Colour stability and water-holding capacity of *M. longissimus* and carcass characteristics in fallow deer (*Dama dama*) grazed on natural pasture or fed barley

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Abstract: The effects of feeding regimen on carcass characteristics, meat colour and water-holding capacity of *M. longissimus* were studied in 24 female fallow deer (*Dama dama*). All animals were farm raised; twelve were grazed on pasture and twelve were fed barley and a small amount of hay prior to slaughter. The animals were slaughtered at two occasions (during the Southern Hemisphere spring); after 19 weeks of feeding (n=12; 6 grazing and 6 barley fed animals; group 1) and after 24 weeks of feeding (n=12; 6 grazing and 6 barley fed animals; group 2). The barley/hay-fed deer had significantly higher body condition scores and carcass weights than the pasture raised group. No difference in meat ultimate pH values between the treatment groups was recorded. The meat from the pasture raised deer had significantly longer colour display life after 2 and 3 weeks of refrigerated storage (+ 2.0 ºC) in vacuum bags. There was no difference in drip loss between the two treatment groups. However, significantly lower drip losses were found in meat from the animals in group 2 compared with the ones in group 1 ($P \leq 0.001$). It was concluded that the feeding regimen of the animals is an important factor that contributes to the variation in quality of fresh chilled deer meat (venison), mainly the colour stability and display life of vacuum packaged meat.

Key words: farmed deer, feeding regimen, meat quality, venison, ultimate pH.

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Introduction

Quality assurance of venison (deer meat) is important to long-term product marketability and has been identified as a key challenge for the Australian deer industry, but also for other meat industries world-wide. Consumer attitudes and preferences are increasingly important for all meat industries, and pasture based production systems (as used for deer) are often valued by consumers as more animal friendly and ethical compared with the more commercial production of beef, pork and chicken. Venison is a high quality product that also has several other attributes attractive to health conscious consumers, *e.g.* low fat content, favourable fat composition and high levels of minerals (Drew & Seman, 1987; Wiklund *et al.*, 2003a).

Muscle pigment oxidation is one of the major problems causing shelf life quality deterioration in meat and affecting meat colour, which is of criti-

cal importance in consumer purchase decisions for fresh meat (Risvik, 1994). The speed of the colour oxidation process is depending on several factors like antioxidant content, oxygen consumption and reducing enzyme activity in the meat (Faustman & Cassens, 1990; 1991). The water-holding capacity of meat is also a consumer important sensory attribute related to the juiciness of the final product. The visual appearance at purchase of *e.g.* slices of steak in a meat-tray or a whole piece of meat in a vacuum bag may also be negatively affected if an excess amount of meat juice has leaked from the meat. Factors demonstrated to decrease the water-holding capacity of meat are conditions of low pH and high temperatures in post-mortem muscle (Offer & Knight, 1988), electrical stimulation of carcasses by accelerating muscle pH decline (den Hertog-Meischke *et al.*, 1997) and low levels of antioxidants like vitamin E (Buckley *et al.*, 1995).

Previous and recent research has demonstrated quality differences in meat from ruminants [beef, reindeer (*Rangifer tarandus tarandus*) and red deer (*Cervus elaphus*)] that have been grazing pasture or fed grain-based feed mixtures (Daly *et al.*, 1999; Wiklund *et al.*, 2001a; 2003a; 2003b; Wood *et al.*, 2003; Bruce *et al.*, 2004). Generally though, research in venison quality has been very limited and there is still a considerable amount of information missing regarding the relationship between production system, slaughter handling techniques and consumer acceptance of the final products.

The purpose of the present study was to compare the colour stability and water-holding capacity in meat from a group of fallow deer that had grazed natural pastures and a group fed barley. In addition, the comparison of carcass parameters was included.

Material and methods

Animals

Twenty four fallow deer does (36 months old, average live weight 43 kg, body condition score (BCS) 2-4 (Flesch *et al.*, 2002) raised at the University of Western Sydney (UWS), were included in the study. The animals were quarter-bred hybrids between the European type of fallow deer (*Dama dama*) and the Mesopotamian type (*D. d. mesopotamica*). Twelve animals had been grazing lush rye grass pasture *ad libitum* and twelve had been fed barley (800 g/animal/day) and lucerne hay (500 g/animal/day) during the feeding period. The animals were slaughtered at two occasions, group 1 after 19 weeks of feeding (n=12; 6 grazing and 6 barley/hay fed animals) and group 2 after 24 weeks of feeding (n=12; 6 grazing and 6 barley/hay fed animals), following exactly the same slaughter and sampling procedure. All animals were fasted for 16 h prior to slaughter and their live weights recorded before they were stunned with a captive bolt and bled using thoracic stick exsanguination within 10 s of the stun (Mulley & Falepau, 1999) (ethics approval UWS 00.09). The slaughter took place at the UWS, so the deer were not transported and were exposed to a minimum of pre-slaughter handling. Electrical stimulation of the carcasses was not used in this experiment. Dressed carcass weights were recorded and the carcasses then immediately put in the chilling room (+2 °C). Temperature and pH values were measured in *M. longissimus* (LD; at the last rib) at 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12 and 24 h *post mortem*.

At 24 h *post mortem*, LD from the left side of each carcass was excised, cut in to 4 equal size pieces that were randomly allocated to sampling at 24 h *post mortem*, 1, 2, or 3 weeks of refrigerated storage at + 2 °C. Samples allocated for storage were vacuum packaged. Each muscle was sampled at 24 h *post mortem* for colour measurements. Drip loss (purge in the vacuum bags) and colour measurements were done after 1, 2 and 3 weeks of refrigerated storage at + 2 °C.

Temperature and pH measurements

For calibration of the pH equipment, buffers of pH 7.0 and 4.0 (TPS Pty. Ltd., Brisbane, Australia) at room temperature were used. Temperature and pH was measured by inserting a glass electrode (IJ44, ionode Pty. Ltd., Queensland, Australia) and a temperature probe (Stab Temp/ATC Sensor, TPS Pty. Ltd. Brisbane, Australia) attached to a portable pH meter (LC80A pH-mV-TEMP, TPS Pty. Ltd., Brisbane, Australia) that was temperature compensated.

Colour and water holding capacity

Triplicate colour measurements were made on each freshly cut steak 2 h after opening the vacuum bag, then twice daily using a Minolta Chroma meter

(CR-300, Japan) as found appropriate for venison (Stevenson *et al.*, 1989). Days of acceptable colour (display life) were calculated as the time taken to reach an a^* (redness) value of 12 using linear interpolation between consecutive samples, as previously determined for red deer venison (Stevenson *et al.*, 1989; Wiklund *et al.*, 2001b).

Drip loss (purge) was measured by the following procedure: (1) the combined weight of muscle and the vacuum pack was recorded before opening; (2) at opening, any surplus drip on the meat was removed using a paper towel and the drip-free weight of the meat recorded. The combined dry bag (average weight of 25 empty vacuum bags) and drip-free meat weights were subtracted from the unopened package weight to derive the total drip weight. Drip weight was then expressed as a percentage of the original weight of meat packed.

Statistical analysis

Carcass measurements were analysed by analysis of variance, fitting treatment, slaughter month (October; group 1 or November; group 2) and their interaction. The same model was used for analysing pH, temperature, colour and drip loss data at each time. No more detailed analysis of the repeated measures aspects of these data was found necessary, as the univariate analyses conveyed a clear description of the process. All analyses were conducted using GenStat (2002).

Results

Carcass characteristics

The fallow deer fed barley and hay had significantly higher body condition scores and carcass weights than the pasture raised animals (Table 1). The animals in group 1 produced carcasses of higher weights and dressing percentages ($P \leq 0.001$) than group 2 (Table 1).

pH and temperature decline in LD over 24 h post-mortem

The carcasses from the pasture-raised deer had lower mean temperature in LD ($P \leq 0.05$) than the carcasses from the barley/hay-fed animals at 1, 2, 6, 7, 8, 9 and 24 h *post mortem* (Fig. 1a). The pH values measured in LD from the barley/hay-fed deer were lower at 1, 3, 4, 5, 6, 7, 8 and 12 h *post mortem* ($P \leq 0.05$) than in LD from the animals grazing pasture (Fig. 1b). However, at 24 h *post mortem*, there was no significant difference in pH values between treatment groups (Fig. 1b; Table 2).

pH at 24 h post-mortem *and during storage*

The ultimate pH values (measured at 24 h *post mortem*) were significantly lower in the animals in group 1 compared with group 2 (Table 2). No significant differences were found comparing pH values for the two treatment groups at any of the storage times (Table 2).

Table 1. Mean live weight and carcass parameters for fallow deer from two feeding treatments (pasture raised and barley/hay-fed), with standard errors of the difference (S.E.D.)

Trait	Body Condition Score (BCS)[1]	Live weight, kg	Carcass weight, kg	Dressing %
Group 1 (October)				
Pasture (*n*=6)	2.42	42.3	28.4	67.2
Barley/Hay (*n*=6)	4.25	44.9	30.1	67.1
Group 2 (November)				
Pasture (*n*=6)	2.67	41.8	25.3	60.5
Barley/Hay (*n*=6)	3.50	42.7	27.5	64.4
S.E.D.	0.273	1.59	0.941	1.146
Degree of sign. month[2]	n.s.	n.s.	***	***
Degree of sign. treatment[2]	***	n.s.	**	*

[1] Flesch *et al.*, 2002.

[2] n.s. = $P > 0.05$; * = $P \leq 0.05$; ** = $P \leq 0.01$; *** = $P \leq 0.001$.

Table 2. Mean ultimate pH values (measured 24 h post slaughter) and pH values after 1, 2, and 3 weeks of refrigerated storage (+ 2 ºC) in *M. longissimus* (LD) for fallow deer from two feeding treatments (pasture raised and barley/hay-fed), with standard errors of the difference (S.E.D.)

Trait	pH LD 24 h	pH LD 1 week	pH LD 2 weeks	pH LD 3 weeks
Group 1 (October)				
Pasture (*n*=6)	5.50	5.50	5.51	5.53
Barley/Hay (*n*=6)	5.58	5.52	5.52	5.56
Group 2 (November)				
Pasture (*n*=6)	5.63	5.52	5.49	5.54
Barley/Hay (*n*=6)	5.56	5.45	5.46	5.49
S.E.D.	0.022	0.021	0.025	0.026
Degree of sign. month[1]	**	n.s.	*	n.s.
Degree of sign. treatment[1]	n.s.	n.s.	n.s.	n.s.

[1]n.s. = $P > 0.05$; * = $P \leq 0.05$; ** = $P \leq 0.01$.

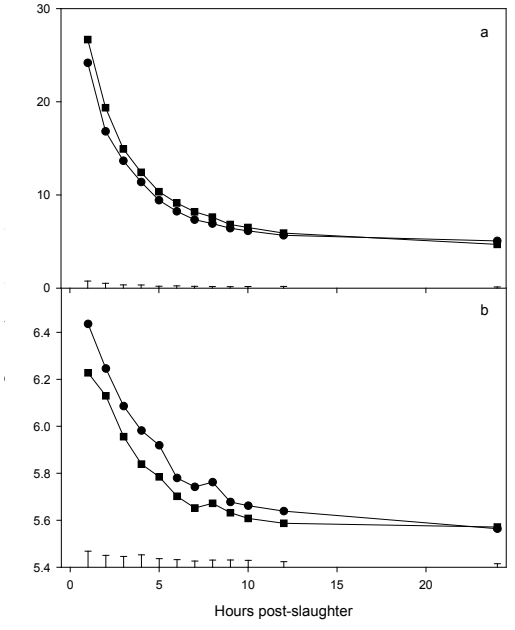

Fig. 1. Mean temperature (a) and pH (b) profiles in *M. longissimus* from the fallow deer from two treatments (● pasture raised and ■ barley/hay-fed, *n*=12 in each group) included in the study, measured at 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12 and 24 h *post-mortem*, with error bars indicating standard errors of difference (S. E. D.).

Colour stability and drip loss

The meat from the pasture raised deer had longer ($P \leq 0.01$) display life (hours of Minolta a^* value ≥ 12) after 2 and 3 weeks of refrigerated storage than the meat from the animals fed barley and hay (Fig. 2). After 1 day and 1 week of storage there was no significant difference between treatment groups in display life of the meat (Fig. 2). The decrease in a^* value during display at all the mentioned storage times is shown in Fig. 3.

There was no significant difference between the two treatment groups in the amount of drip loss (purge) in the meat at any of the measured storage times (Table 3). However, significantly lower drip losses were found in meat from the animals slaughtered in group 1 compared with group 2 ($P \leq 0.001$; Table 3).

Discussion

The nutritional status and physical condition of reindeer has been demonstrated to have a considerable effect on muscle glycogen content and meat ultimate pH values (Wiklund *et al*., 1996), and the use of commercial feed mixtures have generally improved nutritional status and carcass weights (Wiklund *et al* 2000; Nilsson *et al*., 1996). However, carcasses from feral, grass-fed or feedlot-raised red deer were analysed for differences in composition and the results indicated that variation in carcass fatness was mainly a function of carcass weight and not environment (Drew, 1992). In a recent study of carcass composition of male fallow deer grazed on pasture and fed a concentrate mixture (40% maize, 25% sugar beet pulp, 20% lucerne (alfalfa), 13% soy flakes, 2% vitamins and minerals) for 16 weeks prior to slaughter, it was demonstrated that the concentrate-fed deer had significantly higher live weights, carcass weights and dressing percentage compared with pasture raised animals (Volpelli *et al*., 2002). The present results are in good agreement with the mentioned fallow deer study (Volpelli *et al*., 2002) and it could be concluded that also the grain/hay-fed female fallow deer included in our study had higher body condition scores and carcass weights than the pasture raised deer. In contrast to this clear indication of a better nutritional status of the grain/hay-fed deer, the measured ultimate

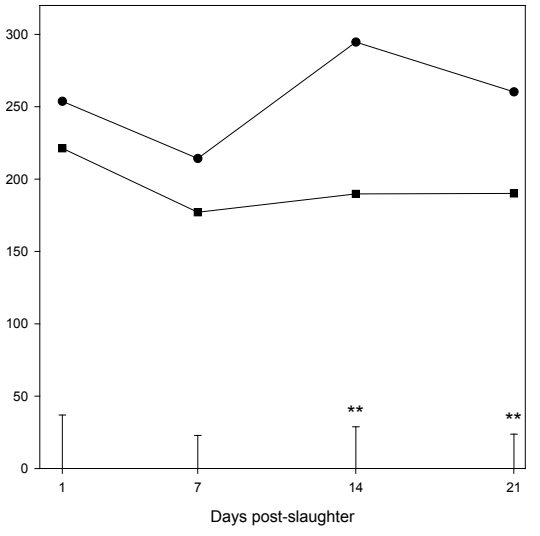

Fig. 2. Mean display life (hours of Minolta a* value ≥ 12) in *M. longissimus* from the fallow deer from two treatments (● pasture raised and ■ barley/hay-fed, *n*=12 in each group) included in the study, measured after one day, and after opening the vacuum bag after 1, 2, and 3 weeks of refrigerated storage (+ 2 °C), with error bars indicating standard error of difference (S.E.D).

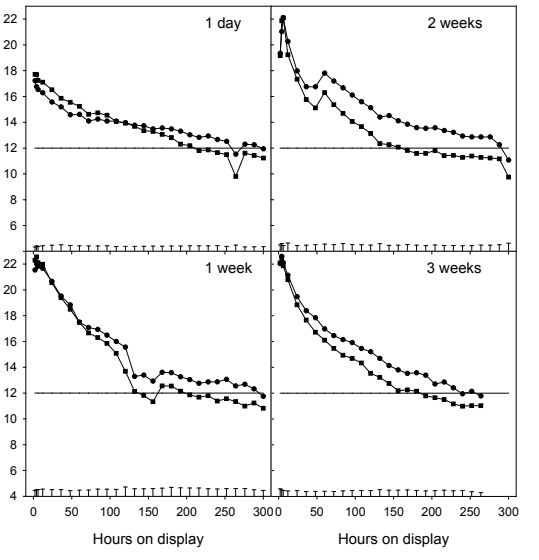

Fig. 3. Mean Minolta a* value in *M. longissimus* from the fallow deer from two treatments (● pasture raised and ■ barley/hay-fed, *n*=12 in each group) included in the study, measured after one day *post mortem*, after opening the vacuum bag after 1, 2 and 3 weeks (0-300 h of display) of refrigerated storage (+ 2 °C), with error bars indicating standard error of difference (S.E.D).

pH values in *M. longissimus* in the present study did not indicate a difference in muscle energy content between the two treatment groups. Volpelli *et al* (2003) observed similar results where an improved nutritional status did not influence muscle glycogen stores (or meat ultimate pH values) in male fallow deer.

Temperature and pH decline in LD from the fallow deer in the present study followed a similar pattern to that reported in an earlier study evaluating the effects of electrical stimulation of red deer carcasses (Wiklund *et al*., 2001b). No electrical stimulation was used in the present work, and the demonstrated continuation in pH decline between 24 h and 1 week after slaughter (Table 2) suggests that the ultimate pH had not been attained within the first 24 h *post mortem*. This result in fallow deer contrasts with the rate of pH decline in reindeer, which is surprisingly rapid (Gundersen & Nummedal, 1996). Even without electrical stimulation, the ultimate pH in reindeer muscles can be measured as early as 15 h *post mortem* (Wiklund *et al*., 1995).

Oxidation of deoxymyoglobin and oxymyoglobin to metmyoglobin accounts for the discoloration (from a bright red to a brownish red colour) of meat in retail display conditions (Liu *et al*., 1996). Red deer meat on display had poor colour stability compared with beef, and it was suggested that the deer meat is prone to oxidative deterioration possibly due to high levels of pro-oxidants like iron (Fe) and copper (Cu) (Drew & Seman, 1987; Stevenson-Barry *et al*., 1999). Contradictory results have been reported regarding the effects of various feeding regimens (pasture versus grain-based concentrates) and dietary manipulations of the feed (added antioxidants and altered fat composition) and their effect on meat colour stability. Studies of beef (Liu *et al*., 1995), pork (Corino *et al*., 1999) and sika deer meat (*Cervus nippon*) (Okabe *et al*., 2002) demonstrated a positive effect of vitamin E supplementation on meat colour stability. Meat from pasture-raised cattle had reduced colour stability compared with grain fed animals at the day of slaughter, although this difference disappeared after ageing of the beef (Yang *et al*, 2002). In the same study, supplementation of both diets (pasture and grain) with vitamin E did not affect beef colour stability (Yang *et al*., 2002). Further, in a study of altered lipid composi-

Table 3. Mean values for drip loss (purge) after 1, 2, and 3 weeks of refrigerated storage (+ 2 ºC) in *M. longissimus* (LD) for fallow deer from two feeding treatments (pasture raised and barley/hay-fed), with standard errors of the difference (S.E.D.)

Trait	Purge %, 1 week	Purge %, 2 weeks	Purge %, 3 weeks
Group 1 (October)			
Pasture (*n*=6)	1.95	2.92	3.30
Barley/Hay (*n*=6)	2.29	2.85	3.56
Group 2 (November)			
Pasture (*n*=6)	0.98	1.40	2.06
Barley/Hay (*n*=6)	1.16	1.69	2.04
S.E.D.	0.260	0.371	0.422
Degree of sign. month[1]	***	***	***
Degree of sign. treatment[1]	n.s.	n.s.	n.s.

[1]n.s. = $P > 0.05$; *** = $P \leq 0.001$.

tion of the feed for lambs there was no significant effect on meat colour stability during refrigerated display (Ponnampalam *et al.*, 2001). The present results in fallow deer meat are in good agreement with a recent study of red deer meat from concentrate-fed versus pasture raised animals, where a positive effect of the pasture diet on colour stability of the meat was reported (Wiklund *et al.*, 2002).

In some recent comparisons of quality characteristics of meat from pasture raised animals versus animals fed various concentrates or supplements, no effects on the water-holding properties of beef (Varela *et al.*, 2004), lamb (Díaz *et al.*, 2002; Santos-Silva *et al*, 2003; Velasco *et al.*, 2004) and fallow deer meat (Volpelli *et al.*, 2003) have been reported. However, in the previously mentioned red deer study (Wiklund *et al.*, 2002) a lower drip loss was found in meat from the pasture raised animals compared with the concentrate-fed group. The results found in the present study did not indicate a difference in water-holding capacity between the two treatment groups, although meat samples from the animals in group 2 had a better water-holding capacity than samples from group 1. Possibly the differences in drip loss observed in the earlier red deer study (Wiklund *et al.*, 2002) between the two feeding treatments could be related to a variation in composition (*i.e.* levels of antioxidants like vitamin E) of the concentrate feed and the pasture. A similar difference in drip loss was therefore expected in the present study, especially since the fallow deer in our study were exposed to a much longer feeding period (19 and 24 weeks) than the red deer (10 weeks; Wiklund *et al.*, 2002). One explanation to the present results might be that the paddock used for the fallow deer fed barley/hay was very dry and had almost no vegetation at all at the beginning of the feeding period (winter), but as the experiment progressed a small amount of green vegetation became visible, and was consumed by the deer. Although the % DM (dry matter) contributing to the diet of these deer would have been very small, nevertheless there would have been a small contribution to nutrient (*e.g.* antioxidant) intake. Therefore the differences in diet and diet composition between the two treatment groups might not have been large enough to influence the water-holding properties of the meat. Additionally, the extra amount of green vegetation consumed by the deer (in both treatment groups) slaughtered at the late occasion (November; group 2) might explain the better water-holding properties of this meat. Considering these reported contradictory results and the fact that there is a very limited amount of meat quality data available for venison, further investigations are recommended to explain and describe the quality variation in meat from different deer species and production systems.

Knowledge about the quality attributes of fresh chilled venison is of strategic importance to the Australian deer industry. Today most of the venison produced is sold frozen, but the demand for fresh meat is expected to increase in the future (Tuckwell, 2003). Pelvic suspension of carcasses has been demonstrated to improve tenderness in meat from young male fallow deer (Sims *et al.*, 2004), the type of animals most likely to be supplied for commercial slaughter in Australia. The water-holding properties of fresh chill-stored fallow deer venison were also improved by pelvic suspension (Wiklund *et al.*, 2004). The present results indicate that the diet of the animals is another important factor that contributes to the variation in characteristics of fresh chilled venison, mainly

the colour stability and display life of vacuum packaged meat. Sensory evaluation (using a trained expert panel and consumer preference tests) of fallow deer venison from the two feeding treatments, as well as from carcasses representing the variation in body condition scoring and comparative studies in other deer species, are subjects recommended for further investigation.

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Abstract in Swedish / Sammanfattning:
I denna undersökning ingick 24 dovhjortshindar (*Dama dama*) för att studera effekterna av olika typer av foder (bete och korn) på slaktkroppskvalitet samt färg och vattenhållande förmåga i köttet (*M. longissimus*). Alla djur var uppfödda på en hjortfarm, 12 betade gräs och 12 utfodrades med korn och en liten mängd hö före slakt. Djuren slaktades vid två olika tillfällen (under våren på det södra halvklotet); efter 19 veckors utfodring (n=12; 6 betesdjur och 6 kornfodrade djur; grupp 1) och efter 24 veckors utfodring (n=12; 6 betesdjur och 6 kornfodrade djur; grupp 2). De dovhjortar som utfodrats med korn och hö var i bättre kondition och hade högre slaktvikter jämfört med de djur som betat gräs. Ingen skillnad i köttets pH-värde mellan de två utfodringsgrupperna kunde dock påvisas. Köttet från de betande dovhjortarna hade bättre färgstabilitet efter lagring i 2 och 3 veckor (+ 2.0 ºC) i vakuumförpackning. Det fanns ingen skillnad mellan kött från betande och korn/hö-utfodrade djur i vattenhållande förmåga. Däremot hade kött från djur i grupp 2 (slaktade efter 24 veckors utfodring) bättre vattenhållande förmåga jämfört med grupp 1 ($P \leq 0.001$). Vi kunde konstatera att de olika fodertyperna påverkade kvaliteten hos färskt kyllagrat kött, framförallt färgstabiliteten hos vakuumförpackat kött.