

Colour of subcutaneous adipose tissue and muscle of Irish beef carcasses destined for the Italian market

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The purposes of this study were (i) to objectively measure the colour of carcass fat and muscle of heifers that had been previously selected, subjectively, for the Italian market and (ii) to define instrumental colour values which would describe the required fat colour for that market. On one day during each of 5 months (11 April, 13 June, 10 October, 10 November and 19 December) the 'b' (yellowness) value of carcass fat was measured at two positions (proximal pelvic limb area and the area between 9th rib and 4th lumbar vertebra) and the 'L' (lightness) and 'a' (redness) values of two muscles (*M. longissimus dorsi* (LD) and *M. rhomboideus thoracis* (RT)) were measured using a Minolta chromameter. Measurement date had a significant effect ($P < 0.05$) on 'b' values of fat at both positions, with carcasses displaying the most yellow fat on 13 June ($P < 0.05$). The LD was palest and most red on 11 April ($P < 0.05$) and the RT tended to be palest on 13 June but most red ($P < 0.05$) on 11 April. The 'L' value differed between muscles on 11 April ($P < 0.01$) and 19 December ($P < 0.05$) and the 'a' value differed between muscles on all dates except 13 June. The majority of carcasses on each date fell between muscle 'L' values of 31 and 35, regardless of muscle, and between muscle 'a' values of 18 and 22. It is concluded that application of a "cut-off" value to muscle colour would be futile but as 81% of accepted carcasses had fat 'b' values below 14.2, regardless of position, that this could be used as a threshold of acceptable yellowness.

Keywords: Carcass fat; colour; heifers; Italian beef market; muscle

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Introduction

The colour of subcutaneous adipose tissue (carcass fat) is a key component of beef quality (Wood and Fisher, 1997). Muscle colour is a critical visual characteristic of beef which can have a large influence on the purchase decisions of consumers (Cornforth, 1994). Carcass fat and muscle colour have, therefore, been included in beef carcass grading systems (Price, 1995) and in this regard, carcass fat and muscle colour have been used to determine the suitability of Irish beef carcasses for particular markets. To be suitable for certain segments of the Italian market, beef carcasses must possess good conformation and fat cover but critically, must have 'white' or 'pale' carcass fat and 'pink' or 'cherry pink' muscle tissue (Anon, 1999).

Beef production systems represent the combined and interacting effects of genotype, gender, age at slaughter and nutrition before slaughter (Moloney *et al.*, 2001b). Beef production in Ireland remains largely pasture based whereby cattle graze from March to November (Drennan, Keane and Dunne, 1995). Grass silage is the dominant feedstuff offered to cattle over the winter months (O'Kiely, Power and O'Donnell, 1993), and is usually supplemented with concentrates for housed finishing cattle (Moloney *et al.*, 2001a). In contrast, beef production enterprises in Italy typically do not depend to such an extent on grass or grass silage and fattening usually occurs in specialised units, housing 200 to 500 animals. The typical diet consists of maize silage, maize meal, barley, beet-pulp silage and protein supplements (Gigli and Iacurto, 1995).

Inclusion of grazed or conserved grass in cattle diets leads to yellow coloured carcass fat because such forages are rich sources of the compounds responsible for

yellowness, namely β -carotene and lutein (Yang, Larsen and Tume, 1992; Strachan, Yang and Dillon, 1993). Assessment of the suitability of carcasses on the basis of colour is usually subjective and little information is available on objective measures of acceptability of carcass fat colour, such as the 'b' (yellowness) value, which is frequently measured in scientific investigations (Strachan *et al.*, 1993; Muir *et al.*, 1998; Moloney *et al.*, 2001a).

As age at slaughter increases, myoglobin concentration in muscle increases (Boccard *et al.*, 1979; Varnam and Sutherland, 1995) and muscle becomes darker. In Italy, both male and female cattle are usually slaughtered between 10 and 20 months of age (Gigli and Iacurto, 1995). In the most widely practised system of beef production in Ireland, steers are slaughtered at about 24 months of age (Moloney *et al.*, 2001a) but age at slaughter can increase to around 30 months (Drennan *et al.*, 1995).

In several studies, pasture-reared cattle had darker muscle than cattle raised indoors despite being younger at slaughter in some cases (Schroeder *et al.*, 1980; Hedrick *et al.*, 1983; McCaughey and Cliplef, 1996). The exact reasons for this darker coloured beef remain speculative with physical activity, age at slaughter, and carcass weight and fatness all considered to play a role (Priolo, Micol and Agabriel, 2001). Hence, the production of more yellow carcass fat and darker muscle tissue associated with pasture-based production systems, typical of those in Ireland, seems incompatible with the tissue colour specifications of certain segments of the Italian beef market.

The purpose of this study was to objectively measure the colour of the subcutaneous adipose tissue and the muscle of heifers that had already been selected, subjectively, for the Italian market and to

determine an instrumental 'b' value which could be regarded as a 'threshold of acceptability' in terms of carcass fat colour for this market.

Materials and Methods

Carcass selection

On each of five occasions (11 April, 13 June, 10 October, 10 November and 19 December) subcutaneous adipose tissue and muscle colour of heifers reared specifically to meet the criteria of the Italian market were measured. The heifers were referred to as 'special-fed' (SF), indicating that producers were prohibited from including grass silage in the finishing diet. All measurements were made in the same commercial beef processing plant. On each occasion the heifers had been slaughtered 24 h previously and prior to instrumental measurement of tissue colour, the carcasses were subjectively graded by industry graders on the basis of carcass fat colour. Rejection of SF carcasses occurred only on the first measurement date, when 21 of 41 SF carcasses (51%) were deemed unacceptable. Carcasses were also graded for conformation and fatness according to the EU Beef Carcass Classification Scheme (Anon, 1981). On a sixth date, during June, carcass fat colour of 17 conventionally reared (finished on grass silage plus concentrates) steers, representing animals typical of an Irish finishing system and not intended for supply to the Italian market, was measured for comparative purposes.

Tissue colour measurement

A Minolta chromameter (model CR300, Minolta Camera Co. Ltd., Osaka, Japan) was used to measure the 'b' (yellowness) value of subcutaneous adipose tissue and the 'L' (lightness) and 'a' (redness) values of muscle tissue of heifer carcasses (right

side only). On each occasion the chromameter was calibrated using its standard white calibration tile. Improvised yellow and red cards were used as standards for subcutaneous adipose and muscle tissue, respectively, to ensure reproducibility of readings between dates. All measurements were made in the Hunter Lab color space using the D65 illuminant. Tissue colour measurement was carried out as carcasses were transferred from overnight (24 h approximately) storage in the blast chiller to the cutting area. The ambient temperature during colour measurement was <10 °C. Removal of carcasses from the blast chiller prior to measurement was permitted when the internal temperature of carcasses was less than 7 °C.

Measurement positions

Colour of subcutaneous adipose tissue was measured at two positions, one in an area on the proximal pelvic limb posterior to the last lumbar vertebra and extending to the penultimate sacral vertebra (F1) and the other between the 9th rib and the 4th lumbar vertebra (F2).

Measurements were taken within 10-cm lateral to the midline of the carcass but avoiding areas where blistering had occurred during cooling. One reading was taken at each position. Carcasses were cut at the 5th rib ('pistola' cut) and the exposed muscles at the cut surface were permitted to bloom at 4 °C for 90 min (Wulf and Wise, 1999). The colour of *M. longissimus dorsi* (LD) and *M. rhomboideus thoracis* (RT) was recorded – triplicate measurements were made on three non-overlapping zones of each muscle and average values calculated.

Statistical analysis

A one-way (measurement date) analysis of variance was used to determine the effect of measurement date on the colour

co-ordinates of each individual muscle or measurement location. Where date was significant, mean values were separated using Fisher's Least Significant Difference Test. The Student's t-test for two independent samples was used to ascertain whether there were differences between accepted and rejected carcasses on 11 April in colour of each tissue. To determine whether the differences between the sampling positions were different from zero on each date, a paired two-sample Student's t-test was performed on the data for the two fat and the two muscle positions.

Results

Carcass characteristics

Carcass characteristics are presented in Table 1. Carcass weights were similar on all dates. There was no difference between mean carcass weight of accepted and rejected carcasses on 11 April. The dominant conformation grade on all dates was R, achieved by 102 out of 112 carcasses in the survey. The conformation grade distribution was similar for accepted and rejected carcasses on 11 April, with 17/20 and 19/21 of accepted and rejected carcasses achieving an R grade, respectively. Fat class 4 was predominant on all dates,

although more carcasses achieved 4H (n = 58) than 4L (n = 45) classification.

Fat colour

Carcass fat colour ('b' value) data are presented in Table 2. There was little evidence of a difference between measurement positions for fat colour. Only on 13 June was the difference between positions significantly different from zero (P < 0.01). Carcass fat of accepted carcasses was more yellow on 13 June and less yellow on 10 October than on other dates (P < 0.05). On 11 April, rejected carcasses had a higher 'b' value (P < 0.05) and hence, were more yellow. For the F1 position on 11 April, the 'b' values of accepted and rejected carcasses ranged from 8.4 to 14.2 and from 6.9 to 21.3, respectively (Table 2). If the maximum F1 'b' value of accepted carcasses (14.2) was considered a 'ceiling' value for acceptability, then 48% of rejected carcasses would have been acceptable.

On each of the four subsequent dates, all SF carcasses delivered were deemed acceptable. However, on 13 June, only 35% of carcasses had an F1 value below 14.2. On 10 October and 10 November, all carcasses had F1 'b' values below 14.2. On 19 December, 18 of 19 had 'b' values

Table 1. Carcass characteristics of heifers reared for the Italian market

Date	n	Carcass weight (kg) [†]	Conformation ^{††}			Fat score ^{††}			
			U	R	O	3	4L	4H	5
11 April	20 (21) ¹	302 ± 5.2 (299 ± 6.9)	3 (2)	17 (19)	0 (0)	0 (1)	9 (5)	10 (13)	1 (2)
13 June	23	287 ± 4.3	0	22	1	1	12	10	0
10 October	14	309 ± 7.1	0	13	1	0	2	11	1
10 November	15	295 ± 6.1	0	14	1	1	4	9	1
19 December	19	289 ± 4.0	0	17	2	1	13	5	0

[†]Mean ± s.e. There was no significant difference between dates.

^{††}Number of carcasses in each conformation and fatness category where conformation is E (best), U, R, O, P (poorest) and fatness was on the scale 1 (leanest), 2, 3, 4L, 4H and 5 (fattest).

¹Carcasses rejected on April 11.

Table 2. Carcass fat yellowness (mean \pm s.e., range underneath) of heifers reared for the Italian market

Date	n	Position ¹	
		F1	F2
11 April	20	11.9 ^c \pm 0.41	11.8 ^c \pm 0.45
	(21) ²	8.4 – 14.2 (14.0 \pm 0.59) (6.9 – 21.3)	7.6 – 14.9 (14.0 \pm 0.59) (9.1 – 19.9)
13 June	23	15.0 ^d \pm 0.32 12.2 – 17.4	13.8 ^d \pm 0.32 9.9 – 15.8
10 October	14	9.8 ^a \pm 0.37 6.9 – 11.8	9.9 ^a \pm 0.53 5.8 – 12.8
10 November	15	10.7 ^b \pm 0.45 7.2 – 13.5	11.0 ^b \pm 0.63 7.0 – 15.1
19 December	19	11.0 ^b \pm 0.47 6.9 – 15.0	11.0 ^b \pm 0.52 7.0 – 15.1
Significance ³		***	***

¹F1 = proximal pelvic limb, F2 = between 9th rib and 4th lumbar vertebra. The only significant difference between positions was on 13 June ($P < 0.05$).

²Carcasses rejected on 11 April.

^{abcd}Comparison of dates within measuring position; means without a common superscript differ significantly ($P < 0.05$).

below 14.2 (the remaining carcass had a value of 15).

When the same threshold values were used for position F2, 81% of accepted carcasses had 'b' values below 14.2 on 11 April while 52% of rejected carcasses had 'b' values above 14.2. On 13 June, 52% of carcasses had 'b' values below 14.2. On 10 October, all carcasses had F2 'b' values below 14.2. On 10 November, all but one ('b' = 15.5) were below 14.2. On 19 December, 90% of SF carcasses were below 14.2.

The carcass fat colour of 17 conventionally produced steers differed from that for the heifers. The steers had mean F1 and F2 'b' values of 14.1 (s.e. 0.46) and 15.7 (s.e. 0.53), respectively, and the corresponding ranges were 11.3 to 18.4 and 12 to 19.5. Only 47% and 29%, respectively, of steer F1 and F2 'b' values were below 14.2 compared with an average of 81% for all accepted heifer carcasses.

Muscle colour

Mean values and ranges for muscle 'L' and 'a' values are presented in Table 3. Date of measurement had a significant effect on muscle colour co-ordinates for both muscles. The LD was palest (highest 'L' value) and most red (highest 'a' value) on 11 April ($P < 0.05$). No consistent trends emerged with respect to the effect of date on either of these LD colour co-ordinates. The widest range in LD lightness occurred on 11 April, followed by 13 June, but this range narrowed subsequently. A similar pattern emerged with respect to LD redness. The RT tended to be palest on 13 June, but was most red on 11 April ($P < 0.05$). The range in RT lightness and redness tended to narrow with each measurement date.

On 11 April there were no differences in lightness or redness of LD or RT muscles between accepted and rejected carcasses. The distributions of accepted and rejected carcasses in lightness and redness

Table 3. 'Lightness' and 'redness' values (mean \pm s.e., range underneath) of *M. longissimus dorsi* (LD) and *M. rhomboideus thoracis* (RT) of heifers reared for the Italian market

Date	Lightness		Significance ¹	Redness		Significance ¹
	LD	RT		LD	RT	
11 April	34.8 ^c \pm 0.54	32.8 ^b \pm 0.49	*	23.8 ^d \pm 0.50	21.6 ^d \pm 0.58	*
	30.5 – 40.1	27.7 – 36.8		19.5 – 28.9	16.6 – 25.8	
	(33.6 \pm 0.60) ²	(33.8 \pm 0.49)		(22.8 \pm 0.38)	(22.0 \pm 0.62)	
13 June	33.1 ^b \pm 0.43	33.4 ^b \pm 0.44		20.2 ^a \pm 0.36	20.5 ^c \pm 0.42	
	29.7 – 38.3	30.3 – 40.4		16.8 – 23.8	16.7 – 24.1	
10 October	32.3 ^a \pm 0.37	31.3 ^a \pm 0.45		20.9 ^{bc} \pm 0.40	18.9 ^{ab} \pm 0.31	*
	29.9 – 34.2	28.7 – 34.7		18.5 – 23.6	16.4 – 20.9	
10 November	32.5 ^{ab} \pm 0.52	31.4 ^a \pm 0.38		21.2 ^c \pm 0.38	19.5 ^b \pm 0.38	*
	29.7 – 36.5	28.0 – 33.7		18.4 – 23.4	17.0 – 21.4	
19 December	32.7 ^{ab} \pm 0.39	31.7 ^a \pm 0.3	*	20.3 ^{ab} \pm 0.36	18.6 ^a \pm 0.42	*
	29.9 – 35.6	29.8 – 33.6		16.3 – 24.2	16.1 – 22.2	
Significance ³	**	**		***	***	

¹Comparison of muscles.²Carcasses rejected on 11 April.^{abcd}Comparison of dates within muscle; means without a common superscript differ significantly ($P < 0.05$).

categories of LD and RT were similar. The 'L' value differed between muscles of accepted carcasses on 11 April ($P < 0.01$) and 19 December ($P < 0.05$) and the 'a' value differed between muscles on all dates, except 13 June.

For both LD and RT, > 50% of 'L' values of all accepted carcasses fell between 30 and 35, with most carcasses between 33 and 34 for LD and an equal number falling into categories 31 to 32 and 32 to 33 for RT. Forty-seven percent of carcasses had 'L' values for LD below 33 while 74% had 'L' values below 34. Eighty-four percent of carcasses had 'L' values of RT below 34. The majority of carcasses displayed muscle 'a' values falling between 18 and 22, regardless of muscle, with approximately the same number of carcasses falling between these values for both muscles. However, on 19 December, 42% of carcasses had RT muscle 'a' values below 18.

Discussion

Fat colour

Italy is the largest importer of beef in the European Union and although the requirements can depend on the region being supplied, the main requirement is for carcasses that have 'white' fat and brightly-coloured 'pink' meat (Anon, 1999). All carcasses destined for this market in the present study were from heifers. Producers finishing cattle specifically to meet the carcass fat colour specifications of Italian purchasers were prohibited from including grass silage or green forage in the diet, due to a common perception that its inclusion, during finishing, causes carcass fat colour to deviate from the preferred 'white' and become unacceptably 'yellow'. In this regard, heifers had consumed a high-energy indoor ration, excluding grass silage, during their finishing phase for between 90 and 100 days pre-slaughter.

Carcasses were also assessed for suitability on the basis of conformation, as purchasers are concerned about lean meat yield from a carcass, and conformation is considered to indicate muscle proportion. Since the grade distribution was similar for accepted and rejected carcasses, it is likely that fat colour was pre-eminent in the mind of the grader when assessing these carcasses. Nevertheless, in subjective carcass assessments for this market, carcass conformation has the potential to be a confounding factor as it can prove difficult subjectively to separate the relative influences of conformation and colour. Thus, though a carcass may be too yellow to be accepted on the basis of colour alone, its conformation may be considered acceptable and it could be included, particularly in a situation where processors face a deficit of acceptably coloured carcasses relative to customer demand.

On every date, except 11 April, all heifers supplied to the processor were accepted on the basis of carcass fat colour alone. Thus, 11 April, when 51% of supplied carcasses were rejected, represented the only date from which a meaningful 'cut-off point' for carcass fat colour could be estimated. It is recognised that, since customer requirements may have been below numbers of carcasses supplied, the grader was more discriminating on that date. In contrast, the small numbers available on the other dates may have resulted in the grader being less discriminating in selection. Nevertheless, the high proportion of carcasses falling below a 'b' value of 14.2 on each date indicates that the grader displayed reasonable consistency across all dates. If carcasses had been assessed for suitability with the grader remaining oblivious to their dietary history in the months prior to slaughter, thus eliminating any positive bias towards

cattle specifically produced for the Italian market, a more robust 'threshold of acceptability' could have been generated. The fact that all carcasses were accepted on all dates, except 11 April, provides a constraint on identifying an objective 'cut-off point' for acceptable carcass fat colour. The critical information in this regard is the range of carcass fat 'b' values as well as the profile or distribution of the carcasses within the range.

In the authors' experience, the range in carcass fat 'b' values, when measured using the Minolta CR300 chromameter, is generally between about 5 to 6 for exceptionally 'white' or 'pale' carcasses and about 23 to 24 for carcasses that are 'yellow' or 'amber', typically those of culled dairy cows (unpublished observations). Measurements were made on the conventionally produced steers to provide a perspective on the colour of fat and muscle of the SF heifers. In this respect the steers were considerably more yellow than the heifers. It is also important to emphasise that the ceiling values identified in this study are likely to be instrument specific since variation in instrumental measurements of 'b' values of carcass fat is known to occur (Dunne *et al.*, 2000).

Prior to commencement of this study, casual observations that carcass fat on the posterior pelvic limb over the *M. biceps femoris* was more yellow than in other regions, notably the region between about the 6th rib and the 1st lumbar vertebra, led us to hypothesise that there may be differences in carcass fat colour between different regions of the carcass surface. This could be caused by either selective mobilisation and oxidation of carotenoids (Yang *et al.*, 1993) or by selective accretion or depletion of adipose tissue triacylglycerols in different anatomical regions of the subcutaneous adipose tissue. The effect of these processes would be to

either dilute or concentrate, respectively, any carotenoids present, a phenomenon which has been recognised (Knight *et al.*, 2001). In addition to measurement over the LD, measurement of colour on the proximal pelvic limb was also chosen due to ease of access to the site and rapidity of measurement. The lack of difference between carcass fat measurement sites is consistent with the findings of Boom and Sheath (1997) who reported no difference between carotenoid concentration, which is related to the 'b' value (Strachan *et al.*, 1993), in carcass fat on the rump and at the 12th rib.

The trend in fat colour was for carcasses measured in October to be least yellow and carcasses to become more yellow through to June. This may simply reflect a less strict selection in June in particular, due to the need of the factory to meet customer demand. Alternatively it could suggest that the period of feeding a non-green forage ration prior to slaughter was inadequate for this group of animals. Since cattle are generally spring born and housed during winter in Ireland, animals slaughtered in June were likely the oldest and had spent a longer period on a conventional indoor ration prior to the "special" ration than animals slaughtered on the other dates. This suggests an interaction between the duration of conventional and "special" rations with respect to fat colour. The trend towards a decrease in muscle lightness from October through June supports an age hypothesis since muscle generally becomes darker as the animal advances in maturity (Boccard *et al.*, 1979).

Muscle colour

Meat colour was measured at 24-h post-mortem in this study even though the recommended time of colour measurement is 48-h post-mortem (Boccard *et al.*, 1981), dictated by the achievement of the

ultimate pH of the muscle. Muscle colour was evaluated by factory personnel visually examining the surface of the *M. semimembranosus* above the aitch-bone without prior blooming. Priolo *et al.* (2001) recognised that this method of assessment caused problems in the meat industry because, in addition to the inherent bias associated with subjective assessment, variations in lighting conditions in chill rooms can affect colour perception. For scientific purposes the LD is recommended as the standard muscle for meat quality assessment (Boccard *et al.*, 1981).

Little information is available on the colour characteristics of the RT muscle. This study provided an opportunity to collect initial data for this muscle. It was also of interest to determine whether this muscle would be a better indicator of acceptability than the LD. It is somewhat surprising that some colour differences were observed between the two muscles examined because they are both located in the same anatomical region of the carcass and thus, would be expected to exhibit similar metabolic and functional characteristics.

Of the two tissues involved in colour assessment, pre-eminence seemed to be given to the carcass fat colour by the graders, as this is more easily assessed. When 50% of available carcasses were rejected on 11 April, it was on the basis of fat colour rather than muscle colour, as there were differences in fat colour at both positions but not in LD or RT lightness or redness, and both sets of carcasses were similarly distributed in lightness and redness categories and in carcass grades.

No attempt was made therefore to define a 'cut-off point' of acceptability for muscle colour because to measure muscle colour in a commercial environment would require the delay involved in a bloom time and the making of an incision in the carcass

which would compromise aesthetic quality. Furthermore, retrospective examination of the distribution of carcasses in the relevant colour categories revealed that carcasses were more tightly clustered in muscle 'L' and 'a' categories than carcass fat 'b' categories, so discrimination between carcasses on the basis of muscle colour would have been more difficult.

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