Colour of subcutaneous adipose tissue and colour and tenderness of the *longissimus thoracis et lumborum* muscle from Holstein–Friesian, Norwegian Red x Holstein–Friesian and Jersey x Holstein-Friesian cattle slaughtered at two live weights as bulls or steers

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Meat quality traits for Holstein–Friesian (HF), Norwegian Red × Holstein–Friesian (NR) and Jersey × Holstein–Friesian (JE) cattle reared to slaughter as two genders (bulls and steers) and 2 slaughter weights (570 kg and 640 kg) were compared. Adipose tissue from JE was more yellow (p<0.05) than HF or NR which were similar. There was no difference between breeds and no breed-related interactions for chemical composition, cook loss or instrumental tenderness of *longissimus thoracis et lumborum* muscle (LT). When adjusted for differences in lipid concentration, LT from NR-sired animals tended to be less red (p=0.058) and LT from JE-sired animals had a lower hue (p<0.05). Substitution of NR or JE for HF sires in the dairy herd will not have important effects on LT characteristics in the production systems examined but the more yellow carcasses from JE-sired cattle may limit their suitability for markets with a carcass fat colour specification.

Key words: dairy breeds, Holstein–Friesian, Norwegian Red, production systems, slaughter weight

Introduction

Approximately 30% of male cattle produced in Ireland annually is sourced from the dairy herd and is the progeny of predominantly Holstein-Friesian (HF) sires (DAFM 2012). Traditionally, because of the predominantly grass-based production systems, male cattle are produced in Ireland as steers. Within the range of variants of production systems, steers can be slaughtered at a range of live weights. More recently, interest in producing male cattle as bulls has increased, mainly due to their higher growth rate and efficiency and leaner carcasses than steers (O'Riordan et al. 2011). Up to 90% of beef produced in Ireland is exported and of this, 90% is exported to Europe where Irish beef must meet a variety of specifications to maintain its share of the beef market (Bord Bia 2012). Among the criteria that determine market acceptability are carcass weight/classification, gender and age of the animal at slaughter, colour of subcutaneous adipose tissue, colour of lean tissue and ultimately the sensory experience of the consumer.

Declining fertility and health traits within the HF breed has resulted in renewed interest in crossbreeding (Walsh et al. 2007). There is specific interest in crossbreeding with the Jersey (JE) breed which derives, in addition to the fertility and health benefits offered from heterosis, from a desire to increase output of milk solids per ha following the introduction of a milk composition–based payment system (Shalloo 2007). There is also an interest in crossbreeding with the Norwegian Red (NR) breed which derives from the emphasis on health and fertility in the Total Merit Index breeding programme for the breed in Norway and its contributions to the lower incidence of clinical mastitis in the national population (Heringstad et al. 2003). If there are differences in the appearance or sensory quality of beef due to a change in a production system this could compromise the ability of beef producers to service existing markets, where consumers are accustomed to beef with particular attributes of appearance, taste and texture. Alternatively, the ability to develop new markets might be enhanced if beef with different characteristics could be produced from modified production systems.

McNamee et al. (2015) have evaluated the characteristics of NR x HF and JE x HF male cattle from a beef production and carcass quality perspective. Due to the fact that NR and JE are predominantly dairy breeds and relatively new to the dairy industry in Ireland, there is a paucity of information in the current literature regarding the quality of their meat. This manuscript reports on selected quality characteristics, of particular interest to the consumer, of the meat from the animals studied by McNamee et al. (2015).

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Materials and methods

Animals and management

Details of animal management are given in McNamee et al. (2015). In brief, spring-born male calves from HF dams and HF (16 sires), NR (16 sires) or JE (8 sires) sires were sourced on approximately 40 commercial dairy farms. The calves were retained on their farms of origin until they were about 4 weeks of age when they were transferred to the Animal and Grassland Research and Innovation Centre, Grange, Co Meath. After arrival they were penned in groups of 12 and offered a total of 20 kg milk replacer per head over a 42–day period. Calf concentrates (750 g kg^{-1} coarsely rolled barley, 170 g kg^{-1} soya bean meal, 55 g kg^{-1} molasses, 25 g kg^{-1} mineral/ vitamin premix) were offered up to a maximum of 2 kg per head daily and hay was available *ad libitum* until turn–out to pasture on May 29. Concentrate feeding continued at 1 kg per head daily for 4 weeks after turn-out. At pasture the calves were treated with ivermectin by subcutaneous injection (Qualimec, Janssen Animal Health) at 3, 8 and 13 weeks after turn–out for the control of gastrointestinal parasites.

On September 26 the animals were blocked on live weight within breed type taking account of sire. They were assigned within blocks to four treatment groups (n = 10) representative of the range in Irish beef production systems (bulls or steers, Light (570 kg) or Heavy (640kg) target slaughter weight). Thus, 120 cattle were selected for the study. The animals assigned as steers were castrated immediately and all animals continued to graze together until housing for the first winter on October 20. From castration to first housing, a supplement of 1 kg concentrate (875 g kg^{-1} rolled barley, 65 g kg^{-1} soya bean meal, 45 g kg^{-1} molasses, 15 g kg^{-1} mineral / vitamin premix) was offered at pasture. The duration of the first grazing season was 144 days.

During the first winter the bulls and steers were housed separately in two slatted floor sheds and offered grass silage (chemical composition: dry matter (DM) 204 g kg^{-1}, in vitro DM digestibility (DMD) 692 g kg^{-1}, crude protein (CP) 133 g kg DM^{-1}, ash 99 g kg DM^{-1} pH 3.9, Unite Fourragere Viande 0.77), *ad libitum* plus 1.5 kg concentrate per head daily until January 20 when the concentrates were withdrawn for the remainder of the indoor period.

The animals were turned out to pasture on April 14 and grazed to a stubble height of 5.5 cm. Due to adverse weather conditions, the bulls were housed on August 25 while the steers remained at pasture until November 4. The bulls were accommodated by breed type in two pens of 7 and one pen of 6 animals, i.e 20 bulls per breed type. Steers were accommodated in two pens of 8 and one pen of 4 per breed type in a slatted floor shed and both genders were offered a total mixed ration ad libitum of grass silage and the above concentrate, with the proportion of concentrate gradually increasing over a three week period to 0.67 of total dietary DM. Thereafter, this ration remained constant until slaughter. Bulls reaching the target light and heavy slaughter weight were slaughtered on January 26 and March 16, 2010, respectively, while steers reaching those nominal weights were slaughtered on February 16 (light) and May 11, 2010 (heavy).

Tissue collection and analysis

On each of the four dates animals were transported 150 km by truck to a commercial slaughter facility (Meadow Meats Rathdowney, Co. Laois, Ireland) and slaughtered within 1.5 hour of arrival. Carcass conformation and fat classes (Commission of the European Communities 1982) were recorded on a continuous 15 -point scale using a video imaging analysis (VIA) carcass classification machine (vbs2000, E + Vi Germany). At 48 hours *post mortem*, a section of the subcutaneous adipose tissue (7.5 x 7.5 cm) was removed close to the 10^{th} rib. The cube roll was then removed for dissection as described by McNamee et al. (2015). Starting at the 10^{th} rib three samples of *longissimus thoracis et lumborum* (LT) muscle 2.5 cm thick were collected. Muscle and fat samples were vacuum packaged and transported to Teagasc, Food Research Centre Ashtown, Dublin. Fat colour was measured on the evening the samples were taken. The Hunter 'L', 'a' and 'b' values were measured on the external surface of each sample of the subcutaneous fat using a Hunter Lab Ultra Scan XE colorimeter with Universal Software Version 2.2.2 (Hunter Associates Laboratory, Inc., Reston, VA, USA). The spectrocolorimeter was used in reflectance mode and standardised using a white tile and light trap. Diffuse illumination ($D_{65,}$ 10˚) with an 8˚ viewing angle was used with a 25 mm port size and specular component excluded. All measurements were made in the Hunter Lab colour space. Hue and saturation were calculated as $\tan^{-1}(b^*/a^*)$ and $\sqrt{(a^{*2} + b^{*2})}$, respectively. Final conversion of hue from radians to degrees was achieved by multiplying $\tan^{-1}(b^*/a^*)$ by $180/\pi$.

One steak was stored at −18^{0}C for subsequent compositional analysis, one steak was aged at 4^{0}C for 14 days and then stored at −18^{0}C for subsequent Warner Bratzler Shear Force (WBSF) and cook loss measurement and one steak was stored overnight at 2^0 C and colour measured at 72 h post-mortem. Each sample was over–wrapped with oxygen–permeable film and permitted to bloom for 2 h at 4 ^{0}C. The Hunter 'L', 'a' and 'b' values of three non-overlapping zones of each sample were then measured using the Hunter lab Ultra Scan XE colorimeter described above and an average value calculated as the final reading. Reflectance spectra were recorded and used to estimate pigment proportions according to Krzywicki (1979).

The pH of the LT muscle was measured prior to the colour measurement, by making a scalpel incision 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, USA) approximately 2.5 cm into the muscle.

Upon thawing, steaks were homogenised using an Ultra-turrax T25 homogeniser (IKA Labortechnik, Staufen, Germany). Intra-muscular fat and moisture concentration of thawed minced LT samples was determined using an automated, integrated microwave moisture and methylene chloride fat extraction method (Bostian et al. 1985) on a CEM moisture/solids analyser (Model AVC 80, CEM Corp., Matthews, NC, USA). Protein was determined by the method of Sweeney and Rexroad (1987) using a LECO protein analyser (LECO FP 428, LECO Corp., St. Joseph, MI, USA). Approximately 2 g of homogenised LT was used to measure total haem pigments according to the method of Krzywicki (1982).

Warner-Bratzler shear force was measured according to the procedure of Wheeler et al. (1996). Thus, frozen vacuum-packed steaks were thawed in a circulating water bath at 10–15^{0}C and allowed to equilibrate to ambient temperature. Steaks were cooked in retortable vacuum pack bags to an internal temperature of 70^{0}C, by immersing in a water bath (Model Y38, Grant Instruments Ltd.) at 72^{0}C. The internal temperature of the steaks was measured using a Hanna Foodcare digital thermometer (HI 9041, Hanna Instruments Ltd., Bedfordshire, UK). Eight cores (1.25 cm diameter) were cut from the steaks parallel to the direction of the muscle fibres and sheared using an Instron Universal testing machine equipped with a triangular Warner-Bratzler shearing device attached to an Instron Universal testing machine (Model 5543 Instron (UK) Ltd., High Wycombe, UK), using a 500N load cell at a crosshead speed of 5 cm min^{-1}. Instron Series 1X Automated Materials Testing System software for Windows (Instron Corportation, High Wycombe, Bucks, UK) was employed in the analysis. Cook loss was determined by weight prior to cooking and weight after cooking expressed as a percentage.

Statistical Analysis

Data were analysed according to a split plot design using GenStat Release 12.1. (Copyright 1995, Lawes Agriculture Trust, Rothamsted Agriculture Experimental Station, UK) with block and genotype as the main plot and gender, slaughter date and all related interactions contained in the sub-plot. Adipose tissue colour data were also re-analysed using this model but including fat classification as an index of carcass fatness as a covariate. Muscle colour data were also re-analysed using the above model but including muscle lipid concentration as a covariate.

Results

Unless otherwise stated, there were no significant interactions between main effects. At the beginning of the study, the HF animals were on average 15 days older than the NR-sired animals which were 3 days younger than the JE-sired animals (McNamee et al. 2015). Consequently, the HF animals tended to be older than the other breeds at each slaughter point (Table 1). The mean age at slaughter ranged from 23 months for the light NR bulls to 27 months for the heavy JE steers.

Carcass characteristics

Weight and classification

Carcass-related data are presented in Table 1. Holstein-Friesian cattle had heavier (p<0.01) carcasses than NR which in turn were heavier than JE, the heavy slaughter group had heavier (p<0.01) carcasses than their lighter counterparts and bulls had heavier (p<0.01) carcasses than steers. Carcass fat classification was lowest (p<0.05) for JE followed by HF and NR, was lower (p<0.001) for bulls compared to steers and for the light slaughter group compared to the heavy slaughter group.

Table 1. Carcass characteristics of Holstein-Friesian (HF), Norwegian Red x Holstein Friesian (NR) and Jersey x Holstein-Friesian (JE) cattle slaughtered at two liveweights as bulls or steers.

Variable	HF				NR				JE				SED	Significance[a]
	Bulls		Steers		Bulls		Steers		Bulls		Steers			
	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy		
Number of animals	10	10	10	10	10	10	10	10	10	10	10	10		
Slaughter weight (kg)	607.3	658.8	578.2	661.8	590.3	646.9	555.0	653.2	538.0	605.6	523.6	589.2	10.16	B*,G*,S*,G×S*
Age (days)	718	768	740	820	702	745	725	813	711	757	720	811	4.8	B*,G*,S*,B×G*, G×S*
Carcass (kg)	301.3	336.5	283.9	325.5	300.0	330.3	273.3	322.6	270.2	305.2	247.0	280.0	6.79	B***,G***, S***
Fat class[b]	7.26	7.90	8.60	9.70	7.03	8.48	8.20	10.20	6.67	7.01	7.60	9.30	0.554	B*,G***, S***
Adipose tissue colour[c]														
Lightness	64.53	59.96	61.18	61.82	63.93	64.00	61.86	63.00	62.78	62.50	62.01	61.28	1.216	G*, G×S*, B×G×S*
Redness	10.08	10.58	11.98	11.38	9.80	9.84	10.45	10.42	11.57	10.12	11.12	11.58	0.729	B (0.053), G**
Yellowness	16.45	16.46	17.58	18.33	16.56	16.51	16.18	18.26	17.58	16.62	17.16	19.77	0.615	B*,G***,S**, G×S***
Hue	58.83	57.15	55.74	58.17	59.56	59.30	57.32	60.31	56.95	58.93	57.14	59.72	1.703	S*, G×S*
Chroma	19.34	19.64	21.33	21.60	19.27	19.26	19.33	21.05	21.08	19.50	20.48	22.93	0.744	B**,G***, G×S**, B×G×S*
Adipose tissue colour[c,d]														
Lightness	64.50	59.94	61.16	61.81	63.89	63.98	61.83	62.99	62.81	62.53	62.05	61.34	1.326	G(0.06), G×S*, B×G×S*
Redness	10.54	10.79	11.90	10.85	10.41	9.86	10.58	9.74	11.93	10.35	11.11	10.87	0.765	S*
Yellowness	16.62	16.51	17.49	18.03	16.77	16.45	16.17	17.87	17.87	16.86	17.28	19.56	0.659	B*,G* (0.06), G×S*
Hue	57.96	56.72	55.80	58.99	58.40	59.14	56.96	61.33	56.55	58.76	57.37	61.13	1.817	S*, G×S*
Chroma	19.73	19.79	21.21	21.07	19.78	19.22	19.39	20.35	21.52	19.81	20.57	22.37	0.783	B*,G*, (0.06), G×S*, B×G×S*

[a]*$p < 0.05$, **$p < 0.01$, *** $p < 0.001$, B: breed; G: gender; S: slaughter weight.
[b]EU Beef Carcass Classification Scheme, scale 1 (leanest) to 15 (fattest).
[c]Lightness, scale 0 (black) to 100 (white); Redness, scale + 'a' (red) to – 'a' (green); 'b': Yellowness, scale +'b' (yellow) to – 'b' (blue); Hue = $\{\tan^{-1}(b/a)\}\{180 / 3.14\}$, Chroma / saturation / colour intensity = $\sqrt{a^2 + b^2}$.
[d]Adjusted for differences in fatness classification score.

Adipose tissue colour

There was a breed x gender × slaughter weight interaction (p<0.01) with respect to lightness (*'L')* of adipose tissue. Thus, adipose tissue from HF bulls slaughtered at the heavy weight had a lower "L" value compared with that from NR or JE bulls but there was no effect of breed for bulls slaughtered at the lighter weight or no effect of breed on the "L" value for steers slaughtered at either weight. Adipose tissue redness ('a') tended (p=0.053) to be lower for NR than JE and HF which did not differ, and for bulls compared to steers (p<0.01). Adipose tissue from JE was more yellow (higher 'b' value) (p<0.01) than that from NR and HF which did not differ. There was a gender × slaughter weight interaction with respect to the 'b' value of adipose tissue (p<0.001). Thus, steers from the heavy slaughter group had a higher (p<0.05) 'b' value compared to bulls but there was no difference between bulls and steers at the lighter slaughter weight. There was a gender × slaughter weight interaction with respect to adipose tissue "H" value. Thus steers from the lighter slaughter group had a lower "H" value compared to bulls but there was no difference between bulls and steers at the heavy slaughter weight. There was a breed × gender × slaughter weight interaction (p<0.01) with respect to adipose tissue "C" value. Thus, JE bulls slaughtered at the lighter weight had a higher "C" value (p<0.05) than the other breeds, NR steers slaughtered at the lighter weight had a lower "C" value (p<0.05) than HF and JE steers which did not differ, JE steers slaughtered at the heavy weight had a higher 'C' value than NR steers but did not differ from HF steers.

When adipose tissue colour data were adjusted for differences in fat classification, there was little effect on the 'L' value; the difference between breeds and genders in the 'a' value was removed but animals slaughtered at the heavier weight had a higher value; the difference between breeds and the interaction between gender and slaughter weight remained for the 'b' value but the effect of slaughter weight was removed and the effect of gender reduced (p=0.06); there was no effect on the 'H' value; other than a decrease in the significance of the effect of gender (p=0.06), there was no effect on the "C" value.

Muscle characteristics

Chemical composition

There was a gender × slaughter weight interaction with respect to lipid concentration (p<0.01). Thus, LT from bulls had a lower (p<0.05) lipid concentration than LT from steers but the difference was greater at the heavy slaughter weight. The converse was observed for moisture concentrations in LT. Muscle from steers had a higher (p<0.001) protein concentration than LT from bulls.

Shear force and cook loss

Shear force was higher (p<0.001) in LT from bulls than in LT from steers and in LT from animals slaughtered at the lighter weight than in LT from animals slaughtered at the heavy weight. When WBSF data were adjusted for differences in lipid concentration, only the difference between genders remained.

There was a gender × slaughter weight interaction (p<0.05) with respect to cook loss. Thus LT from steers had lower (p<0.001) cook loss than LT from bulls but the difference was greater at the heavy slaughter weight. Adjustment of cook loss data for differences in lipid concentration had a small effect (reduction in significance) on this interaction.

Colour and pH

There was a gender × slaughter weight interaction (p<0.05) with respect to the 'L' value of LT. Thus, LT from steers and bulls had a similar 'L' value at the lighter slaughter weight but the 'L' value of LT from steers was higher than the LT from bulls slaughtered at the heavier weight. The 'a' value was higher (p<0.05) in LT from steers than in LT from bulls and in LT from animals slaughtered at the heavier weight than in LT from animals slaughtered at the lighter weight. The "b" value was higher (p<0.001) in LT from steers than in LT from bulls. The "C" value was higher (p<0.001) in LT from steers than in LT from bulls and in LT from animals slaughtered at the heavier weight than in LT from animals slaughtered at the lighter weight. Neither the 'H' value nor the ultimate pH of LT was affected by the treatments examined.

When adjusted for differences in lipid concentration, the gender × slaughter weight interaction for the 'L' value of LT was removed; NR animals had a lower (p=0.058) 'a' value than the other breeds and bulls tended (p=0.061) to have a lower 'a' value than steers; the effect of gender on LT 'b' value was removed; JE animals had a lower (p<0.05) 'H' value than the other breeds and animals slaughtered at the lighter weight had a higher (p<0.05) 'H' value than animals slaughtered at the heavier weight; the effect of slaughter weight on LT 'C' value was removed and steers tended (p=0.065) to have a higher 'C' value than bulls.

Table 2. Chemical composition, shear force, cook loss and colour of *longissimus thoracis et lumborum* muscle from Holstein-Friesian (HF), Norwegian Red x Holstein Friesian (NR) and Jersey x Holstein-Friesian (JE) cattle slaughtered at two liveweights as bulls or steers.

Variable	HF				NR				JE				SED	Significance[a]
	Bulls		Steers		Bulls		Steers		Bulls		Steers			
	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy		
Number of animals	10	10	10	10	10	10	10	10	10	10	10	10		
Composition (g kg^{-1})														
Lipid	20	32	34	75	28	35	44	75	19	31	58	78	10.1	G***,S *** G×S**
Moisture	750	742	732	700	739	738	722	703	744	743	710	698	83.2	G*** , S *** G×S**
Protein	208	209	216	217	210	212	218	219	214	213	216	218	38.1	G ***
Cook Loss (g kg^{-1})	302.6	308.8	298.1	251.4	301.1	291.3	284.0	257.5	321.6	315.2	727.8	262.3	14.17	G**, S*, G×S*
Cook Loss[b]	295.8	304.2	293.9	255.0	298.9	290.3	284.8	264.2	318.2	314.1	281.9	270.2	14.45	G**, G×S (0.065)
Shear Force (N)	31.27	32.82	30.51	22.03	36.16	34.52	25.87	25.52	33.95	29.67	24.46	20.11	3.664	G*** ,S*
Shear Force[b]	28.86	31.21	29.04	23.35	35.37	34.15	26.16	27.93	32.72	29.27	25.89	22.94	3.554	G*
Colour[c]														
Lightness	36.68	35.48	36.50	37.86	36.05	35.95	36.26	37.65	35.34	34.92	36.62	36.34	0.825	G*** , G×S*
Redness	14.33	14.22	14.93	15.74	13.07	14.22	14.36	15.56	14.05	14.75	15.23	15.35	0.653	G*** ,S*
Yellowness	8.43	8.21	8.71	9.40	7.93	8.29	8.48	9.30	8.02	8.30	8.91	8.623	0.434	G***
Hue	30.49	30.15	30.23	30.84	31.11	30.16	30.56	30.89	29.76	29.31	30.38	29.38	0.683	NS
Chroma	16.63	16.42	17.28	18.34	15.30	16.47	16.68	18.14	16.18	16.92	17.65	17.61	0.757	G***, S*
Colour[c]														
Lightness[b]	37.32	35.84	36.81	37.20	36.40	36.15	36.23	36.89	35.90	35.19	36.25	35.48	0.827	NS
Redness[b]	14.59	14.38	15.07	15.56	13.17	14.27	14.33	15.29	14.20	14.81	15.08	15.04	0.683	B (0.058), G (0.061)
Yellowness[b]	8.71	8.38	8.86	9.18	8.05	8.35	8.46	9.00	8.21	8.38	8.75	8.28	0.437	NS
Hue[b]	30.84	30.35	30.40	30.50	31.29	30.27	30.54	30.48	30.05	29.45	30.18	28.91	0.715	B*, S*
Chroma[b]	16.99	16.65	17.49	18.08	15.44	16.54	16.64	17.75	16.41	17.02	17.43	17.16	0.781	G (p=0.065)
pH	5.58	5.61	5.62	5.58	5.63	5.56	5.61	5.60	5.59	5.56	5.58	5.61	0.021	NS

[a]*p< 0.05, **p < 0.01, *** p <0.001, B: breed; G: gender; S: slaughter weight.
[b]Adjusted for differences in lipid concentration
[c]Lightness, scale 0 (black) to 100 (white); Redness, scale + 'a' (red) to – 'a' (green); 'b': Yellowness, scale + 'b' (yellow) to – 'b' (blue); Hue = {tan $^{-1}$(b/a)}{180 / 3.14} : Chroma / saturation / colour intensity = $\sqrt{a^2 + b^2}$

Muscle pigments and reflectance

Total haem pigment concentration was higher ($p<0.001$) in LT from steers than in LT from bulls and in LT from animals slaughtered at the lighter weight than in LT from animals slaughtered at the heavier weight. Adjustment for differences in lipid concentration did not affect these findings.

The proportion of metmyoglobin was higher and the proportion of myoglobin was lower ($p<0.05$) in LT from JE than in HF and NR which did not differ. The proportion of myoglobin was higher ($p<0.001$) and the proportion of oxymyoglobin was lower in LT from bulls than in LT from steers. When adjusted for differences in lipid concentration, the proportion of metmyoglobin was higher ($p<0.05$) in LT from JE than in HF and NR which did not differ; the proportion of myoglobin was higher ($p<0.001$) and the proportion of oxymyoglobin was lower ($p<0.001$) in LT from bulls than in LT from steers; there was a breed × slaughter weight interaction for the proportion of myoglobin such that LT from NR animals had a higher proportion at the lighter slaughter weight than the other breeds which did not differ while LT from JE animals had a lower proportion at the heavier slaughter weight than HF animals but similar to NR animals; there was a breed × slaughter weight interaction for the proportion of oxymyoglobin such that NR animals had a lower proportion at the lighter slaughter weight than the other breeds which did not differ but there was no difference at the heavier slaughter weight.

Discussion

The focus of the discussion is on the comparison of sire breeds within the production variants examined i.e. interactions between sire breed and slaughter weight/age within steer or bull production systems. Since there is a considerable body of literature on the effects of slaughter weights *per se* and on comparisons of bulls and steers with respect to the meat quality variables examined, in terms of these effects and their interactions, the discussion will only highlight inconsistencies and/or novel findings in the present study.

Sire breed effects

Norwegian Red

The authors are not aware of comparative data for adipose tissue colour of NR animals but in the present study there was no difference between the HF and NR. Similar to the present study, cook loss was not different between muscle from HF compared to NR×HF steers (Lively et al. 2004) or between muscle from HF compared to pure NR bulls (Kirkland et al. 2007). Tenderness is considered to be a major factor of importance in meat quality by consumers (Miller et al. 2001) and was measured instrumentally as WBSF in this study. In the study of Lively et al. (2004) ageing for 21 days post-mortem resulted in a higher WBSF for HF compared to NR×HF steers which seems to be related to the tendency for a higher marbling score in the NR×HF steers (Keady et al. 2004). This was seen in Cycle V1 of the US Germplasm Evaluation program (Wheeler et al. 2004) whereby LT from NR-sired steers had a higher marbling score and a lower WBSF than Friesian-sired steers. A similar numerical but non-significant trend was seen for the light steers in the present study. However, for the heavy steers which had a similar intramuscular lipid concentration, the numerical trend was for the NR to have higher WBSF, an effect also seen by Kirkland et al. (2007) for pure NR bulls compared to pure HF bulls. From the few data available however, differences in WBSF, where they exist are small and unlikely to be of commercial importance (Miller et al. 2001).

The lack of difference between HF and NR sire breeds for muscle colour *per se* was consistent with the literature (Lively et al. 2004, Kirkland et al. 2007). Muscle pH was similar and within the normal range across all treatment groups indicating that pre-slaughter management did not result in excessive glycogen depletion. The lower redness ('a' value) in muscle from NR-sired animals may reflect the dual purpose nature of the breed since Dunne et al. (2004a) reported that muscle from Belgian Blue (beef breed)-sired cattle was less red than muscle from HF-sired cattle and hypothesised that this most likely reflected differences in muscle fibre distribution between the two breed types which was not measured in this study. However, this was only seen after adjustment for differences in lipid concentration in LT. Since many consumers prefer bright, attractive-coloured meat (Carpenter et al. 2001), the data indicate that substitution of NR for HF sires in the dairy herd will not have an important effect on this aspect of beef quality.

Table 3. Pigment composition of *longissimus thoracis et lumborum* muscle from Holstein-Friesian (HF), Norwegian Red x Holstein Friesian (NR) and Jersey x Holstein-Friesian (JE) cattle slaughtered at two liveweights as bulls or steers.

Variable	HF				NR				JE				SED	Significance[a]
	Bulls		Steers		Bulls		Steers		Bulls		Steers			
	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light	Heavy		
Number of Animals	10	10	10	10	10	10	10	10	10	10	10	10		
Haem pigments														
(mg g^{-1} muscle)	7.89	8.17	10.64	8.92	8.97	7.69	10.02	8.35	8.47	8.04	10.33	10.36	0.726	G***, S**
Oxy[b]	65.0	63.3	67.5	69.1	62.8	65.7	66.3	69.5	64.5	65.0	68.9	68.3	1.52	G***
Met[b]	22.2	22.1	22.3	21.5	22.0	21.9	22.8	21.8	22.5	22.8	23.3	24.0	0.65	B*
Myo[b]	12.9	14.7	10.2	9.5	15.2	12.4	10.9	8.7	13.0	12.3	7.8	7.8	1.31	B*, G***
Haem pigments[c]	8.14	8.28	10.72	8.51	9.18	7.82	10.03	7.99	8.80	8.22	10.19	9.97	0.776	G***,S**
Oxy[b,c]	66.1	64.0	68.1	68.0	63.4	66.0	66.2	68.2	65.4	65.4	68.2	66.7	1.50	G*, B×S*
Met[b,c]	22.3	22.1	22.3	21.3	22.1	21.9	22.8	21.7	22.7	22.9	23.3	23.9	0.70	B*
Myo[b,c]	11.6	14.0	9.6	10.7	14.5	12.0	11.0	10.2	11.9	11.8	8.5	9.4	1.25	B*, G**, B×S*

[a]*$p < 0.05$, **$p < 0.01$, *** $p < 0.001$, B: breed; G: gender; S: slaughter weight.
[b]Oxymyoglobin, metmyoglobin and myoglobin, respectively (% of total haem pigment).
[c]Adjusted for differences in lipid concentration

Jersey

Of the colour coordinates, the 'b' value was considered the most relevant to evaluate differences in adipose tissue yellowness between treatments in this study, since this is most often used in the literature (Strachan et al. 1993) and depending on measurement site, the 'b' value can account for up to 79% of the variation in subjective fat yellowness (Knight et al. 1998). The chroma and hue values are also presented as they are claimed to represent subcutaneous adipose tissue more accurately, as it is perceived visually (Rigg 1987). The lightness component may also be relevant since reflectance of lipids and fluorescence of connective tissue, cell membranes and lipids contribute to appearance characteristics (Irie 2001) and thus, probably also to the subjective perception of 'whiteness' of adipose tissue.

The main breed-related finding with respect to meat quality that adipose tissue from JE-sired cattle was more yellow, is consistent with the literature on this topic (Morgan et al. 1969, Barton et al. 1994, Pitchford et al. 2002). For example, Barton and Pleasants (1993), in a survey over five consecutive years of a range of breeds, all raised on pasture and slaughtered at 30 months, found that beef breeds had more carcasses with white fat than dairy breeds and the Jersey had more carcasses with yellow fat than all other breeds. Support for such a breed-specific tendency was provided by Knight et al. (1994), who reported a greater rise in plasma carotenoids of Jersey than of Angus heifers upon return to pasture after feeding of a low carotenoid ration. This indicates a greater quantity of carotenoids being transported to adipose tissue in the Jersey breed. Kruk et al. (1998) reported that pure Jersey cows had higher b-carotene concentrations in their subcutaneous adipose tissue than either Jersey × Limousin or pure Limousin cows and produced more yellow adipose tissue, assessed subjectively, as a result. Kruk et al. (1998) concluded that a major gene(s) was involved in accumulation of b-carotene in fat and resultant yellow colour. Carotenoids were supplied in the diet in the present study since all animals received grass silage on an *ad libitum* basis and grazed pasture also. A predisposition to accumulate carotenoids in fat might derive from higher expression of genes of the yellow fat allele proposed by Kruk et al. (1998).

Examining the effect of carcass fatness *per se* was considered necessary since, at equivalent age, the JE animals had lower carcass weight and associated fatness compared to HR and NR. Since, adipose tissue carotenoids are distributed in adipocytes, any tissue accretion due to an accumulation of triacylglycerols would be expected to 'dilute' carotenoids, thus rendering the adipose tissue less yellow in fatter carcasses (Knight et al. 2001). "Yellow" subcutaneous fat generally renders such carcasses unacceptable for markets with a "white" fat requirement and grass silage as a source of carotenoids is frequently precluded from the diet of cattle targeted at such markets (Dunne et al. 2004b, Moloney and Drennan 2013). Using JE sires would likely exacerbate that situation.

In contrast to Purchas and Barton (1976), the intramuscular lipid concentration of JE animals was not different from that of HF animals which may have contributed to the lack of difference in WBSF. While there is some evidence in the literature that JE animals have more tender muscle than other breeds, these studies either compared JE with beef breeds (Koch et al. 1976, Morris et al. 2001) or breed was confounded with production location (Christensen et al. 2011). Where pure Holstein and JE steers were compared, the JE was rated higher for sensory tenderness (Cole et al. 1964 (no difference in WBSF), Bond et al. 1972 (Trial 2 only)). We are not aware of studies that directly compared JE sires with other dairy sires crossed with dairy dams.

Barton and Pleasants (1993) reported that "Friesians have been known to produce more dark red coloured meat compared to other dairy breeds". However there was no difference in colour between muscle for HF and JE in the present study. Similarly, there is little evidence in the literature of muscle colour differences between HF and JE crossbreds (Burke et al. 1998, Purchas and Morris 2007). That muscle Hue (or saturation) was lower for JE after adjustment for differences in intramuscular lipid concentration suggests that there may be a difference between breeds in muscle structure that influences colour perception or that the different oxidation states of muscle pigments between HF and JE that were detectable instrumentally were masked by the non-significant differences in intramuscular lipid concentration. The higher proportion of metmyoglobin (brown pigment) in muscle from JE is indicative of a higher degree of oxidation which is associated with meat discoloration (Suman and Joseph 2013). This suggests a shorter shelf-life for muscle and muscle products for JE and merits further study.

Gender, slaughter weight/age and their interaction

The higher proportions of protein and lipid in steers compared to bulls agree with the finding of Dunne et al. (2004a) in a similar type of study. Similarly the relatively greater increase in intramuscular lipid concentration with increasing weight in steers compared to bulls is consistent with Dunne et al. (2004a) and likely reflects the early maturity of the testosterone-deficient steers.

In a review of the literature, Matthews (2011) concluded that "the balance of published evidence indicates that the eating quality of bull beef is poorer than that of steers of the same age particularly in terms of tenderness". The WBSF data in the present study support this conclusion. An explanation frequently advanced for differences in muscle tenderness is differences in intramuscular fat content (see above). Thus the apparent increase in tenderness (decrease in WBSF) with increasing age in the present study is consistent with Lively et al. (2005). The removal of this difference in WBSF by adjusting for differences in intramuscular fat concentration supports this view, and likely explains some of the variation in the literature, particularly when the age range within studies is narrow (Matthews 2011). In contrast, that adjustment for intramuscular fat content in the present study did not remove the gender difference indicates that other characteristics such as muscle fibre size/type, connective tissue type and concentration, etc. are more likely explanations in this case.

The interaction for the "b" value of adipose tissue likely reflects the confounding effects of the experimental design. Thus, to achieve the similar target carcass weight for heavy bulls and steers, the steers were maintained on a grass silage-based ration for a further 2 months. The additional consumption of carotenoids in the heavy steers compared to the heavy bulls likely resulted in the greater yellowness, as described above (Dunne et al. 2009). In addition, since heavy steers were older than heavy bulls, this age difference *per se* may also have contributed to the greater yellowness in adipose tissue from the older animals (Walker et al. 1990).

The interaction between gender and age at slaughter for the 'L' value of LT muscle (only for the heavy slaughter weight was LT from bulls darker (lower 'L' value) than LT from steers) was also seen by Dunne et al. (2004a). Since ultimate pH of LT muscle did not differ between genders, greater pre-slaughter stress in the bulls which would give rise to higher pH (Tarrant 1989) was not responsible for this observation. This is supported by the removal of this interaction by adjustment for intramuscular lipid concentration. Meat colour depends on the amount and type of pigment present and the light-scattering properties of the meat (Lawrie 2006). The greater redness and intensity of colour (saturation) of LT from the heavier animals aggrees with Kirkland et al. (2005, 2006), but disagrees with Keane and Allen (1998) and with Weglarz (2010) who saw no effect on LT redness when pre-slaughter live weight increased from 640 to 720 and from 550 to 650 kg, respectively. An increase in redness would be expected to reflect an increase in the pigment content with age (Lawrie 2006). However, haem pigment concentration did not increase with age in the present study (in contrast to Dunne et al. 2004a) and there was no correlation between LT redness and pigment concentration (data not shown). That the effect of slaughter weight on redness and intensity of colour was removed by adjustment for differences in intramuscular lipid concentration highlights the role of muscle fatness *per se* on muscle colour, particularly when examining the effect of age at slaughter.

With respect to gender, the higher colour intensity (and redness) and pigment concentrations in LT from steers are consistent with Dunne et al. (2014a) and Dawson and Moss (2009). The latter authors considered that these characteristics made steer beef more desirable from a consumer perspective. The proportion of oxymyoglobin in LT from steers was higher than in LT from bulls and was positively correlated ($r = 0.82$, $p < 0001$) with redness indicating the importance of the oxidation state of muscle in colour development. The development of the bright red colour is related to the oxygen consumption rate at the cut surface (Dunne et al. 2011). A high rate of oxygen consumption can result in less oxygen being available to oxygenate myogblobin. Since bloom time was similar for steers and bulls in the present study, the data suggest a higher rate of oxygen consumption in LT from the bulls, despite a similar pH and may be related to a difference in the underlying structure and/or biochemistry of bull and steer LT. This observation also merits further study.

Conclusion

The predominant differences between HF, NR and JE sired cattle relate to production variables and these will be the main influence on the selection choices of the beef- farmer. With respect to beef quality from a consumer perspective, there were relatively few differences between sire breeds within steer or bull production systems likely to be of commercial significance. The more yellow carcasses from JE-sired cattle should be considered if such carcasses are destined for a market with a particular carcass fat colour specification.

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