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A note on the effect of *post-mortem* maturation on colour of bovine *Longissimus dorsi* muscle

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Fifteen heifers were housed and fed a concentrate diet while 54 counterparts grazed at pasture for 90 days at which stage six heifers from each group were slaughtered. The remaining animals in the pasture group were then housed and offered either: concentrate only; concentrate plus grass silage with silage accounting for either 20% or 50% of the total dry matter offered; or zero-grazed grass plus concentrate with grass accounting for 83% of the dry matter offered. Heifers (3/diet) were slaughtered 28, 56, 91 and 120 days thereafter. Colour characteristics of *M. longissimus dorsi* (LD) were measured at 48 h *post mortem*. The LD was then vacuum-packaged and stored at between 0 and 4 °C in darkness for 12 days, when colour characteristics were again measured. Maturation of LD resulted in meat that had higher redness values ('*a*' value; P<0.001) and a more intense red colour (higher '*C*' value; P<0.001) at 14 days *post mortem* than at 2 days, regardless of diet/duration of feeding. Maturation also resulted in a brighter colour (higher 'L' value; P<0.001) but this difference was greatest when cattle were slaughtered the day-56 time point.

Keywords: beef; chilled storage; colour; diet; maturation

Introduction

Colour is the most important meat quality attribute at the point of sale since consumers use it as an index of quality and freshness (Carpenter, Cornforth and Whittier, 2001; O'Sullivan *et al*., 2002). Since *post mortem* refrigerated storage of meat, often termed maturation or ageing, permits desirable degradative structural changes in myofibrillar, cytoskeletal and connective

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tissue proteins which enhances its palatability (Ouali, 1990; Takahashi, 1996), beef is often not sold until at least 14 days *post mortem*. Moreover, international trade in meat frequently necessitates prolonged *post mortem* storage during transport to target markets. During this time beef, when removed from carcasses as individual muscles, is generally stored in vacuum-packaging, refrigerated and in darkness (Braghieri *et al*., 2007) to minimise oxidative deterioration while still allowing desirable structural changes. Maturation has also been reported to have beneficial effects on the initial display colour of beef, whereby an increase in certain colour coordinates is manifested as a lighter, more intense red colour (Boakye and Mittal, 1996).

When 'fresh' (48 h *post mortem*) beef colour comparisons have been made, cattle permitted to graze pasture during their production, or those offered forages, have been reported to produce darker meat than counterparts finished on concentrate diets (Schaake *et al*., 1993; Muir *et al*., 1998; Vestergaard, Oksbjerg and Henckel, 2000). However, Yang *et al*. (2002) reported that while fresh pasture-fed beef was darker than fresh grain-fed beef, these differences disappeared when muscles were allowed to age/mature. There is a paucity of information on whether the effect of diet is influenced by the time *post mortem* when meat colour is measured. Therefore, the objective of this study was to determine if differences emerged between day 2 ('fresh') and day 14 ('matured') colour of *M. longissimus dorsi* (LD) and if such differences were influenced by the duration of the period on different rations prior to slaughter.

Materials and Methods

Experimental design

In an experiment, the objective of which was to determine the effects of dietary composition and duration of feeding on subcutaneous adipose tissue and LD colour, and on pigment concentrations, 15 heifers were permanently housed and offered a concentrate diet (PH-CON) while 54 counterparts remained at pasture for 90 days (PAS). Six heifers from each of these groups were then slaughtered and the remaining PAS heifers were housed and offered either a concentrate diet (PAS-CON), or concentrate plus grass silage with the silage accounting for either 20% or 50% of the dry matter offered (PAS-GS20 and PAS-GS50, respectively), or zero-grazed grass (PAS-GRA) plus concentrate with the grass accounting for 83% of the dry matter offered. The objective was to maintain a comparable growth rate across treatments. Heifers (3 per treatment) were slaughtered at 28, 56, 91 and 120 days thereafter. Due to a limitation on the number of animals available, no PH-CON heifers were assigned to slaughter on day 56. Further details of animal management are in Dunne *et al*. (2006). Carcasses were held at 4 °C for approximately 24 h following slaughter and then the right side of each carcass was cut at the $5^{th}/6^{th}$ rib interface ('pistola' cut) and the LD muscle, between the 7^{th} and 13^{th} ribs, was excised and stored at 4 °C until 48 h *post mortem*.

Measurement of colour and pH

At 48 h *post mortem* (day 2), the pH of the LD muscle (pH_u) was measured by making a scalpel incision at the 10^{th} rib and inserting a glass electrode (Model EC-2010-06, Amagruss Electrodes Ltd., Westport, Co. Mayo, Ireland), attached to a portable pH meter (Model no. 250A, Orion Research Inc., Boston, MA 02129, USA), approximately 2.5 cm into the muscle. A steak, 2.5 cm in thickness, was removed from the region of the 12^{th} rib, overwrapped with oxygen-permeable PVC film and

permitted to bloom, in darkness, at 4 °C for 3 h prior to colour measurement. Colour was measured using a Minolta chromameter (model CR300, Minolta Camera Co., Ltd., Osaka, Japan) calibrated for readings of "L" (lightness), "a" (redness) and "b" (yellowness) values using its standard white calibration tile overwrapped with PVC film. Three readings were made on non-overlapping areas of the LD and the average value was used for data analysis. All measurements were made in the Hunter Lab colour space; diffuse illumination (D_{65}, 10°) with a 0° viewing angle was used and the specular component was excluded. The hue angle ('H') and saturation ('C') were calculated as $\tan^{-1}$ (b/a) and $\sqrt{(a^2 + b^2)}$, respectively (McLaren, 1987). The hue angle was converted from radians to degrees for data analysis. The remaining LD muscle was vacuum-packed (Multivac®, model A300/16, Multivac, Ltd., Swindon, SN5 7UY, UK) and allowed to mature at between 0 and 4 °C until day 14 *post mortem*. Another steak, 2.5 cm thick, was then removed and pH and colour were measured as described above. Thus maturation treatment consisted of fresh and matured LD muscle.

Statistical analysis

Data from the animals slaughtered off pasture or after housing for 90 days were analysed as a split-plot design with group in the main plot, and maturation treatment and maturation-treatment by ration-type in the sub-plot. Data from animals slaughtered subsequently were analysed as a split-plot design, with a factorial structure in the main plot (main effects for diet type (R), slaughter day (D) and their interaction) and maturation treatment and all related interactions in the sub-plot. Where significant effects were detected (F-test), means were separated using Tukey's test.

Results

In the case of the heifers slaughtered off pasture and their contemporaries slaughtered after 90 days on concentrate indoors prior to slaughter, there was no interaction between feeding system and maturation treatment for any of the measurements made on the LD, but maturation resulted in a lower pH (5.56 v 5.75, $P<0.05$), a higher '*a*' value (14.6 v 12.9, $P<0.05$), a higher '*C*' value (15.6 v 13.8, $P<0.05$) and a higher '*L*' value (36.7 v 34.8, $P<0.05$). Results for the remaining heifers showed (Table 1) that there was no ration-type by maturation-treatment interaction for pH, lightness, '*a*' or '*C*' values, and no slaughter-day by maturation-treatment interaction for '*a*' or '*C*' values. The '*a*' and '*C*' values were higher (both $P<0.001$) for matured than fresh muscle, indicating that matured LD muscle had greater redness and that the redness was more intense than for fresh (day 2 *post mortem*) muscle. The '*b*' value (yellowness) of LD was also increased by maturation ($P<0.001$) (data not shown). While maturation significantly increased '*L*' value there was an interaction between slaughter day and maturation arising from the fact that the effect of maturation was greatest at day 56, when the increase in lightness was almost 4 '*L*' value units compared with increases of only 1.3 to 1.9 '*L*' value units on the other slaughter days. There was an interaction between slaughter day and maturation for pH reflecting the result that matured LD had a lower ($P<0.05$) value on days 28 and day 91 but not on days 56 or 120.

Discussion

In this experiment the meat that was allowed to mature, in vacuum-packs at between 0 and 4 °C for 12 days and subjected to the same blooming conditions as fresh meat when fabricated into steaks, was brighter and more intense in colour

Table 1. The effect of *post mortem* maturation on muscle pH and colour

Slaughter day[a]	Lightness ('*L*' value)		Redness ('*a*' value)		Intensity of redness ('*C*' value)		pH	
	Fresh[b]	Mature[c]	Fresh	Mature	Fresh	Mature	Fresh	Mature
28	35.0	36.5	12.7	14.8	13.5	15.8	5.66	5.50
56	34.9	38.8	13.1	16.9	14.8	18.0	5.43	5.48
91	35.2	36.5	13.4	17.0	14.5	18.2	5.73	5.58
120	36.7	38.6	14.9	17.6	15.8	18.8	5.41	5.41
s.e.d.[†]	0.56		0.55		0.68		0.043	
F test for:								
Maturation (M)	***		***		***		**	
Slaughter date (D)	***		***		***		***	
M × D	**						**	

[a] Refers to days post-housing for heifers that were at pasture up to housing and to days after day 90 for heifers that were housed on concentrate for previous 90 days.
[b] 48 h *post mortem*, after a 3 h bloom time.
[c] Day 14 *post mortem* following 12 day maturing in vacuum-packs at between 0 and 4 °C followed by a 3 h bloom time.
[†] For M × D mean.

than when assessed at 48 h *post mortem*. As *post-mortem* maturation of meat proceeds, ongoing mitochondrial decay leads to a reduction in oxygen consumption by meat (Hood, 1980), specifically by the mitochondrial enzymes. Gašperlin, Zlender and Abram (2001) found that maturation decreased the specific activity of cytochrome c oxidase. Such a decrease would result in less effective competition with myoglobin for available oxygen, the net result being increased penetration by oxygen and a deeper oxymyoglobin layer (Hood, 1980), thus attenuating any differences apparent at day 2. This would account for increased redness and a more intense redness after the 12-day maturation period. Degradative structural changes in meat during maturation could also explain an increase in brightness/lightness due to changes in the light scattering properties of the meat surface (MacDougall, 1982). Such changes would also facilitate increased oxygen penetration into the meat, thus causing increased meat redness and intensity of redness after maturation.

Usually, little attention is paid to the '*b*' value (not reported) where muscle colour is concerned, as it describes yellowness while the dominant hue of meat is red, although the '*b*' value is implicated in the intensity of redness of meat, due to its involvement in this descriptor of meat colour. As acknowledged by Insausti *et al*. (1999), the '*b*' value of muscle remains unexplained in the literature although these authors claim that small changes in '*b*' might be valuable when related to changes in pigment proportions, as determined by reflectance spectra. In this regard, Lindahl, Lundstrom and Tornberg (2001) found that the '*b*' value was influenced most by the myoglobin forms present.

The evolution of nitrogenous compounds, such as biogenic amines (Lee and Yoon, 2001) resulting from proteolysis by endogenous enzymes and microbial metabolism (Edwards *et al*., 1987), during the *post-mortem* maturation of beef normally means that pH after maturation can be greater than the ultimate pH at 48 h *post mortem*. In the present study, the tendency was for pH at day 14 to be lower

than that prior to maturation. The reasons for this are unknown but ultimately, these effects on pH may have little practical consequence.

To be acceptable for sale in international markets, beef must have an adequate storage life such that following transportation, fabrication into vacuum-packaged primals or retail cuts, distribution and/or storage, it will bloom effectively (Smith *et al*., 2000). In this context, beef produced in North-Western Europe will typically spend a week in refrigerated transit to destinations in lucrative markets in Southern Europe. Fabrication of beef into steaks, perhaps following maturation and refrigerated transport, would thus be expected to produce beef with a brighter, more intense initial colour, commensurate with the requirements of such markets. The results presented above indicate that this brighter, more intense colour at or near point-of-sale is independent of the type of ration and duration of feeding. Since feed costs are a major contributor to the variable costs of beef production, this indicates that in regions of abundant grass growth, cattle producers could continue to utilise this economical resource to produce beef that would have an acceptable initial colour at the point of sale.

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