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Effect of a grazing period prior to finishing on a high concentrate diet on meat quality from bulls and steers.

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Abstract

Bulls and steers (n=60) were assigned to a pre-finishing grazing period and subsequently finished on concentrates or offered concentrates without grazing until slaughter (19 months). Colour and pH of *longissimus thoracis* were measured (48 hours post-slaughter), and samples collected for proximate composition, collagen, sarcomere length, muscle fibre and enzymatic profile analysis. Steaks for texture, cook loss and sensory were aged (14 days). Castration increased intramuscular fat content, cook loss and myosin isoforms IIa and I proportions, and decreased IIx proportion ($P<0.05$). Steer meat was positively correlated to overall tenderness, texture and acceptability ($P<0.05$). The presence of a pre-finishing grazing period decreased intramuscular fat and increased the proportion of IIa compared with animals on concentrates, while no differences were found in sensory. Muscle colour, collagen, sarcomere length and instrumental texture were not modified by diet or castration. In conclusion, beef sensory characteristics were unaffected by diet, whereas castration resulted in a small improvement; however all the treatments produced an acceptable product.

Keywords: castration, grazing period, tenderness, muscle fibre profile.

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1. Introduction

Male beef production in Ireland is typically based on steers grazing at pasture in summer and then housed and offered grass silage and supplementary cereal concentrates during the winter with slaughter at 24 months of age or greater (Drennan & McGee, 2009). Current production systems for bulls generally entail a post-weaning indoor finishing period on *ad libitum* concentrates (Drennan & Fallon, 1998) or high digestibility grass silage plus supplementary concentrates, and slaughter between 12 and 16 months of age with insufficient carcass fat cover being the primary market limitation.. However numerous studies highlight the advantages, in terms of growth rate and feed efficiency of using bulls in comparison with steers for beef production (Jones, Price, Berg, & Hardin, 1981; O'Riordan, Crosson, & McGee, 2011). To exploit these biological advantages, while increasing the profitability of bull production there is interest in the inclusion of a grazing period in order to decrease the cost of production (O'Riordan & O'Kiely, 1996), as feedstuff provision accounts for a major proportion of total costs in most cattle production systems and grazed grass is the cheapest feedstuff in temperate climates (Finneran et al., 2011).

Consequently, the most suitable alternative is the use of older animals. For seasonal, spring-calving grass-based systems, bulls must be slaughtered prior to the indoor winter period for the main herd (October/November), due to housing facility constraints; this corresponds to an age of approximately 19 months. The use of this novel less intensive, forage-based system for older animals seems to be a suitable option for bull production in terms of performance and profitability.

However, as 90% of Irish beef is exported within higher value EU markets a key challenge is to maintain Ireland's premium position within these outlets. Meat quality is influenced by multiple interacting factors including castration and diet (Wood et al., 1999), and the effect of a change in these factors within a beef production system should be careful analysed. Some authors have reported lower tenderness, juiciness (Chrystall, 1994) and flavour (Melton, 1990) in meat from cattle finished on forages compared with intensive grain-fed systems, however beef from forage-fed cattle has been found to be as acceptable as that from grain-fed cattle after the inclusion of a short-length grain based finishing period (Cerdeño, Vieira, Serrano, Lavín, & Mantecón, 2006; Vestergaard, Therkildsen, et al., 2000). Similarly, several studies indicate that

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beef from steers is more tender than beef from bulls, however in many studies comparisons were made at a similar weight at slaughter instead of similar age (Jones, Harries, Robertson, & Akers, 1964). Other studies, however, report only slight differences between castrated and entire animals, and not of a scale that would influence the acceptability of beef by the untrained consumer (Morgan, Wheeler, Koohmaraie, Savell, & Crouse, 1993; Wierbicki, Cahill, Kunkle, & Deatherage, 1953). Finally, bull meat has been reported to be leaner than steer beef (Fritsche & Steinhart, 1998; Kang, Lee, & Lee, 2009), thus meeting increasing consumer demands for quality lean meat (Van Wezemael, Caputo, Nayga Jr, Chryssochoidis, & Verbeke, 2014).

Within this context, the objective of the present study was to assess meat quality characteristics and sensory acceptability from 19 month old suckler bulls and steers, from contrasting production systems, a conventional indoor concentrate system and a modified lower cost system that included a pre-finishing grazing period.

2. Material and methods

2.1 Animals and diets

Spring-born late-maturing breed (Limousin and Charolais) sired suckler male cattle (n=60) ca. 8 months old (369 kg live weight, s.d 27.3 kg), were balanced within breed, weight and age and randomly assigned to one of four treatment groups in a 2 (steer or bull) × 2 production systems differing in the pre-finishing diet factorial arrangement of treatments. All animals were accommodated in replicated pens or batch (3 pens per treatment, 5 animals per pen) and this distribution of animals was maintained throughout the experiment. The castration of the animals (n=30) was undertaken at 9 months of age, two weeks before the start of the trial.

In winter, the animals were maintained indoors and offered a moderate nutritive value grass silage (dry matter (DM) digestibility (DMD) 688 g/kg) *ad libitum* plus 3 kg concentrate (862 g/kg rolled barley, 60 g/kg soya bean meal, 50 g/kg molasses and 28 g/kg minerals / vitamins).

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At the end of the winter, half of the animals were turned-out to rotationally graze on a perennial ryegrass dominant sward (GC), while the other half stayed indoors and were offered a barley-based concentrate (same formulation as above) plus grass silage (DMD 677 g/kg) *ad libitum* (CC), for 98 days. All groups were then housed and finished on a barley-based concentrate diet (same formulation and allowance as above) for 76 days. Slaughter was undertaken in 3 balanced groups (n=20) on 3 consecutive weeks at an average age of ~19 months. Specific details about the production system are described in McMenamin et al. (2015). The study was carried out under license from the Irish Government Department of Health and Children and all procedures used complied with national regulations concerning experimentation on farm animals.

2.2 Slaughter, sampling procedures, pH and colour.

On the day of slaughter the animals were transported approximately 30 km to a commercial slaughter plant and slaughtered immediately after arrival by bolt stunning followed by exsanguination from the jugular vein. Electrical stimulation was not applied and carcasses were hanged by the Achilles tendon. The slaughter and dressing procedures were in accordance with the Regulations (EC) No.1009/2009 and No. 853/2004. Approximately 30 minutes after slaughter, carcasses were placed in a chill set at 9°C and ambient temperature was monitored (1h = 11.5°C, 3h = 12.57°C, 6h = 11.3°C). After approximately 10 h the chill temperature was reduced to 0°C.

The pH and temperature of the *longissimus thoracis* muscle (LT) at the 10^{th} rib were recorded in the left side carcass at 1h, 3h 6h and 48h post mortem, with a portable pH meter with temperature compensation (Model WP-80 (pH/ORP/T meter), TPS Pty, Ltd. Springwood, Queens land, Australia.) and a glass pH probe (Glass electrode: model EC-2010-06, Refex Sensors Ltd. Westport, Ireland.) using a scalpel incision for each measurement as described by Pearce et al. (2010). The pH meter was (re)calibrated at ambient temperature intermittently throughout each measurement period. Within the first hour post-mortem, two samples (5g) of the LT were collected at the 9^{th} rib, immediately frozen in liquid N_2, and maintained on dry ice until storage at -80°C for muscle fibre and enzymatic analysis.

ACCEPTED MANUSCRIPT

After approximately 48 h in the chill carcasses were moved to the deboning hall (4°C) and subcutaneous fat colour was measured at two different locations (rib and rump) to give a more representative estimate of the overall subcutaneous fat colour across the carcass, while colour of the LT was measured at the $5^{th}/6^{th}$ rib interface, 1h after cutting and exposure to oxygen. In both cases, colour was measured as Hunter lab values using a portable spectrophotometer (Miniscan EZ, HunterLab, Reston, Virginia, USA). The cube roll (CR; commercial cut that begins between the 5^{th} and 6^{th} rib and ends between the 10^{th} and 11^{th} rib) was then removed, vacuum packed and transported to Teagasc, Food Research Centre, Ashtown, Dublin. One steak, 2.5 cm thick, was stored at -20°C for composition, sarcomere length and collagen determination. The remainder of the CR was wet-aged for 12 additional days (4°C) to reach a total of 14 days of ageing (wet ageing is the normal ageing in the Irish beef industry), thereafter CR was sliced (2.5 cm thick steaks) for sensory evaluation, cook loss and instrumental texture analysis. All samples were then vacuum packed and frozen at −20°C for subsequent analysis.

2.3 Chemical composition, collagen and sarcomere length analysis

Steaks for proximate analysis, were thawed, trimmed of external fat and connective tissue, and the trimmed muscle was blended (R101, Robot Coupe SA, France). The intramuscular fat content (IF) of each sample was determined using a bench-top nuclear magnetic resonance (NMR) instrument (SMART Trac Fat Analyser; CEM Corporation, Matthews, NC, USA). Approximately 3.5 g of each sample were initially dried using the SMART Trac microwave drying oven and the moisture content of each sample was recorded. Afterwards, the SMART Trac NMR system utilizes NMR and directly measures fat content utilizing the signal-to-mass ratio. Each sample was analysed in duplicate (AOAC, 2000b).

Protein was determined in duplicate using a LECO protein analyser based on the Dumas method (Model FP-428, Leco Corporation, St. Joseph, MI, USA) following AOAC (2000a). Soluble and insoluble collagen concentrations were calculated from the hydroxyproline concentration measured by the method of Kolar (1989) modified by Voutila, Mullen, Ruusunen, Troy, and Puolanne (2007). Sarcomere length was determined in triplicate samples by laser diffraction using the method described by Cross, West, and Dutson (1981).

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2.4 Metabolic enzyme activities and muscle fibre type proportions

Glycolytic enzyme activities [phosphofructokinase (PFK, EC 2.7.1.11), lactate dehydrogenase (LDH, EC 1.1.1.27)] and oxidative enzyme activities [isocitrate dehydrogenase (ICDH, EC 1.1.1.42), citrate synthase (CS, EC 4.1.3.7) and cytochrome c oxidase (COX, EC 1.9.3.1)] were quantified spectrophotometrically in LT samples using the methods described by Jurie, Ortigues-Marty, Picard, Micol, and Hocquette (2006). The PFK, LDH activities were measured by following the disappearance of nicotinamide adenine dinucleotide, reduced form (NADH) at 340 nm, and ICDH activity was measured by following the reduction of nicotinamide adenine dinucleotide phosphate (NADP) at 340 nm. PFK activity was determined according to Beutler (1971), LDH activity according to Ansay, Laurent, and Roupain (1974), and ICDH activity following Briand, Talmant, Briand, Monin, and Durand (1981). CS activity was determined by measuring the rate of initial reaction at 412 nm by means of the DTNB [5,5′-dithiobis-(2-nitrobenzoic acid)] method as described by Shepherd and Garland (1969). COX activity was determined according to Smith and Conrad (1956) with 20 μl of homogenate in 1 ml of a reaction mixture that contained 90 μM reduced cytochrome c as substrate and 50 mM potassium phosphate (pH 7.4). The oxidation of cytochrome C was measured spectrophotometrically at 550 nm. The velocity was calculated from $V = k \times [S]$, in which the first order constant k was determined in the assay and [S] was set at 90 μM. All enzyme activities were measured at 25°C, performed in duplicate and are expressed as micromoles of substrate converted per minute and per gram of protein (μmol min^{-1} g^{-1} of protein), with protein determined using a dye-binding method (Bradford, 1976).

Muscle fibre types were identified by separating myosin heavy chain (MyHC) isoforms (MyHC I, IIa, IIx and IIb) using high-resolution mini-gel electrophoresis as described by Picard, Barboiron, Chadeyron, and Jurie (2011).

2.5 Instrumental texture evaluation and sensory assessment

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Frozen vacuum-packed steaks were thawed in circulating water at 20°C. All external fat and connective tissue surrounding the muscle was removed, the steaks were conditioned for 15 minutes at 20°C before cooking for sensory and instrumental texture analysis. After the excess moisture was removed, the weight of the steaks was recorded. The steaks were subsequently cooked in vacuum pack bags to an internal temperature of 70°C, by immersing in a water bath (Model Y38, Grant Instruments Ltd. Royston, UK) at 72°C. The internal temperature of the steaks was measured using a digital thermometer (HI 904, Hanna Foodcare Instruments, Bedfordshire, UK) (AMSA, 1995). After cooking, all the juices were poured out of the bag and the steaks were left to cool to room temperature and the weight of the cooked steak recorded. The cook loss (CL) was determined by the following formula: CL % = ((raw weight of steak - cooked weight of steak)/ raw weight of steak)*100. All steaks were stored in a closed bag and tempered overnight at 4ºC, for subsequent Warner–Bratzler shear force (WBSF) analysis.

WBSF was measured according to the procedure of Shackelford et al. (1994). Briefly, six cores (1.25 cm diameter) parallel to the direction of the muscle fibres were obtained and sheared using an Instron Universal testing machine, model 5543 (Instron Corporation. Bucks, UK) equipped with a Warner–Bratzler shearing device. The crosshead speed was 5 cm/min. Instron Series IX Automated Materials Testing System software for Windows (Instron Corporation. Bucks, UK) was employed in the analysis. Three parameters were used to define the instrumental texture of meat: WBSF (N) is the peak strength or force required to shear through a meat sample, which is directly related to the myofibrillar component (Møller, 1981); *modulus* of deformability (Mpa) was calculated as the slope in the 20% to 80% segment of the total peak, and it is mainly related to the sample elasticity (Larmond & Petrasovits, 1972); total energy (J), was calculated as the total peak area and is related to the total energy used to chew the meat until it can be swallowed (Mathoniere, Mioche, Dransfield, & Culioli, 2000).

Finally, sensory analysis was performed by a ten member, in-house trained panel on steaks grilled to an internal temperature of 70°C, according to the American Meat Science Association Guidelines (AMSA, 1995). Panellists were asked to assess the samples for the following attributes: tenderness (scale 1–8; 1=extremely tough, 8=extremely tender), overall flavour (scale 1–8; 1=very poor, 8=very good) overall texture (scale 1–8; 1=very poor, 8=very good) overall firmness (scale 1–8; 1=very mushy, 8=very firm) and overall acceptability (scale 1–8; 1=not acceptable 8=extremely acceptable). Samples were presented in duplicate.

ACCEPTED MANUSCRIPT

2.6 Statistical analysis

All data were analysed using the GLIMMIX procedure of SAS (SAS Inst. Inc., Cary, NC, USA) using pen as experimental unit and gender and diet as fixed factors. The random tool of the GLIMMIX procedure was used to include "time" as a repeated measurement for the analysis of pH decline and the "position of the measurement" for the analysis of fat colour. When significant main or interaction effects were detected, the post hoc Tukey test was used to determine the differences between means.

Additionally, analysis of variance (ANOVA)-partial least squares regression (APLSR) was also used to analyse the sensory data using Unscrambler® software (version 10.3 CAMO Software AS, Oslo, Norway). The X-matrix was designed as 0/1 variables for beef samples and the Y-matrix included the sensory variables. Regression coefficients were analysed by Jack-knifing, which is based on cross-validation and stability plots (Martens & Martens, 2001). In order to investigate the multivariate correlation between all the measured variables and treatments, PLSR was used as described above, but in this case the variables were weighted and assigned to the X-matrix, and the treatments were assigned to the Y-matrix.

3. Results

There was no gender by diet interaction for any of the factors analysed. Performance results are available as supplementary material.

3.1 Ultimate pH, fat and muscle colour

The ultimate pH (pHu) of muscle tended to be lower for steers than bulls (P=0.097), but no difference was found between the CC and GC groups (Table 1). Figure 1 shows the evolution of the pH/temperature of LT up to 6 hours post-mortem, no effect of the treatment on pH or temperature was found.

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[INSERT TABLE 1 NEAR HERE, PLEASE]

There was no effect of diet or gender on any of the colour parameters (*L*, *a* and *b*) measured in muscle (P>0.05) (Table 1). Fat from steers was lighter (*L*) and more yellow (*b*) in colour than fat from bulls (P< 0.05), whereas fat from the CC group was lighter than fat from the GC group.

3.2. Chemical composition

The IF content was higher in the CC than in the GC group (P=0.007) and in steers than in bulls (P=0.017). The opposite was observed for moisture concentration (P<0.05). There was no effect of diet or gender on protein and total collagen concentration or on collagen solubility (Table 2).

[INSERT TABLE 2 AND FIGURE 1 NEAR HERE, PLEASE]

3.3 Instrumental texture, cook loss and sarcomere length

There was no effect of diet or gender on any of the instrumental texture variables analysed (WBSF, modulus and Energy) or on sarcomere length (Table 3). However, the modulus tended to be lower in steers than bulls (P=0.089). Cook Loss was higher for bulls than steers (P<0.005), whereas no differences were found between diets.

[INSERT TABLE 3 NEAR HERE, PLEASE]

3.4 Sensory evaluation.

Muscle from steers was rated more tender, less hard and firm (P< 0.05), and was more acceptable (P <0.05) than muscle from bulls (Table 3). No gender differences were found for flavour. Meat from steers was positively correlated with tenderness, texture and acceptability

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(Figure 2) and it differed (P<0.05) from meat from bulls. No differences in sensory characteristics were found (P>0.05) between meat from the GC and CC groups.

[INSERT FIGURE 2 NEAR HERE, PLEASE]

3.5 Metabolic activity and muscle fibre type

Table 4 summarises the data on metabolic activity and muscle fibre types. PFK activity was higher (P<0.05) in steers compared to bulls. Neither LDH nor oxidative enzyme activity was modified by gender or diet.

Castration decreased the proportion of myosin heavy chain (MyHC)-based fibre isoforms MyHC I and MyHC IIa (P< 0.05) in muscle. Inversely the proportion of MyHC IIx was higher in muscle from steers than from bulls. The proportion of MyHC IIa, was higher (P< 0.05) in the GC group compared to the CC group

The MyHC IIb isoform was detected in a small number of animals; bull-CC (3), bull-GC (1), steer-CC (1) and steer-GC (1) no relation was neither found with the sired breed of the animals. These data were not subjected to statistical analysis.

3.6. Multivariate correlation

As differences between the GC and CC groups in instrumental texture measurements and sensory evaluation, with the exception of overall texture, were not statistically significant, only the gender factor was used in this analysis. Figure 3 is a graphical representation of the importance of the measured parameters to the model: those parameters correlated significantly (P<0.05) with gender (bull or steer) are highlighted with a double point.

Overall texture, acceptability, tenderness and the proportion of MyHC IIx were positively correlated with steer meat (negative values of the abscissa axis). Overall firmness, pHu and the proportion of MyHC IIa were positively correlated with bull meat (positive values of the abscissa axis).

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Finally, WBSF and overall firmness were not well correlated despite reflecting similar characteristics of the meat.

4. Discussion

4.1 The relationship between gender and meat quality

Previous studies indicate darker muscle colour (lower *L*) from bulls compared to steers (Dunne, Keane, O'Mara, Monahan, & Moloney, 2004) and this has been related to the higher pHu in bulls compared with steers (Purchas, Burnham, & Morris, 2002). The main reason for differences in pHu between bulls and steers has been attributed to increased stress (Field, 1971) and sexual activity (Katz, 2007) of bulls when forced into close social contact with their cohorts during transportation and lairage.

Although numerically the result for both muscle L and pHu, seem to indicate darker colour and higher pHu in bulls than steers in our experiment, the differences were not statistically significant. The lack of difference in both factors may be related to the extra-care during the lairage, where animals were kept in the same groups as on the farm in order to avoid stress or dominance behaviour. It is important to highlight that all the animals reached normal pHu, and the pattern of pH decrease was not in the cold or hot shortening window (Figure 1) (Thompson, 2002). The lack of important differences in pHu is probably related with the subsequent absence of differences found in sarcomere length between genders (Table 3).

Yellowness (*b*) has been described as the most important colour parameter of adipose tissue (Dunne et al., 2004) mainly because some markets consider yellow fat less acceptable than white fat (Walker, Warner, & Winfield, 1990). The increase in fat yellowness due to castration in the present study is in agreement with Knight, Cosgrove, Death, and Anderson (1999) who found that fat from steers reached higher *b* values than fat from bulls. The reason is not clear but it may be related to hormonal control of carotenoid deposition described in other animal species (Kopec et al., 2015; Nollet & Boylston, 2007) or with the effect of sex on fatty acid composition. Padre et al. (2006) found lower levels of C18:0 in steer than in bulls fed in the same diets, previous studies have also reported that animals with higher concentrations of

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C18:0 had a higher fat melting point, and whiter colour (Wood et al., 2008). The lower lightness (*L*) found in subcutaneous fat from bulls compared to steer might be due to the lower subcutaneous fat covering on those carcasses, increasing the contribution of the underlying lean colour (Knight et al., 1999).

With respect to muscle composition, the lower IF content in bulls was probably a consequence of the relationship between hormonal status and fat deposition in muscle (Fritsche & Steinhart, 1998; Kang et al., 2009). The higher levels of IF in muscle from steers in the present study are in accord with previous experiments (Sharaf-Eldin, Babiker, Elkhidir, & El-Bukhary, 2013) and consistent with the carcass fat score of these cattle (McMenamin et al., 2015). Based on those results, and according to Regulation (EC) No. 1047/2012, bull beef could be considered a low fat meat (less than 3g of IF per 100 g of meat).

The lack of effect on soluble collagen levels in the present study, is likely a result of the increased collagen turnover produced by the higher growth rate (Cassar-Malek et al., 2004) of bulls in comparison with steers (McMenamin et al., 2015), is in agreement with previous experiments (Monteiro, Navas, & Lemos, 2005; Schreurs et al., 2008).

Muscle fibres are dynamic structures capable of altering their phenotype under conditions such as age, altered hormone profiles and exercise (Pette & Staron, 2000). Gender also seems to modify both enzyme metabolic activity and fibre type of LT. This, the higher PFK activity (Table 4) in LT from steers than in bulls was previously described by Brandstetter, Picard, and Geay (1998) who found higher glycolytic activity in steers compared with bulls, while the oxidative activity was not modified by gender. Schreurs et al. (2008) reported a higher proportion of MyHC IIx in bulls in contrast with our experiment, however this study underlines also the crucial effect of the degree of maturity in percentage of MyHC IIx. The lower proportion of MyHC IIx in entire animals found in our experiment may be related to the animals being slaughtered at the same age, but at different body weight, and hence at a different degree of maturity.

Bulls had a higher proportion of MyHC IIa and MyHC I than steers in the present study, while no differences were found by Gagaoua et al. (2016). These differences might be again related to the different slaughter protocol since in Gagaoua et al. (2016) all the animals were slaughtered when they achieved a subcutaneous fat score of 3.

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It is interesting that the MyHC IIb isoform was only found in a few animals within very different groups as some authors have related the presence of MyHC IIb with higher glycolytic activity (Picard & Cassar-Malek, 2009), or with higher muscular development (Depreux, Grant, & Gerrard, 2002). In our case, with only six animals it was impossible to establish the relationship of this fibre isoform with tenderness-related variables.

Tenderness is the most important quality characteristic of meat (Belew, Brooks, McKenna, & Savell, 2003; Guillemin, Bonnet, Jurie, & Picard, 2011). In this study, all samples had a WBSF value below 40N, considered as the threshold of consumer acceptability for beef (Huffman et al., 1996). The literature is inconsistent about the effects of gender on instrumental texture evaluation. Some authors found bull beef to be tougher than steer beef (Field, Nelms, & Schoonover, 1966; Peachey, Purchas, & Duizer, 2002; Purchas & Aungsupakorn, 1993), but these studies differ in the breed used, or time of storage (less than 7 days) compared with our study. No differences were found in the instrumental tenderness of LT aged for 14 days from steers and bulls in the present study, which is consistent with the findings of Cahill, Kunkle, Klosterman, Deatherage, and Wierbicki (1956) and with Gerrard, Jones, Aberle, and Lemenager (1987) who concluded that any difference in WBSF due to gender disappears after 13 days of ageing. Furthermore, most of the factors that are considered dominant contributors to cooked meat toughness such as sarcomere length (Herring, Cassens, & Rriskey, 1965; Smulders, Marsh, Swartz, Russell, & Hoenecke, 1990) or collagen (Purslow, 2014) did not differ between genders in the present study.

The correlation between sensory and instrumental measures of tenderness has been reported as being highly variable (Szczesniak, 1968), and WBSF seems an imprecise predictor of beef tenderness as determined by trained panellists (Shackelford, Wheeler, & Koohmaraie, 1995, 1997). The non-significant correlation between the WBSF values and the overall tenderness, texture and firmness parameters evaluated by the panel (Figure 3) in the present study supports these earlier reports.

The sensory panel rated meat from steers slightly more tender and acceptable than meat from bulls in agreement with previous studies (Dransfield, Nute, & Francombe, 1984; Peachey et al., 2002). However, all the samples tasted by the panel were rated around the mid-point of the scale (1 to 8) and no extreme values were found. This indicates that despite the statistical differences found in the sensory evaluation between bull and steer meat, the meat had similar characteristics.

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The differences perceived by the panel in tenderness, texture and acceptability seem related with CL and mainly with the muscle fibre type profile (MyHC IIa and IIx proportions) (Figure 3). The relationship of sensory tenderness with the myofibrillar component has been previously highlighted (Hoffman, Kroucamp, & Manley, 2007; Muchenje et al., 2008). Nevertheless, Chriki et al. (2012) suggested that fibre type composition is not a definite predictor of meat tenderness in beef.

It has also been suggested that increasing the proportion of MyHC IIx could have a beneficial effect on tenderness in those species exhibiting slow post-mortem maturation, such as cattle (Seideman & Crouse, 1986; Zamora et al., 1996). In contrast, Dransfield et al. (2003) found that tenderness was negatively correlated to the proportion of MyHC IIa rather than MyHC IIx, which seems to be confirmed by the present study where the lower proportion of MyHC IIa in LT from the steers matched their better tenderness scores. This is in accordance with the results of Picard et al. (2014) indicating a positive relationship between slow oxidative properties and tenderness of LT muscle of young bulls from French beef breeds.

The correlation obtained in the present study between CL and muscle fibre type profile has been previously highlighted (Henckel, Oksbjerg, Erlandsen, Barton-Gade, & Bejerholm, 1997; Maltin et al., 1997). Despite IF having been reported to have an important influence on meat tenderness (Aberle, 2001), no correlation was found between IF content and sensory characteristics. Ozawa et al. (2000) related the higher amount of IF in steers with better retention of water during cooking. In agreement we have detected an increase in CL (Figure 3) for entire animals that can lead to a less juicy meat.

[INSERT FIGURE 3 NEAR HERE, PLEASE]

4.2 The relationship between production system and meat quality.

Meat from cattle finished on pasture has been reported to be darker (lower *L* value) and to have a higher pHu than meat from animals finished on concentrates (Priolo, Micol, & Agabriel, 2001; Varnam & Sutherland, 1995) However, the lack of effect of the grazing period on colour

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and pHu in the present study agrees with Vestergaard, Oksbjerg, and Henckel (2000) who found a dilution of this effect after a 70 day finishing period on concentrates.

The lower lightness (*L)* for fat colour on animals pre-finished on pasture may also be related to the lower covering of subcutaneous fat. The lack of subcutaneous fat thickness causes transparency and increase the importance of the underlying meat colour as previously highlighted (Knight et al., 1999).

No significant differences in yellowness of fat (*b*) were detected between the GC and CC groups in the present study. Knight, Death, Lambert, and McDougall (2001) suggested that these lack of differences in yellowness may be due to a dilution effect of carotenoids when animals are moved to a lower carotenoid ration. In addition, as carotenoids are accumulated in adipocytes, any accumulation of triacylglycerols (high concentrates) would be expected to `dilute' carotenoids and hence the yellowness of fat.

Previous studies have indicated that grazing results in a lower IF concentration when compared with similar animals finished on concentrates (Vestergaard, Oksbjerg, et al., 2000). However the difference in IF content in animals with a final short finishing period in concentrates is very variable in the literature (McCaughey & Cliplef, 1996; Vestergaard, Therkildsen, et al., 2000) probably due in part to the differences between studies in breed composition and slaughter objectives (similar age, similar carcass weight, similar fat score, etc.).

The lack of difference between diets in the present study in total and soluble collagen concentration may be due to the higher growth rate during the finishing phase of the GC group compared to the CC group increasing the collagen turnover at the end of the experiment in this group. In line Allingham, Harper, and Hunter (1998) suggested that the rapid growth rate of grain-finished animals reduces the contribution of the connective tissue component of toughness by increasing the muscular turnover and collagen solubility.

In agreement with our results which indicate no instrumental texture differences between the GC and CC groups, studies with a short- finishing period of concentrates have reported no differences between forage and concentrate finished cattle (Vestergaard, Therkildsen, et al., 2000). Furthermore, no differences in the sensory characteristics examined were found between pre-finishing diets in agreement with Dinius and Cross (1978).

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Vestergaard, Therkildsen, et al. (2000) reported an increase in the proportion of MyHC IIa in *semitendinosus* muscle of animals produced extensively. This difference was suggested to be mainly related with differences in physical activity, exercise promotes the conversion of isoforms "white to red" in the following sequence MyHC IIb or x> IIa> I. The higher proportion of MyHC IIa found in the GC group in the present study supports this observation. However further investigation is required to confirm that a 98 period on pasture is enough to cause those differences in the muscle fibre type profile. Additionally animals fed with less calorie dense diets have been related also with higher proportions of MyHC IIa fibres (Suzuki, Tamate, & Okada, 1976), in line our results indicates higher proportion of IIa in GC animals.

5. Conclusions

Based on the results obtained in the present study it can be concluded that, despite the statistically significant differences between genders, the LT from bulls aged for 14 days was evaluated as above average by trained panellists, and the values of texture were under the consumer rejection limit (40N). Therefore, the differences have limited commercial relevance. This finding, together with the higher performance, higher profitability and the potential added value of the greater leanness in bulls can increase the attractiveness of bulls in a grass based production system followed by a 76 days finishing period.

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Table 1. Ultimate pH (48 hours post mortem) and colour of the *longissimus thoracis* muscle and subcutaneous fat of young bulls and steers (Gender) finished on *ad libitum* concentrates with (GC) or without (CC) a pre-finishing period at pasture (Diet).

Variable	CC		GC		SED	p-value		
	Bull	Steer	Bull	Steer		Diet	Gender	D*G
Muscle colour								
L	32.59	33.77	31.52	32.69	1.217	0.247	0.208	0.999
a	22.98	22.20	22.44	22.79	0.697	0.967	0.675	0.282
b	14.32	14.33	13.92	14.35	0.371	0.500	0.430	0.444
Fat colour								
L	70.28	72.07	65.12	67.13	0.888	**<.000**	**0.006**	0.829
a	7.31	8.31	8.29	8.98	0.594	0.070	0.065	0.706
b	13.68	15.05	13.68	14.97	0.552	0.938	**0.023**	0.938
Ultimate pH								
pHu	5.59	5.52	5.58	5.52	0.049	0.955	0.097	0.940

Data presented as least-squares means (LSM).Pre-finishing diet by gender interaction (D*G).

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Table 2. Proximate composition of *longissimus thoracis* muscle of young bulls and steers (Gender) finished on *ad libitum* concentrates with (GC) or without (CC) a pre-finishing period at pasture (Diet).

Variable	CC		GC		SED	p-value		
	Bull	Steer	Bull	Steer		Diet	Gender	D*G
Protein	222.27	220.27	223.82	221.54	0.389	0.622	0.458	0.960
Fat	21.41	37.18	12.00	19.17	0.541	**0.007**	**0.017**	0.293
Moisture	747.48	733.58	751.45	746.88	0.577	0.067	0.054	0.286
Soluble collagen	1.09	1.25	1.04	0.91	0.259	0.321	0.933	0.457
Insoluble collagen	4.14	4.25	4.33	4.53	0.628	0.606	0.735	0.911
Total collagen	5.23	5.49	5.36	5.44	0.790	0.940	0.765	0.875

Data presented as least-squares means (LSM). All the variables were measured as mg g^{-1} meat. Pre-finishing diet by gender interaction (D*G)

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Table 3. Texture related parameters: Instron analyses (WBSF, Modulus and Energy), cook loss and sarcomere length and sensorial attributes in *Longissimus thoracis* muscle of young bulls and steers (Gender) finished on *ad libitum* concentrates with (GC) or without (CC) a pre-finishing period at pasture (Diet).

Variable	CC		GC		SED	p-value		
	Bull	Steer	Bull	Steer		Diet	Gender	D*G
WBSF (N)	26.28	25.88	30.27	24.74	2.386	0.421	0.117	0.168
Modulus (Mpa)	0.60	0.57	0.65	0.54	0.049	0.656	0.089	0.285
Energy (J)	0.08	0.18	0.12	0.09	0.076	0.650	0.494	0.253
Cook loss (%)	26.71	24.31	26.25	25.01	0.707	0.818	**0.007**	0.285
Sarcomere length (μm)	1.55	1.66	1.57	1.65	0.083	0.878	0.153	0.768
Tenderness	4.16	4.98	4.19	4.46	0.239	0.185	**0.012**	0.137
Flavour	5.03	5.23	5.04	5.11	0.131	0.557	0.187	0.479
Firmness	5.56	5.07	5.55	5.29	0.191	0.461	**0.025**	0.412
Texture	4.68	5.19	4.57	4.79	0.157	**0.050**	**0.012**	0.234
Acceptability	4.82	5.33	4.80	4.97	0.179	0.181	**0.028**	0.223

Data presented as least-squares means (LSM).). Pre-finishing diet by gender interaction (D*G).

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Table 4. Muscle enzyme activity and muscle fibre type in *longissimus thoracis* muscle of young bulls and steers (Gender) finished on *ad libitum* concentrates with (GC) or without (CC) a pre-finishing period at pasture (Diet).

Variable	CC		GC		SED	p-value		
	Bull	Steer	Bull	Steer		Diet	Gender	D*G
Glycolytic enzyme activity (µmol/min/g of protein)								
LDH	5064	5158	4612	5032	207.5	0.084	0.118	0.300
PFK	617.3	715.0	626.0	698.7	48.43	0.914	**0.038**	0.725
Oxidative enzyme activity (µmol/min/g of protein)								
ICDH	4.45	4.11	4.77	4.95	0.939	0.409	0.901	0.707
COX	70.00	55.67	75.33	70.67	9. 687	0.176	0.203	0.500
CS	7.24	10.47	5.30	10.38	6.638	0.835	0.402	0.848
Fibre type profile (%)								
MyHC IIx	35.80	55.41	33.29	41.64	5.793	0.082	**0.009**	0.207
MyHC IIa	43.24	24.38	44.45	38.88	4.188	**0.029**	**0.003**	0.055
MyHC I	20.73	18.48	20.26	16.54	1.408	0.262	**0.017**	0.482

Data presented as least-squares means (LSM). Pre-finishing diet by gender interaction (D*G). Phosphofructokinase (PFK, EC 2.7.1.11), lactate dehydrogenase (LDH, EC 1.1.1.27, (µmol/min/g of protein)), citrate synthase (CS, EC 4.1.3.7), isocitrate dehydrogenase (ICDH, EC 1.1.1.42), cytochrome c oxidase (COX, EC 1.9.3). Type I fibres or slow oxidative (MyHC I), Type IIa fibres or fast oxidative/glycolytic (MyHC IIa), Type IIx or fast glycolytic fibres (MyHC IIx).

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Figure caption list

Figure 1. Pattern of pH/temperature decrease post-mortem (1 to 6h) of young bulls and steers (Gender) finished on ad libitum concentrates with (GC) or without (CC) a pre-finishing period at pasture (Diet). Data presented as mean value per group.

Figure 2. Correlating loading graphic (X-axis parameters in burgundy colour: GC, CC, Bull, Steer) (Y-axis parameters in blue colour: Tenderness, overall firmness, overall flavour, overall acceptability, overall texture): red highlighted variables indicate statistically significant differences ($P<0.05$).

Figure 3. Correlation loading graphic of eating quality parameters (X-axis in burgundy colour) with steers and bulls (Y-axis in blue colour): red highlighted eating quality parameters indicate statistical significance ($P<0.05$).

Footnotes: pHu: ultimate pH, Fat: intramuscular fat, MI: Type I isoform or slow oxidative MyHC I, MIIA: isoform IIa or fast oxidative/glycolytic MyHC IIa, MIIX: Type IIX isoform or fast glycolytic fibres MyHC IIx, PFK: Phosphofructokinase; LDH: lactate dehydrogenase, ICDH: isocitrate dehydrogenase; COX: cytochrome c oxidase, WBSF: warner bratzler shear force

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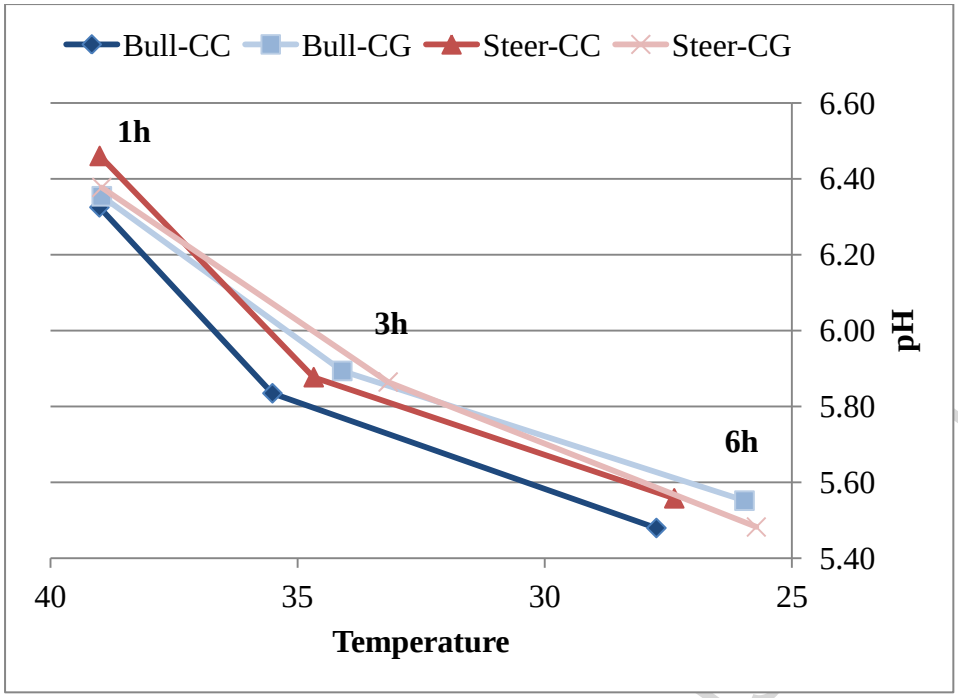

Figure 1

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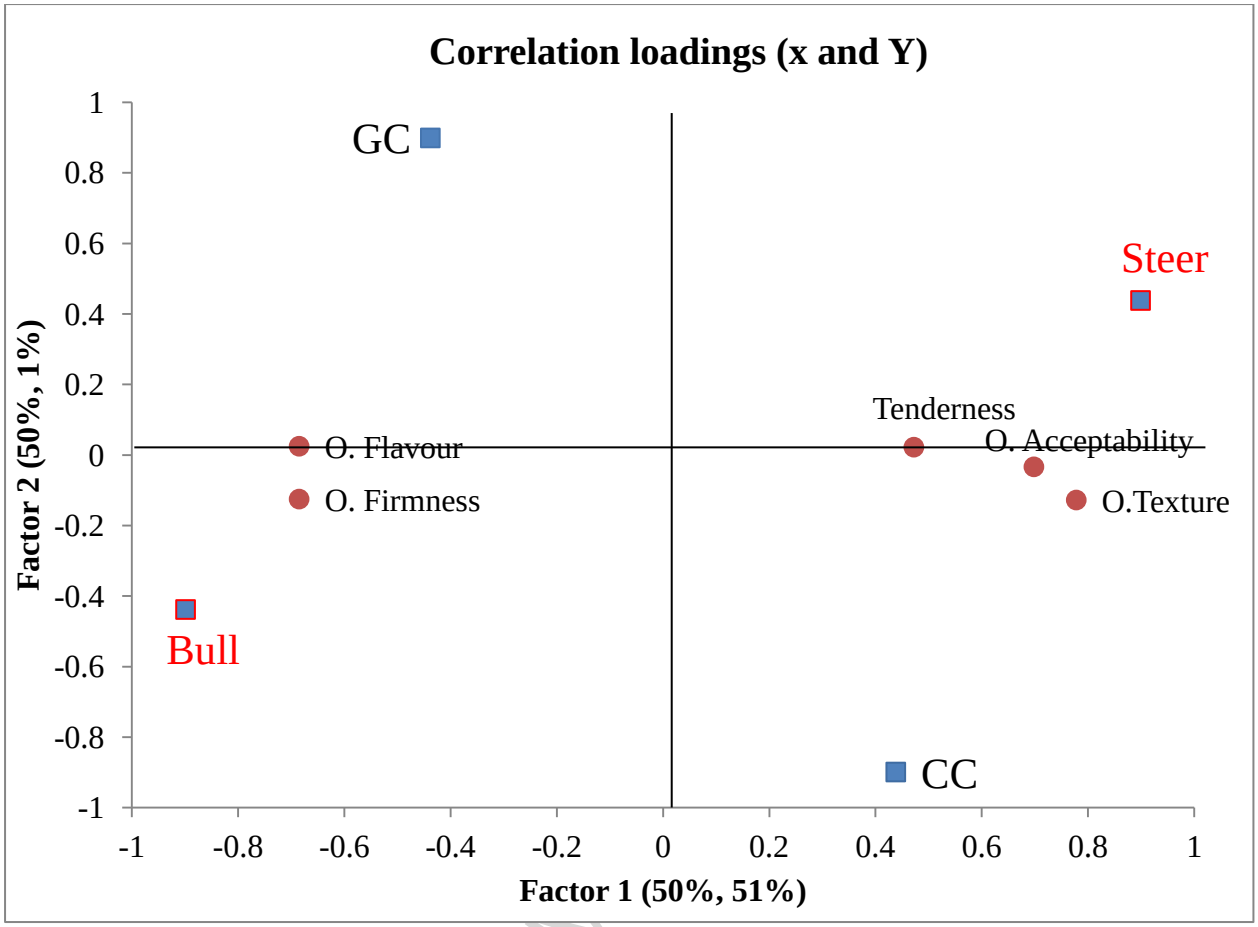

Figure 2

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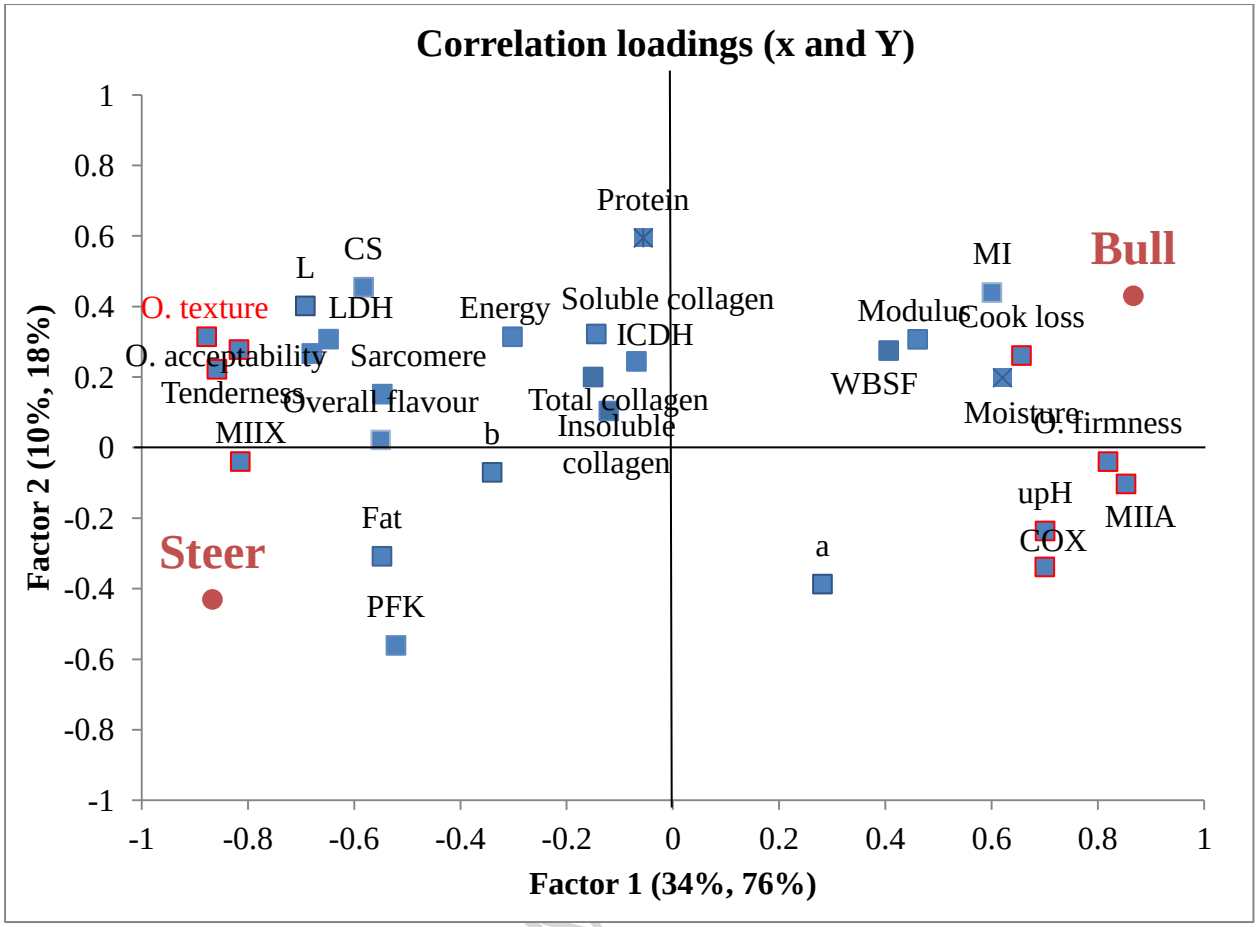

Figure 3

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Highlights

- The quality of meat from bulls and steers from two production systems was examined.
- Trained assessors rated meat from steers more tender and more acceptable than meat from bulls
- However these differences have limited commercial relevance
- Inclusion of a grazing period in the production system did not affect meat quality
- The lower fat content of bull beef compared to steer beef may be more attractive to the consumer

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