenine dinucleotide phosphate (NADPH) the oxidised glutathione is immediately converted to the reduced form with concomitant oxidation of NADPH to $NADP^+$. The decrease in absorbance at 340 nm was measured for 3 min on the Ultraspec 3000. GPx activity was expressed as U g^{-1} muscle where one unit (U) was defined as 1 μmol of NADPH oxidised per minute.

2.4. Sensory descriptive analysis

The frozen meat samples were transferred to a defrosting chamber at 4 °C for one night, cut perpendicular to the fibres in slices 1.5 cm thick. Each slice was vacuum-packed in coded plastic bags and heated in a water bath at 70 °C for 30 min prior to assessment. Sensory analysis was performed according to international standard methods (ISO, 1985a,b, 1988). The panel consisted of eleven well-trained assessors who carried out a descriptive test (ISO, 1985a). The assessors were trained to use the attributes in a separate session in which two extreme samples were evaluated. The definition and quantification of the attributes across the two samples were discussed and the assessors agreed on a consensus list of attributes for profiling (Table 1). Panellists were given no information on the purpose of the experiment.

Samples (approx. 50 °C) were served in the plastic bags in random order according to experimental group, replicate and assessor. The assessors evaluated odours immediately after opening the plastic bags. Colour was assessed on a freshly cut cross-section of the sample. Flavour and texture attributes were assessed on the entire sample. For rinsing the mouth between samples, water and crackers were served. A continuous non-structured scale was used for evaluation of sensory attributes ranging from the lowest intensity of each attribute (value 1.0) to the highest intensity (value 9.0). Each assessor evaluated the

Table 1
Description of sensory attributes used in profiling of reindeer meat.

Odour properties	
Gamy odour	Odour of wild animal
Liver odour	Odour of animal liver
Sharp odour	Strong, acrid odour
Acidic odour	Relates to fruit acid, a fresh, sour/sweet/fruity odour
Sickeningly sweet odour	Relates to unwell, sweet, insipid, little aromatic and nauseating odour
Metal odour	Relates to odour of metal (ferrous sulphate)
Colour properties	
Whiteness	Colour judged on a newly cut slice of meat after the NCS system, black or pure colour to white colour
Hue	Yellow/red to red/blue after the NCS system
Colour intensity	None to intense after the NCS system
Flavour properties	
Gamy flavour	Flavour of wild animal
Liver flavour	Flavour of animal liver
Sharp flavour	Acrid, strong flavour
Acidic taste	Relates to fruit acid, a fresh, sour/sweet/fruity taste
Bitter taste	Relates to basic bitter flavour (caffeine, quinine)
Sickeningly sweet flavour	Relates to unwell, sweet, insipid, little aromatic and nauseating flavour
Metallic flavour	Flavour of metal
Texture properties	
Hardness	Mechanical textural attribute related to the force required to bite through the sample. Assessed with the molars of 1 bite
Tenderness	Mechanical textural attribute related to the time and number of chews required to masticate the sample ready for swallowing
Juiciness	Perception of juice absorbed from the sample after 3 to 4 chewing

Table 2
The effect of origin, gender, age and muscle type on carcass weight, ultimate pH and chemical composition of reindeer meat.

Variables		Carcass weight kg	Ultimate pH	Water %	Protein %	Fat %
Origin	Nord Norway	26.6 ± 1.16	5.61 ± 0.02	73.6 ± 0.18	23.4 ± 0.14	0.7 ± 0.07
	Mid Norway	28.4 ± 1.22	5.56 ± 0.02	72.8 ± 0.19	24.1 ± 0.15	1.0 ± 0.11
Significance (P value)		*n.s.*	*<0.05*	*<0.001*	*<0.01*	*<0.05*
Gender	Male	29.5 ± 1.12	5.65 ± 0.02	73.7 ± 0.17	23.6 ± 0.14	0.7 ± 0.07
	Female	25.5 ± 1.78	5.53 ± 0.03	72.7 ± 0.27	23.9 ± 0.22	1.0 ± 0.11
Significance (P value)		*n.s.*	*<0.01*	*<0.01*	*n.s.*	*<0.05*
Age	Under 1.5 years	23.7 ± 1.64	5.55 ± 0.03	73.0 ± 0.25	23.6 ± 0.20	1.0 ± 0.11
	Over 1.5 years	31.3 ± 1.19	5.63 ± 0.02	73.5 ± 0.18	23.9 ± 0.15	0.7 ± 0.08
Significance (P value)		*<0.01*	*<0.05*	*n.s.*	*n.s.*	*n.s.*
Muscle	SM	27.5 ± 1.19	5.59 ± 0.02	73.4 ± 0.18	23.5 ± 0.15	0.8 ± 0.08
	LD	27.5 ± 1.19	5.58 ± 0,02	73.0 ± 0.18	24.0 ± 0.15	0.9 ± 0.08
Significance (P value)		*n.s.*	*n.s.*	*n.s.*	*<0.05*	*n.s.*

samples at their own speed on a computerised system for direct recording of data (CSA, Compusense, Ontario, Canada).

2.5. Statistical analysis

Data were analysed by univariate Analysis of Variance (ANOVA) using the general linear model method (GLM) (Minitab Statistical Software; Release 15.0, Minitab Inc., State College, PA). The models included the fixed effect of origin (Nord Norway versus Mid Norway), gender (male versus female), age (below and above 1.5 years) and muscle type (LD versus SM). The results are shown as least square means with standard errors and P-values. Univariate correlation analysis (Pearson correlation) between quality parameters and antioxidant activities was performed by Minitab. The sensory data were subjected to univariate Analysis of Variance (ANOVA) using SAS software package (1996).

3. Results and discussion

3.1. Carcass characteristics

ANOVA results (means ± SE and P-values) for carcass weight, pH and chemical composition of the reindeer meat are presented in Table 2. Since the carcass weight of reindeers was one of the selection criteria (over 19.0 kg), the values ranged from 19.0 kg to 36.0 kg at both slaughterhouses and did not show any significant differences between origins. Age influenced weight the most ($P<0.001$). Older animals were about 8.0 kg heavier than younger ones. These results are consistent with earlier findings of Wiklund et al. (2001, 2003) and Sampels, Pickova, and Wiklund (2005) for pasture fed Swedish reindeers. Another criterion for carcasses selection was an ultimate pH of the LD (*M. Longissimus dorsi*) under 6.0 and the pH values ranged from 5.48 to 5.76 The reindeer muscle from North Norway (NN) had higher pH values than the muscle from Mid Norway (MN). Higher pH values were found in males and older animals, no significant muscle type differences were detected. The pH range was in agreement with Rincker et al. (2006) using beef, reindeer and caribou and Wiklund et al. (2003) using reindeer muscles.

The proximate analysis of the muscle showed the effect of origin (Table 2). Muscles from NN animals had more moisture, less protein and fat than muscles from MN. Gender influenced the moisture and fat contents. Females had more fat and less moisture in their muscles. No effect of age on proximate composition was found, although the carcass weight differed significantly between age groups. Protein content depended on the muscle type and was higher in LD than in SM. Generally, reindeer meat was very lean (0.5–1.6% fat) and rich in protein (22–25%); presumably reflecting their active out-door life on the mile-long pasture. The results are in good agreement with Rincker et al. (2006), Sampels et al. (2004), Sampels et al. (2005), Wiklund et al. (2001) showing that free-range animals have a low fat content.

3.2. Colour of reindeer muscles

Colour parameters depended on origin (Table 3). The lower L^*, a^* and b^* values for NN reindeer indicated muscles with darker appearance, less red and yellow colours than muscles from MN. Other factors did not affect the meat colour. Similar values for a^* and b^* have been obtained by Rincker et al. (2006) on reindeer and caribou while the L^* values were substantially lower (25.3). Statistical analysis of beef and reindeer meat colour revealed significant differences in lightness ($P<0.001$) and yellowness ($p=0.015$) while redness and chroma were similar for both species. Beef was lighter

Table 3
The effect of origin, gender, age and muscle type on colour and myoglobin content in reindeer meat and comparison to beef.

Variables		Lightness L^*	Redness a^*	Yellowness b^*	Chroma	MB mg g^{-1} meat
Origin	North Norway	31.4 ± 0.5	17.6 ± 0.6	5.8 ± 0.3	18.6 ± 0.6	10.52 ± 0.30
	Mid Norway	33.1 ± 0.6	19.6 ± 0.6	7.5 ± 0.4	21.0 ± 0.7	9.58 ± 0.31
Significance (P value)		*<0.05*	*<0.05*	*<0.01*	*<0.05*	*<0.05*
Gender	Male	31.5 ± 0.6	18.7 ± 0.6	6.5 ± 0.4	19.9 ± 0.7	10.55 ± 0.38
	Female	33.0 ± 0.9	18.5 ± 0.9	6.8 ± 0.6	19.7 ± 1.0	9.54 ± 0.49
Significance (P value)		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Age	Under 1.5 years	33.3 ± 0.9	18.6 ± 0.9	6.4 ± 0.6	19.7 ± 1.0	9.45 ± 0.47
	Over 1.5 years	31.2 ± 0.6	18.7 ± 0.7	6.9 ± 0.4	19.9 ± 0.7	10.64 ± 0.40
Significance (P value)		*n.s.*	*n.s.*	*n.s.*	*n.s*	*n.s.*
Muscle	SM	32.8 ± 0.6	18.2 ± 0.6	6.2 ± 0.4	19.3 ± 0.6	9.96 ± 0.34
	LD	31.7 ± 0.6	19.0 ± 0.6	7.0 ± 0.4	20.3 ± 0.6	10.13 ± 0.28
Significance (P value)		*n.s.*	*n.s.*	*n.s.*	*n.s.*	*n.s.*
Species	Beef	40.4 ± 0.3	18.4 ± 0.3	5.9 ± 0.2	19.3 ± 0.4	4.16 ± 0.34
	Reindeer	32.3 ± 0.4	18,6 ± 0.4	6.6 ± 0.2	19.8 ± 0.4	10.05 ± 0.19
Significance (P value)		*<0.001*	*n.s.*	*<0.01*	*n.s.*	*<0.001*

with less yellowness in comparison to reindeer meat. A clear relationship between lightness (L*) and amount of myoglobin was found. Groups with the higher haem pigment content had lower L* values which means darker colour. Myoglobin content varies with species and makes a principal contribution to meat colour. Myoglobin concentration in Norwegian reindeer ranged from 8.06 to 11.38 and was on average 10.16 mg/g meat while the beef (LD) analysed contained on average 4.2 mg/g meat. Rincker et al. (2006) reported 7.29 mg g^{-1}, 8.59 mg g^{-1} and 9.71 mg g^{-1} myoglobin in beef, caribou and reindeer, respectively.

3.3. Antioxidant status of reindeer meat

Pastures where reindeer graze dominated by vegetation rich in bioactive components which may influence the composition of reindeer meat. Berries, herbs and grasses provide a wide range of natural antioxidants to the animals. It has been stated that dietary delivered natural antioxidant from pasture significantly improves the antioxidant status of muscle and enhances the oxidative stability of meat (Descalzo & Sancho, 2008). Apart from studies on the effect of diet on vitamin E content (Sampels et al., 2006) no study has been reported on the antioxidant status of reindeer meat.

The oxygen radical absorbance capacity (ORAC) was higher for muscles from North Norway (Table 4). Muscles from female carcasses showed significantly higher ARP and total phenols values than those from male carcasses. Antioxidant activity was not affected by age. Antioxidant activities of beef and reindeer muscle differed by all three methods. Beef had almost seven fold lower antiradical power (ARP) than reindeer meat: i.e. 0.17 versus 1.20 mg DPPH g^{-1} muscle, respectively plus lower ORAC activity and with considerably less total phenols. Significant correlations were obtained between total phenols and ARP ($r = 0.686$; $p < 0.001$) and between total phenols and ORAC ($r = 0.433$; $p = 0.013$). No correlation between ARP and ORAC was detected (0.244; $p = 0.178$). It is worth noting that the ORAC test is suitable for water-soluble antioxidants and the antiradical test (ARP) with DPPH• in a polar medium (ethanol) is applicable for lipid-soluble antioxidants.

The activities of CAT, SOD and GPx in reindeer meat and beef are presented in Table 5. CAT activity ranged from 160.50 to 566.25 U g^{-1} meat and was not significantly influenced by any variable. Gatellier et al. (2004) indicated a significant effect of sex (cows higher than steers and heifers) but did not observe any effect of diet or age on CAT. Similarly, Descalzo et al. (2007) reported no difference in CAT activity in *M. Psoas major* (PM) from steers fed pasture or grain diets. Activity of reindeer catalase was significantly higher ($p = 0.024$) than that of beef catalase. Similar results for beef muscle (285 ± 19 U g^{-1} meat) were obtained by Mei et al. (1994). However, the present results were slightly lower than reported by Pradhan et al. (2000) for beef (LD − 520 U g^{-1} meat; SM − 410 U g^{-1} meat) and pork (LD − 705 U g^{-1} meat).

Superoxide dismutase (SOD) activity in reindeer meat ranged from 167.05 to 463.95 U g^{-1} muscle while glutathione peroxidase (GPx) activity ranged from 9.5 to 25.6 U g^{-1} muscle (Table 5). Origin modified SOD and GPx activities in reindeer muscles (Table 5). Reindeer from Mid Norway had higher values both for SOD and GPx compared with North Norway. These differences could be caused by diet or more precisely by the variety of pasture. Muscle from pasture-fed cattle has higher SOD and GPx activity than muscle from grain fed animals (Descalzo & Sancho, 2008; Gatellier et al., 2004). However, results from cross breed steers have indicated a moderate effect of pasture diet on SOD activity (Descalzo et al., 2007). Animal age and muscle type had no influence on SOD or GPx activity. GPx activity was more pronounced in reindeer than in beef muscle while that of SOD was similar in both muscles.

GPx activity was positively correlated with carcass weight ($r = 0.500$, $P = 0.004$), content of fat ($r = 0.411$, $P = 0.020$) and protein ($r = 0.475$, $P = 0.006$) and negatively with content of moisture ($r = -0.466$, $P = 0.007$). Moreover GPx activity showed a positive correlation with ARP ($r = 0.431$, $P = 0.014$) and SOD ($r = 0.423$, $P = 0.016$) but not with CAT activity. SOD correlated with redness ($r = 0.418$, $P = 0.017$) and yellowness ($r = 0.502$, $P = 0.003$). In turn CAT was negatively correlated with ORAC ($r = -0.434$, $P = 0.013$).

Table 5
The effect of origin, gender, age and muscle type on antioxidant enzyme activities in reindeer meat and comparison to beef.

Variables		CAT U g^{-1} meat	SOD U g^{-1} meat	GPX U g^{-1} meat
Origin	North Norway	316.88 ± 23.64	270.36 ± 15.68	12.78 ± 0.80
	Mid Norway	291.39 ± 26,80	331.36 ± 17,78	15.44 ± 0.91
Significance (P value)		*n.s.*	*<0.05*	*<0.05*
Gender	Male	314.78 ± 26.80	293.93 ± 17.78	12.15 ± 0.91
	Female	293.49 ± 38.94	307.79 ± 25.84	16.06 ± 1.32
Significance (P value)		*n.s.*	*n.s.*	*n.s.*
Age	Under 1.5 years	271.76 ± 37.90	293.06 ± 25.15	14.29 ± 1.29
	Over 1.5 years	336.51 ± 28.25	308.65 ± 18.75	13.93 ± 0.96
Significance (P value)		*n.s.*	*n.s.*	*n.s.*
Muscle	SM	284.93 ± 23.64	289.98 ± 16.10	13.10 ± 0.82
	LD	323.34 ± 26.80	311.74 ± 16.10	15.12 ± 0.82
Significance (P value)		*n.s.*	*n.s.*	*n.s.*
Species	Beef	214.25 ± 36.12	308.75 ± 27.14	8.97 ± 1.46
	Reindeer	304.16 ± 15.64	300.86 ± 11.75	14.11 ± 0.63
Significance (P value)		*<0.05*	*n.s.*	*<0.01*

Table 4
The effect of origin, gender, age and muscle type on antioxidant status in reindeer meat and comparison to beef.

Variables		ARP mg DPPH g^{-1} meat	ORAC μmol TE g^{-1} meat	Total phenols mg GAE g^{-1} meat
Origin	North Norway	1.21 ± 0.03	19.86 ± 0.47	28.93 ± 0.80
	Mid Norway	1.18 ± 0.03	16.16 ± 0.53	27.08 ± 0.90
Significance (P value)		*n.s.*	*<0.001*	*n.s.*
Gender	Male	0.86 ± 0.03	17.50 ± 0.58	25.46 ± 0.98
	Female	1.54 ± 0.05	18.52 ± 0.78	30.55 ± 1.33
Significance (P value)		*<0.001*	*n.s.*	*<0.05*
Age	Under 1.5 years	1.19 ± 0.05	17.94 ± 0.76	27.28 ± 1.28
	Over 1.5 years	1.21 ± 0.03	18.08 ± 0.59	28.73 ± 1.00
Significance (P value)		*n.s*	*n.s*	*n.s*
Muscle	SM	1.23 ± 0.03	18.70 ± 0.48	29.03 ± 0.81
	LD	1.17 ± 0.03	17.32 ± 0.48	26.98 ± 0.81
Significance (P value)		*n.s*	*<0.05*	*n.s*
Species	Beef	0.17 ± 0.06	14.26 ± 0.05	17.77 ± 0.08
	Reindeer	1.20 ± 0.05	18.01 ± 0.04	28.00 ± 0.06
Significance (P value)		*<0.001*	*<0.001*	*<0.001*

Table 6
Sensory attributes assessed by trained panel — significance (P-values)* from ANOVA.

Variables	Origin	Gender	Age	Muscle
Odour properties				
Gamy odour	n.s.	n.s.	n.s.	0.006
Livery odour	n.s.	n.s.	n.s.	0.001
Sharp odour	0.001	n.s.	n.s.	n.s.
Acidic odour	0.002	0.037	n.s.	0.001
Sickeningly sweet odour	0.001	n.s.	n.s.	n.s.
Metallic odour	n.s.	n.s.	n.s.	n.s.
Colour properties				
Whiteness	n.s.	0.037	0.018	0.015
Hue	n.s.	0.010	0.010	0.036
Colour intensity	n.s.	0.014	0.032	0.035
Flavour properties				
Gamy flavour	n.s.	n.s.	n.s.	0.002
Livery flavour	n.s.	0.030	n.s.	0.003
Sharp flavour	0.001	n.s.	0.002	0.031
Acidic flavour	n.s.	n.s.	n.s.	0.001
Bitter flavour	n.s.	n.s.	0.015	0.030
Sickeningly sweet flavour	0.002	n.s.	n.s.	0.003
Metallic flavour	n.s	n.s.	n.s.	n.s.
Texture properties				
Hardness	n.s.	0.001	n.s.	n.s.
Tenderness	n.s.	0.002	n.s.	0.019
Juiciness	n.s.	n.s.	n.s.	0.014

* P value<0.05 indicates a significant effect of the tested variable; n.s. — not significant.

3.4. Sensory profile

The results of descriptive sensory test carried out on the heat treated reindeer meat are shown in Table 6. Some of the attributes revealed greater dependence (P<0.05) on the examined factors than others. For example, colour intensity was influenced by all factors whereas the metallic odour and flavour were not affected.

Significantly higher scores for sharp odour (3.35 ± 0.09) and flavour (3.04 ± 0.08), sickeningly sweet odour (2.81 ± 0.08) and flavour (2.54 ± 0.07), and lower scores for acidic odour (2.91 ± 0.07) were found for MN meat compared to NN meat i.e. 2.75, 2.60, 2.37, 2.22 and 3.23, respectively. Grazing appears to have an important impact on the development of various "wild" flavours, and flavour differences in reindeer meat have been related to the diet prior to slaughter (Wiklund et al., 2003). Therefore, the sensory differences between reindeer meat from two Norwegian regions (NN versus MN) could be explained by the variety of pasture plants as well as by the sample-collecting period. The animals from MN were slaughtered 1 month later (beginning of November) than the animals from NN possibly giving a more "gamy" flavour (Wiklund, Finstad, Worker, & Bechtel, 2008).

Gender affected primarily the colour and texture and to a lesser extent, some of the odour or flavour attributes. Panellists scored meat from male animals higher for acidic odour (3.20 ± 0.05) and livery flavour (3.87 ± 0.08) than females 2.94 and 3.51, respectively. Female meat gained lower scores for whiteness (3.00 ± 0.09), hue (5.73 ± 0.16) and colour intensity (3.98 ± 0.13) indicating darker and less chromatic colour than meat from males, 3.22, 6.25 4.38, respectively. Colour measurements (L*, a*, b*) on raw samples, however, did not show any significant differences between genders. Gender influenced considerably both hardness and tenderness of meat samples. The intensity of hardness as related to the force necessary to bite through the sample, was greater for meat from the female (4.31 ± 0.13) than from males (3.83 ± 0.14). Tenderness — related to the time and number of chews necessary to masticate the sample prior swallowing, showed that the meat from males required little chewing, and thus received higher scores (6.46 ± 0.15) for this attribute than that from females (5.44 ± 0.15). Similar values for tenderness have been reported for bulls and steer reindeer from Alaska (Wiklund et al., 2008).

The present study indicated small differences in sensory profile between young (under 1.5 years) and adult reindeers (over 1.5 years). Higher scores for tenderness of young reindeer were expected but due to a great variance in this group (5.8–8.0) this was not confirmed (Rødbotten, Kubberød, Lea, & Ueland, 2004; Wiklund, Hansson, & Åhman, 2002).

Significant differences between age groups were found for colour as well as for sharp and bitter flavour. Older animals had sharper (3.04 versus 2.6) and more bitter (4.33 versus 4.05) flavour, higher hue (6.24 versus 5.74) and colour intensity (4.35 versus 4.01) while for whiteness the older animals received lower scores (2.99 versus 3.24).

Sensory profiles (mean values) of LD (*M. Longissimus dorsi*) and SM (*M. Semimembranosus*) are presented in Fig. 1. Significant differences between means were seen in many attributes and are marked on the plot with an asterisk while P-values are presented in Table 6. LDs had higher scores for the positive attributes gamy, acidic odour and flavour, as well as tenderness compared to SM. The reindeer LDs received lower scores for sickeningly sweet and sharp flavour. Livery

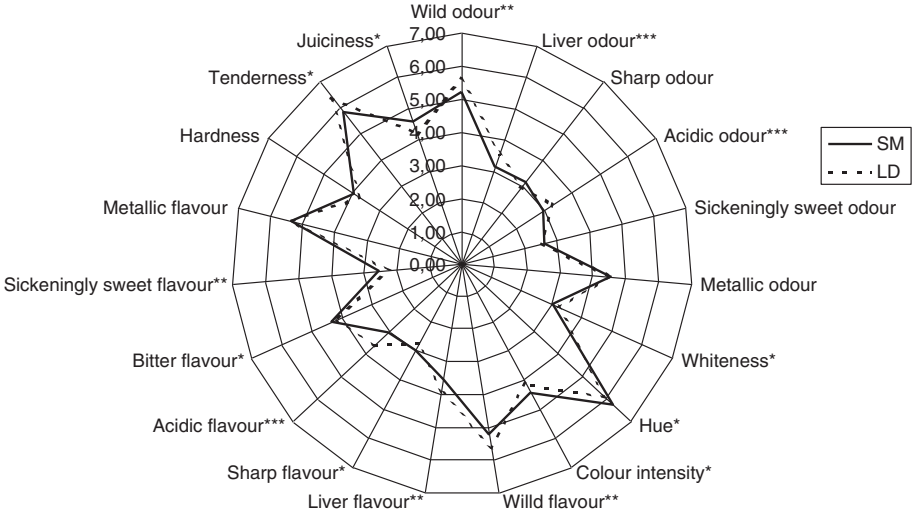

Fig. 1. Radar diagram for sensory profile of muscles *Longissimus dorsi* (LD) and *Semimembranosus* (SM) from reindeer assessed by trained sensory panel according to attributes listed in Table 1. Asterisks indicate significant differences; *P<0.05, **P<0.01, ***P<0.001.

odour and flavour scored higher for LD than for SM, however, it is not clear if this attribute ought to be considered as a negative or positive characteristic. The gamy taste is sometimes described as livery in studies on beef, caribou and reindeer. Rincker et al. (2006) have indicated that the livery or gamy flavour is typical for venison samples. Wiklund et al. (2003, 1996) found relationships between low ultimate pH, acidic flavour and liver flavour in reindeer meat in good agreement with the present results. SM was identified as having a darker and more intense red colour than LD.

Tenderness, gamy odour and flavour, hue and metallic flavour (scores over 5.0.) describe reindeer meat best (Fig. 1). This conclusion is consistent with a sensory map of 15 species, both domesticated and non domesticated (Rødbotten et al., 2004) which grouped reindeer and ostrich meat close together with high scores for gamy and liver flavour as well as for hue.

4. Conclusion

Reindeer meat was darker in colour and had higher antioxidant capacity than beef. All reindeer muscles were lean (0.5–1.6% fat) and rich in protein (22–25%). Several quality differences (chemical composition, colour, antioxidant status and sensory profile) between muscles from North Norway Mid Norway were identified. Presumably, the differences between muscles from animals grazing in two different Norwegian regions were due to diet and rearing condition. Female muscles had higher radical scavenger activity expressed as ARP and total phenols. Carcass weight and the sensory attributes colour, sharp and bitter flavour were higher for older animals.

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