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Performance, carcass and meat quality of young bulls, steers and heifers slaughtered at a common body weight

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ABSTRACT

Young bulls of lean continental cattle breeds raised on concentrates achieve high weight gains during fattening but may yield carcasses with low fat cover, which may have negative effects on meat quality. Fattening steers or heifers might be an alternative for these systems, but few studies have analysed in lean breeds the impact of castration of bulls at a similar BW or the performance of females. The aim of the trial was to characterise the growth, carcass and meat quality of bulls, steers and heifers of Pirenaica breed (lean beef breed) fed on concentrates and straw until a common body weight (475 kg). Bulls had greater weight gains than steers and heifers throughout the fattening period ($P < 0.001$). Bulls had greater plasma IGF-I concentration throughout the fattening period but lower leptin concentration from 400 kg onwards than steers and heifers when compared at the same BW. Regarding metabolites, the concentrations of glucose, beta-hydroxy-butyrate, urea and non-esterified fatty acids evolved differently in bulls, steers and heifers. At slaughter, steers and heifers had deposited more fat than bulls without other differences in carcass morphology. Regarding meat quality, meat of heifers had greater lightness and lower yellowness, chroma and hue value than that of bulls and steers. Meat shear force only tended to be different amongst sexes after 14 days of ageing ($P < 0.10$). Heifers had greater intramuscular fat content than steers and bulls. Total saturated fatty acids were similar amongst groups but monounsaturated fatty acids proportion was greatest in heifers, intermediate in steers and lowest in bulls. Polyunsaturated fatty acid proportion was greater in bulls than in steers and heifers. Only minor effects of sex were detected by the sensory panel, with more desirable flavours and higher tenderness in heifers. Therefore, despite the faster growth of entire bulls, fattening steers and especially heifers can lead to improved fat-related meat quality traits in lean breeds.

1. Introduction

In continental Europe, young bulls and, in a lower proportion, heifers are raised for meat rather than steers. In Spain and other Mediterranean countries, young bulls are usually finished on concentrates diets until 12–14 months of age (Albertí et al., 2005), when they are slaughtered producing pale meat with low intramuscular fat content. When finished as yearlings on high-concentrate diets, bulls of specialised European beef cattle breeds usually produce carcasses with low subcutaneous fat cover (Albertí et al., 2008), which might cause cold shortening of the muscles and compromise meat tenderisation (King et al., 2003). Castration of males may ensure a sufficient fatness, but it can also affect the performance and meat quality to a different extent depending on the diet (Steen, 1995) and the breed (Mandell et al., 1997). Most of the studies have focused on breeds with medium to high fatness, but, to our knowledge, castration has been scarcely studied in lean breeds, such as Piedmontese (Biagini and Lazzaroni, 2007) or Belgian Blue crosses (Keane, 2003). Moreover, bulls and steers have usually been compared after a fixed time on feed (Marti et al., 2011; Moran et al., 2017). In these comparisons, bulls have greater weight gains than steers and are concomitantly heavier at slaughter. Thus, there is a confounding effect of body weight (BW) at slaughter on carcass and meat quality (Albertí et al., 2005). The performance, carcass and meat quality of beef heifers has been compared to those of bulls and/or steers in breeds with medium to high fat deposition at a similar (Hedrick et al., 1969) or different slaughter BW (Steen, 1995; Steen and Kilpatrick, 1995). These traits have been compared in heifers and bulls of lean breeds at a different slaughter BW (Bureš and Barton, 2012; Schiavon et al., 2013) but rarely at a common BW. From the available information it is difficult to assess the effects of

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the sexual status on carcass and meat quality in lean breeds, which is needed to design specific recommendations for the management of both live animals and their products. Thus, the aim of this study was to compare in a lean beef breed the performance, carcass and meat quality of bulls, steers and heifers slaughtered at a common BW.

2. Material and methods

All procedures were conducted according to the guidelines of the European Union Directive 2010/63 on the protection of animals used for experimental and other scientific purposes.

2.1. Animals and handling

Twenty-four Pirenaica pure-bred weaned calves (average age: 213 days ± 14.5; average BW: 194 ± 21 kg), 16 males and 8 females, raised in La Garcipollera Research Station (42° 37′ N, 0° 30′ O, 945 m a.s.l.) were used in the experiment. The 16 males were randomly assigned to one of two groups, which were balanced by age and BW at weaning. One group remained intact (bull) and the animals of the other group were castrated (steer) 2 weeks after weaning. The animals were castrated by surgical removal of the testes using local anaesthesia and analgesia with xylazine (5 cc Rompún®, Bayer) and ketamine (5 cc Imalgene®, Mérial) and local antibiotics with penicillin and posterior analgesia with flunixin-meglumine (Finadyne®, Schering-Plough). All the animals were transported to CITA research centre (41° 43′ N, 0° 48′ W; 225 m a.s.l.), in the Ebro Valley (Spain) 2 weeks after the castration and the experiment started 2 weeks after.

Thereafter, the animals were kept indoors on straw-bedded pens and fed for ad *libitum* intake with concentrate and barley straw until they reached the target slaughter weight of 475 kg. The main ingredients of the concentrate (15.8% CP and 13.3 MJ ME/kg DM) were corn (38.0%), barley (32.4%), corn gluten feed (15.0%), soybean meal (7.5%), rapeseed oil (5.0%), palm kernel flour (5.0%), sugar beet pulp (4%), palm oil (2.7%) and mineral and vitamin supplements. Concentrate intake was recorded on a group basis. Slaughter was undertaken in 3 balanced groups on 3 different weeks when the average weight was 475 kg BW. The animals were transported to a commercial abattoir (MercaZaragoza, Zaragoza, Spain) 6 km from the Research Centre without mixing groups and without unfamiliar animals.

2.2. Measurements, blood sampling and analyses

Throughout the experimental period, individual BW was obtained weekly at 0800 h without deprivation of feed and water. These measurements were used to calculate average daily gain (ADG) by linear regression of BW on date. Overall ADG was calculated considering the whole experimental period, and ADGs were calculated for three 80-kg BW gain periods: phases 235–315 kg, 315–395 kg and 395–475 kg BW.

Individual blood samples were obtained monthly at 0800 h by venipuncture of the coccygeal vein with an 18-gauge needle, 2.5 cm in length. Samples for IGF-I and IGFBP-3 concentrations were collected into test tubes with heparin and samples for leptin concentration into test tubes with potassium-EDTA. Plasma was obtained after centrifugation and stored in aliquots before being frozen at –20 °C. Analyses of IGF-I concentrations were determined by a chemiluminescent assay system (INMULITE 1000, Siemens Healthineers, Erlangen, Germany), IGFBP-3 concentrations with Bovine Insulin-like growth factor binding protein 3 (IGFBP-3) ELISA kit (CSB-E12780B. Cusabio, Cusabio Technology LLC, Houston, TX 77,054, USA) and leptin concentrations using RIA (Delavaud et al., 2000). Intra- and inter-assay CV were 3.6% and 6.6% for IGF-I, 4.2 and 8.6% for IGFBP-3, and 7.1% and 7.4% for leptin concentration analyses, respectively.

Samples for non-esterified fatty acids (NEFA), urea, β-hydroxy-butyrate (BHB) and glucose were collected into test tubes containing EDTA to obtain plasma. Plasma concentration of BHB (enzymatic-colorimetric method) and urea (glutamate dehydrogenase method, kinetic UV test) were determined with an automatic analyser (Bitalab Selectra, Merck, Darmstadt, Germany). Reagents for urea were provided by Diagnostica Merck (Merck KGaA 64,271, Darmstadt, Germany) and for BHB by Sigma Diagnostics (St. Louis, MO., USA). Plasma NEFA concentration was determined with a commercial enzymatic colorimetric kit (Randox Laboratories Ltd., Crumlin, Co. Antrim, UK). Intra- and inter-assay CVs were < 6% for urea, BHB and glucose, and 9.1 and 11.3% for NEFA concentration analyses.

Subcutaneous fat thickness (SFT) and body measures were recorded the day before slaughter. Subcutaneous fat thickness (including skin) was measured by ultrasonography with a multi-frequency probe (7.5 MHz; Aloka SSD-900, Aloka Co., Ltd., UK) at the 13th thoracic vertebra perpendicularly to the backbone and on the rump (P8). Skin contact with the transducer was achieved using an ultrasound contact gel. Body development was studied using size measurements. The height at withers, rump length, rump width, and heart girth were measured (Ripoll et al., 2016). The proportionality index (body length/wither height), corporal index (body length/chest girth), pelvic index (rump length/rump width), thoracic index (chest girth/wither height) and *in vivo* blockiness (slaughter BW/body length) were calculated.

2.3. Slaughtering and carcass characteristics

Cattle were slaughtered immediately upon arrival to minimize pre-slaughter stress, stunned by captive bolt pistol, and dressed according to standard commercial practices. The hot carcass weight was recorded immediately after slaughter and carcasses were chilled for 24 h at 4 °C. Then, the degree of fat cover of the left half carcasses and their conformation were graded using the European grading system (E.U., 2006). Carcass conformation was based on a visual assessment (SEUROP classification) with an 18-point scale (from 1 = poorest to 18 = best). The degree of fat cover was evaluated with a 15-point scale (from 1 = very low to 15 for very high).

Carcass measurements were recorded: the length and width of the carcass, the length, width, depth and perimeter of the hind leg were measured as described in Albertí et al. (2008). The length and perimeter measurements were taken by tape measure, whereas the width and depth measurements were taken by calliper. Carcass and leg blockiness (weight/length x 100) indexes were calculated.

Subcutaneous fat colour was measured three times on the dorsal area, between the 5th and 7th thoracic vertebrae, avoiding blood spots and discovered areas using a Minolta CM-2006d spectrophotometer (Konica Minolta Holdings, Inc, Osaka, Japan) in the CIELab space as reported in Ripoll et al. (2016). The lightness (L*), redness (a*) and yellowness (b*) were recorded and Chroma ($\boldsymbol{C^*_{ab}} = \sqrt{(\boldsymbol{a}^*)^2 + (\boldsymbol{b}^*)^2}$) and Hue angle values ($h_{ab} = \tan^{-1}(\frac{b^*}{a^*}) \cdot \frac{180^\circ}{\pi}$) were calculated

The *longissimus thoracis (LT)* and the *longissimus lumborum (LL)* muscle between the 5th thoracic vertebra and the 3th lumbar vertebra of each left half carcass was removed for further meat quality analyses. The 6th rib was excised for dissection. The rib joint was weighed and dissected into muscle, fat (subcutaneous and intermuscular), bone and others (tendons and noticeable blood vessels) according to the methodology described by Panea et al. (2012).

2.4. Meat sampling and meat quality analyses

The LT muscle was excised and sliced into steaks for pH, chemical composition and fatty acid composition, instrumental texture, instrumental colour determinations whereas the LL muscle was sliced into steaks for the consumers' sensory test.

Instrumental meat colour. Meat colour was determined as described in Blanco et al. (2017). Briefly, a 2.5-cm steak of LT muscle per animal was cut in halves and placed in 2 polystyrene trays wrapped with an oxygen permeable film and kept in darkness at 4 °C for colour

determination at 4 h of blooming, 1 and 2 d of display. Just after cutting the steak in halves, ultimate pH (24 h) was measured with a Crison pHmeter (Crison Instruments, SA, Barcelona, Spain), which has a temperature compensator.

Chemical and fatty acid analyses. These analyses were performed in duplicate as detailed in Blanco et al. (2017). The following parameters were determined: dry matter (DM) content, crude protein (CP) using a Nitrogen and Protein analyser (Model NA 2100, CE Instruments, Thermoquest SA, Barcelona, Spain), intramuscular fat content (IMF) (Ankom Procedure AOCS Am 5–04) with an Ankom extractor (Model XT10, Ankom Technology, Madrid, Spain). The fatty acids were converted to methyl esters (Official Methods ISO 5509), separated and analysed using a HP-6890 gas chromatograph equipped with a flame ionisation detector, along a H-88 column (100 m × 0.25 mm id; 0.20 µm film thickness, Agilent Technologies, Waldbronn, Germany). Individual fatty acids were expressed as a percentage of the total amount of the identified fatty acids. After individual FA determination, the sum of the saturated FA (SFA), mono-unsaturated FA (MUFA), poly-unsaturated FA (PUFA), PUFA n-6, PUFA n-3 and PUFA n-6:n-3 ratios were calculated. In general, only fatty acids representing over 0.5% of the total FAME were included in the table of results.

Instrumental tenderness determination. Two 3.5-cm steaks of LT muscle per animal were vacuum-packaged and stored in a cooler at 4 °C until 7 or 14 day of *post-mortem* ageing for subsequent Warner-Bratzler shear force determination using an Instron machine (Model 5543, Instron Limited, Barcelona, Spain) provided with a Warner-Bratzler device and with a cross-head speed of 150 mm/min. Thawed samples were boiled in a water bath to an internal temperature of 70 °C measured with an internal thermocouple (Jenway, Bibby Scientific Ltd, Stone, UK). When cooled, at least ten probes were cut at a 10 mm × 10 mm x 30 mm with the fibre direction parallel to a long dimension. Values for shear force (maximum load per unit of cross section) were recorded (Blanco et al., 2017).

Sensory evaluation with a trained panel test. A 2-cm steak of LL muscle per animal was sliced, vacuum-packed and aged at 4 °C until 7 days before freezing and kept at −18 °C until analyses. The evaluation was performed as described in Blanco et al. (2017) and ISO 8586–1:1993. Panellists used 100-point non-structured scales anchored in extremes to quantify tenderness, juiciness, the intensities of beef odour, beef flavour, liver flavour and abnormal flavour.

2.5. Statistical analyses

Statistical analyses were performed with SAS v.9.1. (SAS Inst. Inc., Cary, NC, USA). Before further analyses, the normality of the residues of all the variables was confirmed with the Shapiro-Wilk test. Mixed models based on Kenward-Roger's adjusted degrees of freedom solution for repeated measures were used to analyse BW, hormones, metabolites and meat colour and shear force. Different variance-covariance matrixes were tested to model heterogeneous residual error, and the one with the lowest AIC and BIC was chosen. In the models of BW and meat colour parameters and shear force, the sex (bull, steer or heifer), time and their interaction were the fixed effects and the animal the random effect. In the models of metabolite and hormone concentrations, the sex was the fixed effect with the BW as covariate, and the animal as the random effect. The initial model tested for linear, quadratic, and cubic effects of BW and their possible interactions with sex. Terms that were not significant were removed from the model, and the analyses were repeated. The sensorial parameters were analysed with a mixed model considering as fixed effect the sex and as random effect the panellist nested in the session. Weight gains, fattening period length, carcass characteristics, the chemical composition of meat and intramuscular fat were analysed by ANOVA using the GLM procedure with the sex as fixed effect. Least square means (LS Means) were estimated and differences between LS Means were tested using pdiff. Pearson's correlation coefficients between variables were calculated. To study the relation between sensory variables and groups of animals a Generalized Procrustes Analysis was performed using the program XLStat 2009 (Addinsoft, Paris, France). For all tests, the level of significance was set at 0.05. Trends were discussed when P-values were <0.10.

Table 1
Performance during the fattening period and *in vivo* zoometric measurements and subcutaneous fat thickness before slaughter of bulls, steers and heifers.

	bull	steer	heifer	s.e.m.	P-value
n	8	8	8		
Performance					
Initial BW, kg	239	234	235	4.4	0.89
Slaughter BW, kg	476	479	473	7.4	0.96
Daily concentrate intake, kg DM/d	7.7	6.9	6.6	–	–
Age at slaughter, d	384a	433b	444b	3.0	0.001
Overall ADG, kg/d	1.758a	1.354b	1.253b	0.0282	0.001
Subcutaneous fat thickness, mm					
at the 13th rib	7.5b	9.2a	8.2ab	0.23	0.02
at the rump (P8)	9.1b	11.0a	12.5a	0.37	0.004
Body measurements					
Wither height, cm	121	121	120	0.6	0.69
Hip height, cm	126	127	127	0.5	0.47
Rump width, cm	41	43.6	43	0.6	0.24
Rump length, cm	51.9a	45.5b	49.5a	0.7	0.004
Chest girth, cm	188	184	185	0.9	0.32
Body length, cm	143b	150a	150a	0.6	0.001
Proportionality index[1]	118b	124a	125a	0.8	0.01
Corporal index[2]	0.96	0.95	0.95	0.0	0.60
Pelvic index[3]	126a	96b	88b	1.8	0.001
Thoracic index[4]	154	154	154	1.1	0.99
Blockiness[5]	3.28	3.18	3.06	0.043	0.30

[1] Body length/wither height x 100.
[2] Body length/chest girth x 100.
[3] Length of rump/width of rump x 100.
[4] Chest girth/wither height x 100.
[5] Slaughter BW/body length x 100.
Within a parameter, means with different letter differ at $P < 0.05$.

3. Results

3.1. Performance

Bulls had greater overall weight gains than steers and heifers ($P < 0.001$; Table 1), which had similar gains. Consequently, bulls were 49 and 60 days younger than steers and heifers at slaughter at a common BW, respectively ($P < 0.001$). When considering the three consecutive phases of 80-kg gain, ADG differed amongst all treatments during the first phase (235–315 kg BW, $P < 0.001$), ranked as bulls > steers > heifers (Fig. 1). Thereafter, gains of steers and heifers did not differ and were lower than those of bulls ($P < 0.001$).

Concerning subcutaneous fat thickness before slaughter, values at the 13th rib were the highest in steers and the lowest in bulls, those of

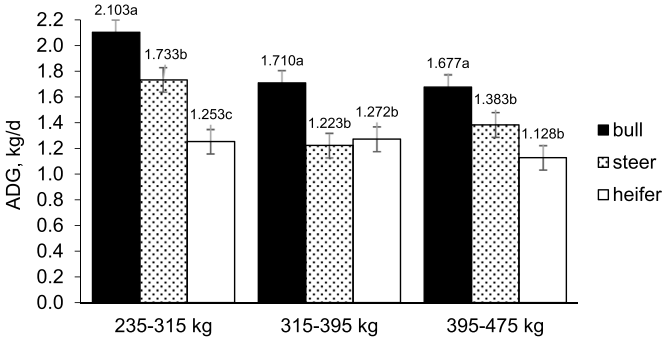

Fig. 1. Effect of the sex on average daily gain (ADG) during the fattening period ($n = 24$, 8 animals per sex). Within a period, means with different letters differ at $P < 0.05$. The vertical bars represent the standard error.

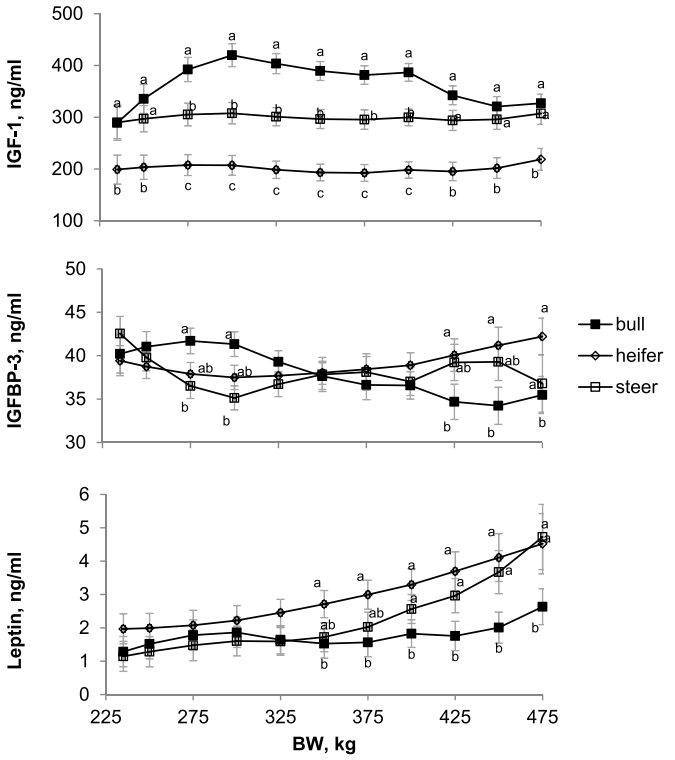

Fig. 2. Plasma concentrations of IGF-I, IGFBP-3 and leptin throughout the fattening period in bulls, steers and heifers (n = 24, 8 animals per sex). Within a hormone and BW, means with different letters differ at $P < 0.05$ The vertical bars represent the standard error. .

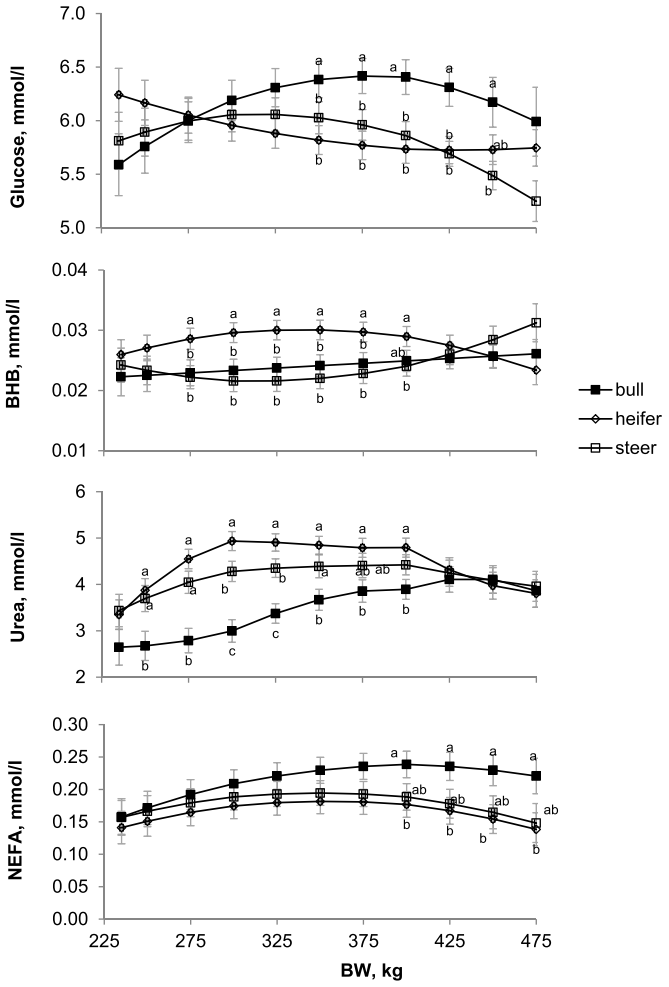

Fig. 3. Glucose, β-hydroxi-butyrate (BHB), urea and non-esterified fatty acids (NEFA) concentrations in plasma throughout the fattening period in bulls, steers and heifers (n = 24, 8 animals per sex). Within a metabolite and BW, different letters indicate differences at $P < 0.05$. The vertical bars represent the standard error.

heifers being intermediate ($P < 0.05$) (Table 1). At the rump, both steers and heifers had higher fat thickness than bulls ($P < 0.01$). amongst the zoometric measurements, only rump and body length differed. Steers had shorter rump length than bulls and heifers ($P < 0.01$). Bulls were shorter than steers and heifers ($P < 0.001$), and had a lower proportionality index and a greater pelvic index than steers and heifers ($P < 0.01$). However, the blockiness index did not differ amongst sexes ($P > 0.05$).

3.2. Plasma hormone and metabolite concentrations

The concentrations of IGF-I, IGFBP-3 and leptin in plasma were affected by the interaction between the sex and BW ($P < 0.05$; Fig. 2). The plasma IGF-I concentration changed with BW in bulls whereas it minimally changed with BW in heifers and steers ($P < 0.05$). Bulls had the greatest IGF-I concentration, steers had intermediate values and heifers had the lowest at the same BW ($P < 0.001$). Throughout the experiment, monthly IGF-I concentrations were poorly correlated with ADG observed in the previous month (r = 0.36, $P < 0.001$). Plasma IGFBP-3 concentration also evolved differently with BW in bulls, steers and heifers ($P < 0.05$) (Fig. 2), but without a clear pattern. At the same BW, the concentration of IGFBP-3 was similar amongst sexes ($P > 0.05$), except for the greater concentration in bulls than in steers at 275–300 kg and in heifers than in bulls from 425 kg onwards ($P < 0.05$).

At low BW, leptin concentration did not differ amongst sexes but steers and heifers had greater concentration than bulls from 400 and 350 kg onwards, respectively ($P < 0.05$). Monthly leptin concentrations were related with BW registered in the previous month (r = 0.47, $P < 0.001$). Plasma leptin concentration before slaughter was correlated with intermuscular fat percentage in the 6th rib (r = 0.49, $P < 0.05$), subcutaneous fat percentage in the 6th rib (r = 0.54, $P < 0.01$), intramuscular fat content (r = 0.50, $P < 0.05$) but not with the *in vivo* measurements on the 13th rib or the rump estimated with ultrasounds.

The concentration of all the metabolites was affected by the interaction between the sex and BW ($P < 0.05$ to $P < 0.01$; Fig. 3). At the same BW, heifers and steers had similar glucose concentration ($P > 0.05$), which was lower than that of bulls from 350 to 450 kg ($P < 0.05$). The concentration of BHB at the same BW was similar in steers and bulls, and in both cases lower than that of heifers from 275 to 400 kg BW, whereas there were no differences thereafter. Urea concentrations were lower from 250 kg to 350 and 400 kg in bulls than in steers and heifers, respectively, and they only differed between heifers and steers at 300 to 325 kg ($P < 0.05$). The concentrations of NEFA were similar amongst sexes until 400 kg BW, then bulls had greater NEFA concentrations than heifers ($P < 0.05$).

3.3. Carcass characteristics

Carcass characteristics are presented in Table 2. Heifers had lower hot carcass weight and dressing percentage and carcasses with greater fatness score than bulls and steers ($P < 0.01$). The carcasses of steers had lower conformation score than those of bulls and heifers ($P < 0.01$). The carcass measurements and the blockiness indexes were not affected by the sex ($P > 0.05$), except for thorax depth ($P < 0.01$). Regarding the composition of the 6th rib, bulls had greater muscle and lower fat proportions in the 6th rib than steers and heifers, which had

Table 2
Carcass characteristics of bulls, steers and heifers slaughtered at a common BW.

	bull	steer	heifer	s.e.m.	P-value
n	8	8	8		
Hot carcass weight, kg	290a	287a	273b	2.0	0.01
Dressing percentage,%	60.89a	60.30a	57.14b	0.434	0.004
Conformation score (scale 1 to 18)	9.7a	8.5b	10.3a	0.16	0.0014
Fatness score (scale 1 to 15)	5.1b	5.5b	7.1a	0.09	0.001
Carcass measurements					
Carcass length, cm	122	123	124	0.5	0.27
Carcass width, cm	59.7	60.1	59.5	0.23	0.56
Thorax depth, cm	34.0b	37.1a	36.8a	0.28	0.003
Hind leg length, cm	78.1	79.2	77.8	0.39	0.34
Hind leg width, cm	28.7	28.9	28.3	0.27	0.84
Hind leg perimeter, cm	115	114	116	0.5	0.23
Hind leg depth, cm	41.8	42.6	43.7	0.32	0.10
Carcass blockiness index[1]	2.28	2.26	2.24	0.008	0.32
Leg blockiness index[1]	0.37	0.36	0.36	0.004	0.88
6th rib composition					
Muscle,%	74.4a	67.1b	68.2b	0.68	0.001
Subcutaneous fat,%	1.3a	2.3b	1.9ab	0.15	0.0497
Intermuscular fat,%	8.4a	14.3b	14.7b	0.34	0.001
Total fat,%	9.8a	16.6b	16.6b	0.41	0.001
Bone,%	16.3	15.8	15.2	0.68	0.57
Subcutaneous fat colour					
Lightness (L*)	71a	66b	66b	0.28	0.006
Redness (a*)	3.8	3.9	3.4	0.38	0.77
Yellowness (b*)	10.5a	9.9a	7.6b	1.32	0.02
Hue angle (h_{ab})	71	69	65	0.4	0.30
Chroma (C^*_{ab})	11.3a	10.7a	8.4b	0.41	0.04

[1] Weight/length x 100;
Within a parameter, means with different letter differ at $P < 0.05$.

similar proportions. Bone proportion did not differ with sex ($P > 0.05$). Lightness of subcutaneous fat was greater in bulls than in steers and heifers ($P < 0.01$) whereas b* and C^*_{ab} were greater in bulls and steers than in heifers ($P < 0.05$).

3.4. Meat quality

Meat colour variables were affected by the interaction between the sex and the time of air exposure (Fig. 4). Meat L*, b* and h_{ab} were similar at blooming and 1 day of air exposure, but meat from heifers had greater L* and lower b* and h_{ab} than bulls and steers after 2 days of air exposure ($P < 0.01$). Bulls had lower redness than steers and heifers at blooming and after 1 day of air exposure ($P < 0.05$). Steers had the greatest and bulls the lowest C^*_{ab} after 1 day of air exposure, values of heifers being intermediate ($P < 0.001$). Steers and bulls had greater C^*_{ab} than heifers after 2 days of air exposure ($P < 0.001$).

Meat pH, chemical composition and fatty acid profile are reported in Table 3. Muscle pH was greater in heifers than in bulls and steers ($P < 0.01$). Meat from heifers had the greatest dry matter and intramuscular fat contents ($P < 0.001$), whereas meat from bulls had lower dry matter content ($P < 0.01$) but similar intramuscular fat content ($P > 0.05$) than that from steers. Shear force did not differ with sex after 7 days of ageing ($P > 0.05$) but bulls had greater shear force than heifers ($P < 0.05$) and slightly greater than steers ($P < 0.10$) after 14 days of ageing.

Regarding the major fatty acids, bulls had lower C16:0 ($P < 0.001$) and C18:1n-9 ($P < 0.001$) percentages than steers and heifers but similar C18:0 ($P > 0.05$). Bulls had greater C18:2n-6, C18:3n-3, C20:4n-6, C20:5 n-3 and C22:5 n-3 percentages than steers and heifers ($P < 0.001$). Total SFA tended to be affected by the sex ($P < 0.10$). Concerning total MUFA heifers had the greatest, steers intermediate and bulls the lowest percentage ($P < 0.001$). Bulls had greater PUFA, PUFA n-3 and PUFA n-6 percentages in LT muscle than steers and heifers ($P < 0.001$). The ratio n-6:n-3 was lower in steers than in bulls, heifers presenting intermediate values ($P < 0.05$).

Most of the sensory attributes evaluated by the trained panel were not affected by the sex ($P > 0.05$; Table 4). Only, bulls were ranked higher than steers and heifers for rancid odour ($P < 0.05$) and heifers were ranked higher than bulls for greasy flavour intensity ($P < 0.05$). Regarding the bi-plot of the generalized procrustean analysis, the first factor explained 67% of the variability, involving most of the variables. However, the second factor explained 33% of the variability, mainly due to juiciness. Heifers were positively associated with beef and greasy flavour intensities, residue and tenderness whereas bulls were characterized by rancid odour and acidic flavour. On the other hand, meat from steers was ranked higher in juiciness than that of the other groups.

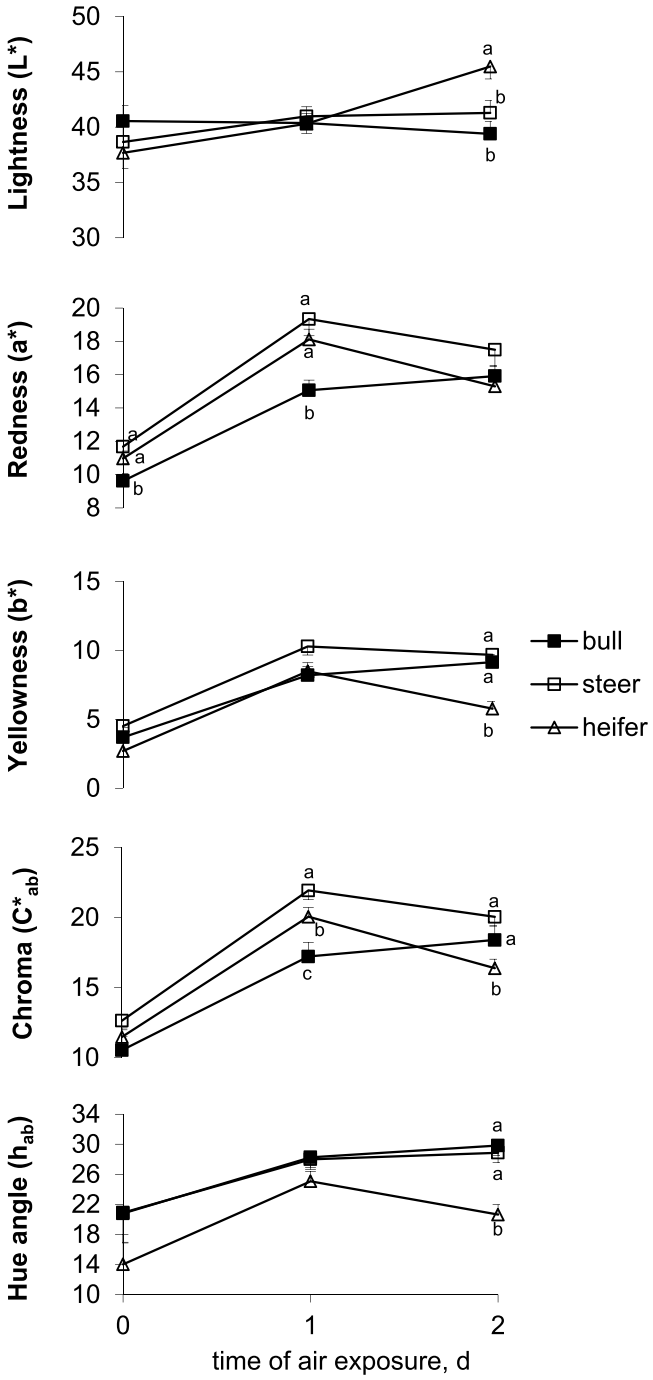

Fig. 4. Colour variables in *longissimus thoracis* muscle in bulls, steers and heifers ($n = 24$, 8 animals per sex). Within a trait and time of air exposure, different letters indicate differences at $P < 0.05$. The vertical bars indicate the standard error.

Table 3
Longissimus thoracis muscle pH, shear force, chemical composition, and fatty acid (FA) profile of bulls, steers and heifers.

	bull	steer	heifer	s.e.m.	P-value
N	8	8	8		
pH at 24 h *postmortem*	5.52b	5.56b	5.61a	0.008	0.002
Shear force, N/cm^2					
7d of ageing	46.3	46.8	40.6	1.14	0.36
14 d of ageing	49.5^a	40.6^b	39.8^b	1.03	0.08
Dry matter,%	24.1 c	25.2 b	26.9 a	0.18	0.001
Crude protein,% FM[1]	20.8	21.0	21.0	0.13	0.79
Intramuscular fat,% FM[1]	1.0 b	1.5 b	2.8 a	0.12	0.001
FA,% identified FA					
C10:0	0.07	0.06	0.06	0.002	0.52
C12:0	0.059b	0.065ab	0.074a	0.004	0.04
C14:0	2.12b	2.35b	2.78a	0.117	0.002
C14:1	0.36b	0.33b	0.50a	0.049	0.05
C15:0	0.31	0.33	0.31	0.019	0.78
C16:0	23.49b	25.52a	26.58a	0.424	0.001
C16:1	2.65b	2.79b	3.45a	0.204	0.03
C17:0	0.83	0.88	0.81	0.048	0.60
C17:1	0.56	0.58	0.62	0.047	0.69
C18:0	18.05	18.91	16.62	0.805	0.15
C18:1n-9	32.97b	36.72a	39.43a	0.982	0.001
C18:1n-7	2.09	2.13	2.37	0.121	0.24
C18:2n-6	12.37a	6.29b	4.19b	0.770	0.001
C18:3n-3	0.34a	0.20b	0.16b	0.016	0.001
C18:2n-7	0.25b	0.27b	0.36a	0.022	0.004
C20:0	0.12 a	0.11 a	0.094b	0.006	0.03
C20:1n-9	0.14	0.14	0.14	0.009	0.85
C20:4n-6	2.37a	1.65 b	1.03 c	0.189	0.001
C20:5n-3	0.15 a	0.07b	0.05b	0.014	0.001
C22:4n-6	0.28a	0.30a	0.20b	0.025	0.01
C22:5n-3	0.43a	0.28b	0.18c	0.033	0.001
Saturated FA	45.04	48.23	47.33	0.908	0.06
Monounsaturated FA	38.76c	42.70b	46.50a	1.139	0.001
Polyunsaturated FA (PUFA)	16.18a	9.07b	6.17b	1.023	0.001
PUFA n-6	15.01a	8.25b	5.41b	0.972	0.001
PUFA n-3	0.91a	0.54b	0.38b	0.059	0.001
n-6:n-3	16.48a	14.96ab	14.24b	0.533	0.02

[1] Fresh matter. Means with different letter differ at $P < 0.05$.

Table 4
Effect of the sex on intensity of sensory attributes[1] of Longissimus muscle.

	bull	steer	heifer	R.S.D.[2]	P-value
N	8	8	8		
Beef odour	39.9	39.6	38.2	1.07	0.78
Rancid odour	26.3a	17.9b	18.0b	1.32	0.01
Tenderness	54.5	55.8	60.1	1.31	0.19
Juiciness	53.0	54.7	54.3	1.09	0.81
Fibrosity	44.4	42.7	37.5	1.31	0.08
Residue	46.9	47.0	48.7	1.14	0.76
Beef flavour	50.5	50.5	50.8	0.90	0.99
Metallic flavour	30.5	30.2	28.3	1.08	0.66
Greasy flavour	33.9b	36.9ab	41.1a	0.99	0.01
Acid flavour	38.30	36.44	35.27	1.15	0.56

[1] Evaluated with 100-point non-structured scales anchored in extremes.
[2] Residual Standard Deviation

4. Discussion

4.1. Performance

Previous studies simultaneously comparing the three sexes under similar feeding and slaughtering conditions, either at a similar BW (Röpke et al., 1994) or age (Steen, 1995), have reported greater gains in bulls than in steers, which in turn grew faster than heifers. In the current study, the greater weight gains of bulls over the other two treatments was maintained throughout the fattening period, but that of steers over heifers disappeared in the phase from 315 to 395 kg gain and thereafter.

The higher gains of bulls than steers are well documented in literature, and considered mostly as a consequence of the anabolic effects of testosterone. The lower feed conversion ratio and higher rate of lean growth of bulls has been associated to their better performance over steers (Kirkland et al., 2006) and when compared to heifers (Bureš and Barton, 2012; Schiavon et al., 2013). In Hereford calves, Govoni et al. (2003) indicated that males start to grow significantly faster than females at 16 weeks of age, and maintain this advantage throughout the first year. As in the current experiment, heifers and steers had similar performance in Angus (Al-Husseini et al., 2014) and Nellore (Silva et al., 2015) breeds. Moreover, Angus heifers and steers had similar feed:gain ratios and Nellore heifers and steers also had similar digestibility and net energy and protein requirements for maintenance and growth (Al-Husseini et al., 2014).

Sex seems to have had only a limited effect on linear body measurements in the current study, even if castration was performed before puberty, when it can affect skeletal development (Biagini and Lazzaroni, 2007). This is probably due to the fact that measurements were obtained at a similar BW, whereas BW at the time of measurement differed amongst treatments in literature (Gilbert et al., 1993). Comparing bulls and steers, McNamee et al. (2015) described that some body measures relative to BW at slaughter were affected by sex, although not always in the same sense as observed here, where bulls were longer and had higher pelvic and proportionality index than steers and heifers.

The differences in the subcutaneous fat thickness measured with ultrasounds agree with the results of Crews et al. (2002), who found that steers were fattest, heifers intermediate, and bulls leanest both when comparing fat thickness measured *in vivo* by real time ultrasound and on the carcass. Bruckmaier et al. (1998) did not find any difference in the backfat thickness between intact and castrated males at 450 kg LW, but described a higher diameter of the *longissimus dorsi* muscle in bulls, which they considered to be an expression of their greater muscle growth and anabolism.

4.2. Plasma hormone and metabolite concentrations

Metabolic hormones and metabolites, in general, reflected the metabolic status of the animals of the three treatments. Several hormones are implicated in the regulation of growth by the somatotropic axis. amongst these, IGF-I and IGFBP-3, its most abundant binding protein, play a major role that can be influenced by factors such as diet, age (Govoni et al., 2003) or sexual status (Bruckmaier et al., 1998). The IGF-I concentrations were higher in bulls, followed by steers and then by heifers, as reported by Ropke et al. (1994). However, both in the current experiment and the abovementioned studies, the differences were not consistent in time. Initial concentrations did not differ between bulls and steers, probably due to the delayed effects of castration on anabolism, which was reflected in weight gains. Thereafter, IGF-I concentration was higher in bulls than in steers, as observed by Bruckmaier et al. (1998), but the difference disappeared around 450 kg BW, which suggests that IGF-I was regulated by factors other than testosterone. The IGF-I concentrations were consistently higher in males than females throughout the study, but weight gains did not differ between steers and heifers, as observed by Walker et al. (2010). This could be ascribed to the increment in IGFBP-3 around 11 to 12 months of age in females, associated with the onset of puberty (Govoni et al., 2003), which could have intensified the anabolic effect of circulating IGF-I.

The increase in leptin concentrations observed throughout the fattening phase in all sex classes, highly correlated with BW, reflects the increased fat deposition. The lack of difference amongst sexes during the first half of the fattening phase is perhaps due to the low fat deposition in these young animals (Byrne et al., 2018). The differences amongst sexes in the second half mirror their different body fat, as reflected by the relationship with all fat measures on the 6th rib and the

intramuscular fat content, as observed in steers and heifers (Brandt et al., 2007).

Concerning metabolites, glucose concentrations were greater in bulls than steers, as observed by Bruckmaier et al. (1998), and heifers. This was more evident in the second half of the experiment, reflecting their different energy balance and gains in the different phases. The decreasing trend observed as age advanced was also described young heifers by Rodríguez-Sánchez et al. (2015), and in young bulls by Bourgon et al. (2017), which they associated with higher cell glucose uptake for increased deposition of fat.

The opposite ranking of sexes and trend during the experiment was observed in the case of BHB, as it is a product of the catabolism of adipose tissue under lower planes of nutrition (Byrne et al., 2018). Consequently, it had a weak but significant negative relationship with weight gains. Circulating urea has been associated with protein intake, synthesis and breakdown, and therefore the ranking of bulls, steers and heifers, also reported by Bruckmaier et al. (1998) and Walker et al. (2010), reflects enhanced protein utilization and muscle growth in the former, which would be supported by the negative relationship between urea and IGF-I concentrations. The increase of urea throughout the fattening period agrees with the results of Bourgon et al. (2017), who suggested that the lower values in younger animals was due to their greater efficiency to convert nitrogen into protein and muscle growth. Finally, the plasmatic concentrations of NEFA were surprisingly greater in bulls than steers and heifers at the end of the fattening period. This was unexpected because NEFA are a product of the lipolysis of fat reserves associated with a lower energy balance (Byrne et al., 2018), which was not supported by the rest of the parameters.

4.3. Carcass characteristics

The similar carcass weight and dressing percentage of bulls and steers observed here agrees with the results reported in Piedmontese breed (Biagini and Lazzaroni, 2007), a lean breed, or in Holstein-Friesian breed slaughtered at 450 kg BW (Kirkland et al., 2006). However, bulls had heavier carcasses and greater dressing percentage than steers in Holstein-Friesian crosses compared at heavier weights, above 550 kg (Keane, 2003; McNamee et al., 2015). Similarly, bulls had heavier carcasses and had lower fatness than steers and heifers slaughtered at 560 kg (Steen and Kilpatrick, 1995). The lower conformation score of steers when compared to bulls and heifers observed in the current experiment was also reported in cross-bred cattle slaughtered at 560 kg (Steen and Kilpatrick, 1995). Regarding the composition of the rib, the lower proportion of fat and greater proportion of muscle of bulls when compared to steers and heifers observed in the current experiment are consistent with previously reported studies (Steen and Kilpatrick, 1995; Keane, 2003; Kirkland et al., 2006; McNamee et al., 2015).

4.4. Meat quality

The sex of the animals influences weight gains and their composition, which can affect intramuscular fat and haeminic pigments concentration of meat. Therefore, comparisons at a fixed BW or age can lead to very different conclusions. The lack of differences in meat colour of bulls and steers in the current experiment agrees with the results reported in steers and bulls did not differ when slaughtered at same age (Moran et al., 2017), even at a different BW (Ripoll et al., 2016). Similarly, entire bulls and immuno-castrated males slaughtered at the same BW had similar values of Chroma and Hue angle through 15 d of display although their lightness differed (Ripoll et al., 2019). Contrarily, McNamee et al. (2014) found differences in colour between steers and bulls of three breeds slaughtered at two BW, ascribed to differences in lipid concentration which were not observed in the current study. Gagaoua et al. (2018) also found differences amongst young bulls and heavier, older steers, related to physicochemical properties of meat being a function of sex. The higher lightness and lower yellowness, chroma and hue angle of heifers when compared to steers and bulls observed in the current experiment agrees partially with the results reported by Page et al. (2001), who described higher meat lightness and yellowness in heifers than bulls, and Carvalho et al. (2018), who found higher lightness and redness in heifers than immuno-castrated steers. Both studies associate their findings to the higher IMF content of heifers, which was also observed here. The similar intramuscular fat content of meat from steers and bulls in the current study contrasts with others reporting meat from bulls to be leaner than that from steers (Bureš and Barton, 2012), but it explains our lack of differences in colour and tenderness amongst castrated and entire males.

Accordingly with the current study, when slaughtered at same age, meat from heifers was slightly more tender than that of bulls due to a higher IMF content (Weglarz, 2010). After ageing for 14 days, meat from steers tended to be more tender than that of bulls. Several studies report higher tenderness in meat from steers than bulls when slaughtered a similar BW (Jones et al., 1964; Moran et al., 2017). Although changes in the myofibrillar proteins are the responsible of the tenderisation, the responsible of base toughness is the collagen. Moreover, collagen can be affected by the interaction between age/BW and animal sex (Kopp and Bonnet, 1982). These authors indicated that while the meat collagen content of bulls increased from 9 to 13 months, that of heifers was reduced. However, the great content of intramuscular fat of heifers could explain the lower shear force values compared with bulls and steers (Destefanis et al., 2000). Lower meat collagen content in surgically castrated males (Gerrard et al., 1987) has been connected to the lack of the anabolic effects of testosterone on collagen synthesis (Destefanis et al., 2003). In agreement with these results, Ripoll et al. (2019) reported higher meat toughness in entire bulls than in immuno-castrated males.

Very few studies compare the fatty acid profile of the intramuscular fat amongst the three sexes in similar conditions of husbandry, in particular animal feeding. Concerning the different proportions of the most abundant individual fatty acids (measured as percentage of the total fatty acids), our results agree with those of Mueller et al. (2019), who observed lower concentrations of C16:0 and C18:1n-9 and higher of C18:2n-6 in bulls than in steers and heifers. Other authors report a similar effect of castration when comparing bulls and steers (Monteiro et al., 2006), but Kazala et al. (1999) and Jaborek et al. (2019) observed differences in the proportions of C18:1n-9 and C18:2n-6 between steers and heifers which have not been elicited in our study, despite their different IMF content. When the major groups of FA are considered, our results indicate that entire males had a greater proportion of PUFA (both n-6 and n-3) and tended to have a lower proportion of SFA than the rest. Bulls had higher n-6:n-3 ratio and lower MUFA proportions than heifers, whilst the meat of steers had intermediate values. Mueller et al. (2019) ranked the three sexes similarly for all traits, with a more favourable FA profile for human health in steers and especially in heifers as compared to bulls, but Fernandes et al. (2009) found no differences amongst sexes. Our results agree with other studies involving bulls and steers (Nian et al., 2018) or bulls and heifers (Karolyi et al., 2009; Barton et al., 2011). These differences have been associated with their different growth and maturing rates, since sex hormones can influence lipid metabolism. The greater rate of fat deposition of heifers during the finishing phase, reflected in their higher IMF content, results in larger adipocytes (Eguinoa et al., 2003). This larger size implies a different FA composition, with higher triacylglycerides (high in SFA and MUFA) in the inner lipid droplets and a lower proportion of membrane phospholipids (high in PUFA) (de Smet et al., 2004).

Concerning the sensory analysis by the trained panel, meat from heifers was associated with higher tenderness and more positive flavours than that of bulls, whereas that of steers was associated with higher juiciness. Partially agreeing with our results, Mueller et al. (2019) indicated a higher score assigned to juiciness,

flavour, and overall acceptance of steers and heifers as opposed to bulls. Bureš and Barton (2012) did not find differences between bulls and heifers in beef odour or flavour intensity, but meat from heifers was assessed as more tender and acceptable. Weglarz (2010) found that meat from heifers had more desirable flavours and juiciness than that of bulls, associated with its higher IMF content. Contrarily, Choat et al. (2006) did not find clear differences between steers and heifers, but meat from bulls obtained better scores than meat from heifers. The major volatile compounds responsible for the development of flavour are produced by the thermal degradation of fat and the oxidation of fatty acids, to which unsaturated ones are particularly prone (Mottram, 1998). Therefore, the greater percentage of PUFA n-6 and n-3 of bulls meat, especially those with more than 4 unsaturated carbons, explains the greater intensity of rancid odour of bull's meat. Heifers had more intensity of greasy flavour because the high amount of intramuscular fat and high proportion of C18:1 which is related with cooked beef fat (Larick and Turner, 1990)

In summary, despite the faster gains of entire bulls, fattening steers but especially heifers can be an interesting alternative for high-concentrate finishing systems when meat quality is considered. Not only carcass and muscular fatness are enhanced, but also meat tenderness and desirable flavours are improved, which can allow for an increased added value in niche markets.

CRediT authorship contribution statement

M. Blanco: Conceptualization, Investigation, Formal analysis, Writing - review & editing. **G. Ripoll:** Investigation, Formal analysis, Writing - original draft. **C. Delavaud:** Formal analysis, Writing - original draft. **I. Casasús:** Funding acquisition, Conceptualization, Investigation, Writing - review & editing.

Declaration of competing interest

None

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Supplementary materials

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