# Ultimate pH values in reindeer meat with particular regard to animal sex and age, muscle and transport distance

**E. Wiklund[1]*, A. Andersson[1], G. Malmfors[1], K. Lundström[1] & Ö. Danell[2]**

[1] Swedish University of Agricultural Sciences, Departement of Food Science, P.O. Box 7051, S-750 07 Uppsala, Sweden.

[2] Department of Animal Breeding and Genetics, P.O. Box 7023, S-750 07 Uppsala, Sweden.

*Corresponding author

*Abstract:* The distribution of ultimate pH values and the frequency of high pH values in three reindeer muscles (*M. longissimus*, *M. biceps femoris* and *M. triceps brachii*) from bulls, cows and calves after short and long distance transport were studied. About 3400 reindeer carcasses from 12 different herds were included in this study. The postmortem processes in reindeer meat seemed to develop very rapidly, and therefore an early measurement (approx. 15h *post mortem*) of ultimate pH can be done without electrical stimulation of the carcasses. In a comparison between muscles, *M. triceps brachii* had a higher ultimate pH value than *M. longissimus* and *M. biceps femoris*. Meat from reindeer calves had higher ultimate pH values than meat from adult animals, indicating that calves are more susceptible to stress than adult animals and hence deplete their energy stores more readily. Road transport by lorry did not cause any increase in ultimate pH values in bulls and calves. Reindeer cows, however, did have an increase in ultimate pH, while more borderline cases of DFD ($5.80 \leq pH < 6.20$) were observed when cows were transported over more than 500 km. The physical condition and energy balance of the animals before transport were suggested to determine their ability to tolerate transport stress.

Key words: *Rangifer tarandus tarandus* L, preslaughter handling, meat quality, DFD

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## Introduction

Reindeer are often exposed to various stress factors before slaughter, such as rounding up, herding, road transport and long lairage times. These procedures contribute to ante mortem glycogen depletion and hence affect ultimate pH values and meat quality. A low glycogen content in muscle could result in a high ultimate pH in the meat, a quality defect that reduces the shelf life of meat.

Whereas normal ultimate pH values in beef are in the range 5.5–5.7, DFD (dark, firm and dry) carcasses have high ultimate pH values and a shorter shelf life, especially if the meat is vacuum-packed. DFD meat contains very small amounts of glucose (the spoilage bacteria's main substrate). As a result, bacterial proteolysis will occur and spoilage odours will arise, even at quite low bacterial concentrations (Gill & Newton, 1981). In some studies, DFD carcasses are defined as having an ultimate pH in *M.*

Table 1. Characteristics of the 12 various reindeer herds included in the study.

| Herd | Transport distance, km | Number of | | | | Slaughter month |
|---|---|---|---|---|---|---|
| | | bulls | cows | male calves | female calves | |
| 1 | 0 | 241 | – | – | – | August |
| 2 | 0 | 364 | 4 | 9 | – | September |
| | 580 | – | – | 16 | 23 | November |
| 3 | 0 | 25 | 58 | 137 | 144 | November |
| | 850 | 8 | 42 | 14 | 15 | November |
| 4 | 110 | 24 | 17 | 16 | 14 | November |
| 5 | 150 | 20 | 24 | 21 | 3 | November |
| 6 | 120 | 60 | 123 | 51 | 69 | November |
| 7 | 0 | – | 119 | 41 | 45 | November |
| | 830 | – | 15 | 34 | 18 | January |
| | 850 | 71 | 63 | 153 | 157 | November |
| 8 | 0 | 122 | 28 | 3 | 9 | March |
| | 700 | 51 | 70 | 27 | 53 | March |
| 9 | 0 | 101 | – | – | – | April |
| | 850 | 216 | – | – | – | April |
| 10 | 700 | 16 | 2 | 1 | 6 | April |
| 11 | 100 | 7 | 79 | – | – | April |
| 12 | 0 | 15 | 3 | 34 | 26 | April |
| | 1000 | 44 | 31 | 27 | 136 | April |

*longissimus* ($pH_u$) ≥ 6.0 (Tarrant & Sherington, 1979; Gill & Newton, 1981; Vanderzant *et al.*, 1983; Dainty & Mackey, 1992). Other threshold values have also been used, e.g. $pH_u \geq 6.2$ (Bem *et al.*, 1976; Fabiansson *et al.*, 1984; van Laak *et al.*, 1989) or $pH_u \geq 5.8$ (Tarrant, 1989). Stressful procedures and situations, as well as physical activity, lead to glycogen depletion. This is why the handling of animals prior to slaughter is of great importance regarding meat quality (Tarrant, 1989; Warriss, 1992).

Electrical stimulation is commonly used for beef carcasses, mainly to enable the carcasses to be rapidly chilled without the risk of cold shortening. One of the most widely recognized effects of electrical stimulation is an accelerated rate of postmortem pH decline in the muscles, and ultimate pH can be measured at 24h *post mortem* (Fabiansson, 1984). Electrical stimulation is not used for reindeer carcasses.

The National Food Administration in Sweden has issued new directives regarding meat inspection at slaughter, requiring that slaughter should take place only in approved slaughterhouses (National Food Administration, 1993). Since these directives also cover reindeer, many of the outdoor slaughter

sites have been closed, resulting in an increased number of transported reindeer.

Lorry transport of reindeer is a common handling procedure in Sweden. In autumn and spring, reindeer are sometimes transported over very long distances between different pasture regions and, ultimately, to the abattoir. The lorries used are designed especially for reindeer. They are sectioned into several pens allowing separation of calves from adult animals. This construction is important for the animals' wellbeing, markedly reduceing bruising and other injuries (Andersen, 1978). As the degree of tameness of the reindeer is considered to play an important role in their ability to tolerate stress, the loading, transport and unloading can be done more easily if the animals are accustomed to manual handling (Rehbinder, 1990).

The purpose of this investigation was to study the distribution of ultimate pH values and the frequency of high pH values in three reindeer muscles from bulls, cows and calves after transportation over short and long distances.

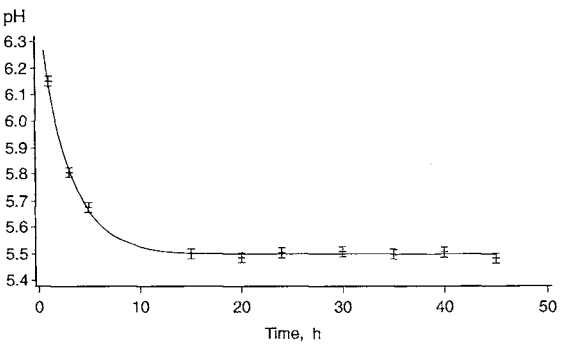


Fig. 1. Decline of pH in *M. longissimus* in reindeer bulls measured at 1, 3, 5, 15, 20, 24, 30, 35, 40 and 45h *post mortem* (n=21), fitted non-linear function and measured mean values with standard errors.

## Material and methods

A pilot study was carried out to establish the right time to measure ultimate pH. A group of 21 reindeer bulls which had been supplementary fed were slaughtered in April. The mean carcass weight was 36.2 kg (SD 7.6) and the mean trim fat content (% of carcass weight) was 3.8 (SD 1.0). Ultimate pH was measured at 1, 3, 5, 15, 20, 24, 30, 35, 40 and 45h *post mortem*. The reindeer carcasses were not subjected to electrical stimulation.

During the autumn and winter of 1991≤92, when reindeer from 12 different herds had been transported over distances varying from 100 to 1000 km (see Table 1), ultimate pH values were measured in 3400 carcasses from bulls, cows and male and female calves, i.e. four animal categories. The measurements were made 30 h *post mortem* in three muscles: *M. longissimus* (LO) (at the last rib), *M. biceps femoris* (BF) and *M. triceps brachii* (TB), using a KNICK Portamess 651-2 pH-meter (Knick Elektronische Mess-geräte GmbH & Co, Germany) equipped with an INGOLD electrode (Ingold Messtechnik AG, Switzerland, lot 406 M-6 Xerolyt).

In addition, pH values in a group of 360 animals were measured. These animals were herded by helicopter for at least 10 days, and subsequently transported to the slaughterhouse by lorry over a distance of 300 km. This group will be referred to as the 'exhausted group'. The 'exhausted group' was not categorized for age and sex and, therefore, were not included in the statistical analysis.

## Statistical analyses

To describe the pH decline from 1 to 45 hours *post mortem* in *M. longissimus*, the following non-linear function was fitted to the measured values (Fig. 1).

$y = a\,(1+be^{-kt})$

$y$ = pH at time $t$
$a$ = ultimate pH
$t$ = time *post mortem*
$e$ = base of the natural logarithm
$b$, $k$ = parameters of function describing the shape of the curve

To compare the three muscles *M. longissimus*, *M. biceps femoris* and *M. triceps brachii*, a model including the effects of animal (random) and muscle was used (Table 2).

To study the effects of transport distance and animal category, a statistical model including these effects and the interaction was used (Tables 3 and 5). The transport distances were divided into three groups: 0 km, < 200 km, and > 500 km. No animals were transported between 200 and 500 km.

When pH values were converted to hydrogen ion concentrations, they showed a more normal distribution than did measured pH values. The statistical analyses were therefore based on the converted pH values. The mean values presented in the tables are transformed back from estimates on the concentra-

Table 2. Ultimate pH values (back-transformed least squares means and ranges for means ± SE) and the frequency of DFD and intermediate DFD in three muscles; *M. longissimus, M. biceps femoris* and *M. triceps brachii* in reindeer bulls, cows and calves.

| Muscle | Ultimate pH | Per cent intermediate DFD (5.8≤pH<6.2) | Per cent DFD (pH≥6.2) |
|---|---|---|---|
| *M. longissimus* | 5.67[a] 5.670–5.674 | 23.1 | 6.0 |
| *M. biceps femoris* | 5.72[b] 5.717–5.721 | 29.3 | 8.6 |
| *M. triceps brachii* | 5.98[c] 5.979–5.987 | 54.9 | 27.6 |

Table 3. Ultimate pH values (back-transformed least squares means and ranges for means ± SE) and the degree of significance for the effect of animal category in *M. triceps brachii*, *M. longissimus* and *M. biceps femoris* for reindeer bulls, cows and calves.

| Muscle | Bulls (n=1385) | Cows (n=678) | Male calves (n=595) | Female calves (n=738) | Degree of significance[1)] |
|---|---|---|---|---|---|
| *M. triceps brachii* | 5.93[a] 5.921–5.936 | 5.97[b] 5.959–5.975 | 6.06[c] 6.041–6.070 | 6.04[c] 6.036–6.056 | *** |
| *M. longissimus* | 5.65[a] 5.642–5.654 | 5.63[a] 5.629–5.640 | 5.72[b] 5.708–5.726 | 5.67[c] 5.666–5.682 | *** |
| *M. biceps femoris* | 5.67[a] 5.666–5.678 | 5.68[a] 5.672–5.684 | 5.76[b] 5.754–5.774 | 5.74[b] 5.733–5.752 | *** |

[1)] ***=$p \leq 0.001$.
Within-muscle means having the same superscript are not significantly different ($p > 0.05$).

tion scale. Standard errors, however, became non-symmetric and error ranges on pH scale were therefore calculated from the estimated means ± standard errors.

All statistical calculations were performed using the Statistical Analysis System (SAS Institute Inc., 1989).

## Results

In the pilot study there was a significant ($p < 0.05$) difference in pH of the *longissimus* muscle between 1h and 3h, 3h and 5h and 5h and 15h *post mortem*. After 15h *post mortem* there was no significant decrease in pH value (Fig. 1). In the pilot study, the pH decline in the carcasses indicated that ultimate pH was probably reached already 13h *post mortem*.

In the main material, *M. longissimus* had significantly ($p < 0.001$) lower ultimate pH than both *M. biceps femoris* and *M. triceps brachii*, which was also reflected by the lower frequency of intermediate DFD (5.8≤pH<6.2) and DFD (pH≥6.2) (Table 2 and Fig. 2). By using *M. longissimus* as an indicator muscle for a DFD condition in the whole carcass, it was possible to find 45% of the DFD cases in *M. biceps femoris*, but only 17% in *M. triceps brachii*.

The animal categories reacted differently to transport (significant interaction; $p \leq 0.001$), and therefore the comparisons were made within animal category. Calves had higher pH values than bulls and cows (Table 3). A DFD condition ($pH_u \geq 6.2$ in *M. longissimus*) was rarely encountered in reindeer cows, while bulls and calves had higher incidences of DFD. Carcasses of bull calves exhibited DFD

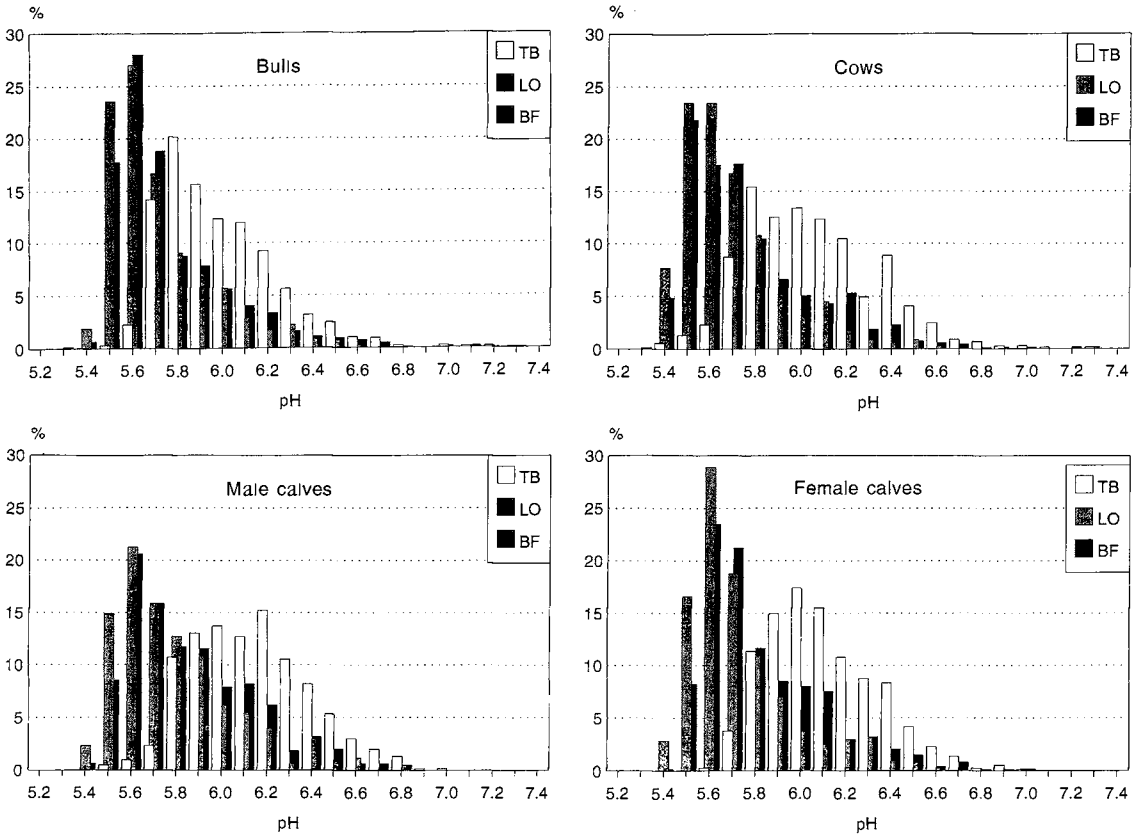


Fig. 2. The distribution of ultimate pH values in three muscles; *M. triceps brachii* (TB), *M. longissimus* (LO) and *M. biceps femoris* (BF) in reindeer bulls, cows, male calves and female calves.

more frequently than the other animal categories. The incidence of intermediate DFD was also highest in bull calves (Table 4).

The animals in the 'exhausted group' were found to have extremely high ultimate pH values (Table 4), with 31.1 % of the carcasses being classified as intermediate DFD and 31.2 % as DFD.

Lorry transport did not appreciably affect the ultimate pH of bulls and calves ($p > 0.05$) (Table 5). The incidence of high ultimate pH and intermediate DFD in reindeer cows was greater only after transport of over more than 500 km (Fig. 3).

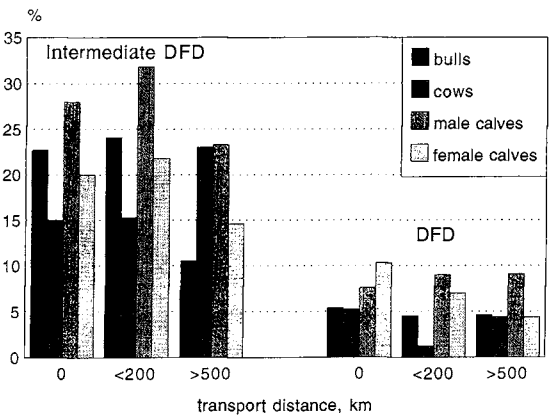


Fig. 3. Percentages of intermediate DFD ($5.8 \leq pH < 6.2$) and DFD ($pH \geq 6.2$) in *M. longissimus* in reindeer bulls, cows and calves transported various distances before slaughter.

## Discussion

The postmortem processes in reindeer meat seem to develop very rapid, and enable early measurment of ultimate pH (approx. 15h *post mortem*). In this study, we used the DFD limit for beef, which in Sweden is $pH_u \geq 6.2$ in *M. longissimus*. In beef carcasses, this muscle is one of the most sensitive muscles regarding dark-cutting (Tarrant & Sherington, 1979; Buchtet, 1981; Malmfors & Brendov, 1988). However, when *M. longissimus* was used as indicator

muscle in reindeer, only 45% of the *biceps femoris* muscles with high pH were found. Thus in reindeer, there seems to be a different sensitivity for individual muscles to develop DFD and hence other and better sites for DFD measurement. Further studies are needed to determine the properties of reindeer meat having a high ultimate pH value.

Petäjä (1983), who measured ultimate pH values in reindeer *Mm. vastus lateralis*, *triceps brachii* and *longissimus*, concluded that the first two muscles had higher ultimate pH values than the latter. Skjenneberg *et al.* (1974) also found high ultimate pH values in various shoulder muscles. Our results are in good agreement with these two studies. The differences in ultimate pH values between muscles are probably due to the way in which the muscle is affected by physical activity, and also by the fibre type distribution within the muscle. Reindeer muscles appear to have a great capacity to oxidize both carbohydrates and lipids (Essén-Gustavsson & Rehbinder, 1984, 1985), and their oxidative capacity is remarkably high in all fibre types (Kiessling & Rydberg, 1983; Kiessling & Kiessling, 1984; Essén-Gustavsson & Rehbinder, 1985). A large proportion of oxidative (types I and IIa) fibre types in beef M. longissimus gave high ultimate pH values and increased the incidence of dark-cutting meat (DFD) (Zerouala & Stickland, 1991). The observed high ultimate pH in *M. triceps brachii* might affect its applicability. Smoked reindeer shoulder is a valuable product, and a high pH value would make the meat less suitable for smoking (Niinivaara & Petäjä, 1984).

Malmfors *et al.* (1985) found that male bovine calves (aged 6 months) were more susceptible to stress factors leading to glycogen depletion than were young bulls (aged 13–15 months). In the same study, bull calves were shown to have higher ultimate pH values than female calves. Their results are very similar to the results of the present study, regarding both ultimate pH and the incidence of DFD and intermediate DFD.

In previous studies on the effects of transporting ruminants by road, various results have been reported. Jones *et al.* (1988) exposed beef cattle to fasting, to mixing with unfamiliar animals and to lorry transport, but found no effect of such treatments on ultimate pH values in *M. longissimus*. Malmfors *et al.* (1983) also concluded that lorry transport of beef cattle had a negligible effect on ultimate pH value. In The Netherlands, van Laak *et al.* (1989) compared two different delivery systems for slaughter bulls. The bulls were either transported from the farm direct to the abattoir, or transported from farm to cattle market and, subsequently, to the abattoir. Bulls transported directly to the abattoir had the lowest incidence of DFD (3.1%), while the other bulls had a highly increased DFD frequency (27.3%). Red deer (*Cervus elaphus*) transported by road to the slaughterhouse appeared to be sensitive to handling procedures, and were found to have higher ultimate pH values than when they were shot in the corral (Smith & Dobson, 1990). When studying reindeer shot without previous handling, in comparison with animals herded by snow-scooter and subsequently transported to the slaughterhouse by lorry, Hanssen *et al.* (1984) found that the latter treatment group had higher ultimate pH values. Since they did not include a group of reindeer driven to the corral and then shot immediately, it is unclear whether the handling as such, or the lorry transport, was the cause of the high ultimate pH values.

Various stress factors may work in concert to produce high ultimate pH values. Graafhuis &

Table 4. Frequencies of DFD and intermediate DFD in *M. longissimus* in reindeer bulls, cows and calves (for numbers of animals, see Table 1).

| | Bulls | Cows | Male calves | Female calves | Exhausted group |
|---|---|---|---|---|---|
| Per cent intermediate DFD ($5.8 \leq pH < 6.2$) | 19.2 | 17.7 | 27.2 | 18.2 | 31.1 |
| Per cent DFD | 5.1 | 3.5 | 8.4 | 6.7 | 31.2 |

Table 5. Ultimate pH values (back-transformed least squares means and ranges for means ± SE) and the degree of significance for the effect of transport, in *M. longissimus* in reindeer bulls, cows and calves transported over various distances before slaughter.

| Animal category | Transport 0 km | < 200 km | > 500 km | Degree of significance[1)] |
|---|---|---|---|---|
| Bulls | 5.68[a] 5.676-5.688 (n=868) | 5.65[a] 5.634-5.666 (n=111) | 5.61[b] 5.606-5.620 (n=406) | *** |
| Cows | 5.62[a] 5.609-5.631 (n=212) | 5.60[a] 5.593-5.614 (n=243) | 5.68[b] 5.670-5.695 (n=223) | *** |
| Male calves | 5.70[a] 5.688-5.714 (n=224) | 5.74[a] 5.721-5.764 (n=88) | 5.71[a] 5.697-5.719 (n=272) | n.s. |
| Female calves | 5.69[a] 5.674-5.699 (n=224) | 5.68[ab] 5.660-5.697 (n=86) | 5.66[b] 5.648-5.664 (n=408) | n.s. |

[1)] n.s.=$p>0.05$; ***=$p\leq 0.001$.
Within-animal category means having the same superscript are not significantly differenr ($p>0.05$).

Chrystall (1989) studied lambs exposed to various treatments regarding nutrition, shearing, preslaughter washing, and transport to the slaughterhouse; although none of the treatments had significant effects of its own, their cumulative effect on ultimate pH was obvious. In the present study, the lorry transport affected neither ultimate pH, nor the incidence of borderline cases of DFD, in carcasses of reindeer bulls and calves.

These, and other results, indicate that factors other than those studied, e.g. physical condition and energy balance of the animals before transport, may also have a major effect on their ability to tolerate transport stress, as indicated, e.g. by the 'exhausted group'. The influence of well supplied energy stores (e.g. through supplementary feeding) on the ability to tolerate various stress factors will be studied further.

Further investigations are also needed in order to ascertain the proportional contribution of each stage in the chain of preslaughter handling of reindeer, such as rounding up and herding by means of helicopter and snow-scooter. Once the most stressful stages are known, the overall handling prior to and during slaughter can be greatly improved.

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