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RESEARCH ARTICLE

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Body size, carcass and meat quality of three commercial beef categories of 'Serrana de Teruel' breed

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Abstract

The aim of this study was to analyse three commercial beef categories of the 'Serrana de Teruel breed' to define the appropriate commercial option. Twenty 'Serrana de Teruel' male calves at 9 months were assigned to the commercial beef categories (young bulls, bulls and steers), slaughtered at 12, 22 and 22 months of age, respectively. The *in vivo* ultrasound backfat thickness was greater than the dorsal fat thickness, and the young bulls and steers had a similar fat thickness, that was greater than the bulls in both areas. The slaughter weight and cold carcass weight were significantly different between the commercial categories. However, the differences were not sufficient to modify the dressing percentage, carcass conformation and fatness degree between the young bulls and bulls. The maximum stress of the muscle at 7 d of ageing was lower in the steers than in the young bulls and bulls. In general, the lightness of the meat in the bulls was lower than that in the young bulls and steers. The subcutaneous fat of the bull carcasses had a vivid colour and stored more carotenoids than that of the young bulls and steers. Hence, bulls produced heavier and better conformed carcasses with more edible meat and less fat than the other categories. However, steers are recommended to produce large carcasses with more trim and cover fat than the other categories. Finally, it seems that bulls are the most suitable commercial category to 'Serrana de Teruel' breed.

Additional key words: cattle; morphometric; ultrasound; colour; fatty acids.

Abbreviations used: ADG (Average Daily Gain); B (Bulls); BD (); BI (Blockiness Index); CL (Carcass Length); CW (Carcass Width); FA (Fatty Acid); LD (*Longissimus dorsi*); LL (*Longissimus lumborum*); LP (Leg perimeter); LT (*Longissimus thoracis*); LW (Leg width); MDA (malondialdehyde); ME (Metabolisable Energy); MUFA (Monounsaturated Fatty Acid); PUFA (Poliunsaturated Fatty Acid); SFA (Saturated Fatty Acid); ST (Steer); SUM (Sumatory of reflectance spectra); TBARS (ThioBarbituric Reactive Substances); YB (Young Bulls).

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Introduction

There are a great number of wide-spread and well-studied cattle breeds in Europe. Albertí *et al.* (2005b) classified 'Spanish' beef cattle into three broad groups: high meat producing animals that correspond to late maturing animals with a short carcass size and high 'blockiness'; medium meat producing breeds with intermediate characteristics, and low meat producing breeds that correspond to early maturing animals with a large carcass size and low 'blockiness'. Local and hardy breeds are not considered as meat producers because they often produce longer carcasses with a poorer conformation and a greater fatness degree (Piedrafita *et al.*, 2003). However, their production can be interesting from the point of view of the added values that these breeds provide, such as the maintenance of animal genetic resources, the conservation of the ex-

tensive systems and generated landscapes, the reduction of fire risk, and the rural setting in areas of low population density. 'Serrana de Teruel' is a local breed that is traditionally raised in the Centre of Spain due to its capacity to adapt to harsh environments. The breed comes from *Bos taurus primigenius* and is genetically comparable to breeds such as Avileña-Negra Ibérica and Serrana (Sánchez-Belda, 2002) and close to other Spanish breeds, such as Parda de Montaña and Pirenaica (Martín-Burriel *et al.*, 2007), which are meat-oriented breeds. An exploratory analysis of the 'Serrana de Teruel' meat quality designation, including representatives of the various stages in the value chain of beef from production to consumption, indicated that there is a prospective market for this breed (Olaizola *et al.*, 2012), but the appropriate commercial option is not well defined.

It is well described that the optimal slaughter ages and weights vary widely among cattle breed types (Kempster *et al.*, 1982) depending on their maturity. In the same way, the sex of the animals and their different maturity levels endow the carcasses with different characteristics. Hence, different breeds must be slaughtered at different ages, resulting in products that are differentiated by their diverse attributes, such as the intramuscular fat content, meat colour and toughness (Ripoll *et al.*, 2013a). These meat attributes are very important to the consumer (Olaizola *et al.*, 2012). In addition to the beef quality traits, body size and carcass composition should also be considered. It is known that castration of bulls can modify the frame of the animals, carcass characteristics and meat quality. Field (1971) reported that steers had increased dorsal fat thickness, fat percentage in the ribs, and muscle to bone ratio than entire bulls. Additionally, the fatty acids could be modified due to the changes in triacylglycerol/phospholipid ratio (De Smet *et al.*, 2004). The role of testosterone on the lipogenic enzyme activity is not clear. Monteiro *et al.* (2006) reported that the meat from steers has a lower n-6 to n-3 PUFA ratio, which is considered to have beneficial effects on human health.

Hence, the aim of this study was to analyse the body size, carcass and meat quality of three commercial beef categories (young bulls, bulls and steers) of the 'Serrana de Teruel breed' to define the appropriate commercial option for this breed.

Material and methods

All procedures were approved by the in-house Ethics Committee for Animal Experiments at the CITA of Aragon. The care and use of animals were performed in accordance with the European Union Directive 2010/63 on the protection of animals used for experimental and other scientific purposes (EU, 2010).

Animal management

The experiment was conducted at the facilities of the CITA de Aragon with 20 'Serrana de Teruel' male calves weaned at 150 d ± 22.4 d old and 149.8 kg ± 22.6 kg live weight. The animals were raised together from weaning to 9 months of age, when the animals were randomly assigned to the treatment groups in this study (commercial beef categories: 7 young bulls (YB), 7 bulls (B) and 6 steers (ST), slaughtered at 12, 22 and 22 months of age, respectively). The calves were fed with concentrates (93.0% dry matter, 11.7 MJ metabolisable energy (ME)/kg dry matter, 13.54 % protein/kg dry matter, 6.11 % fat/kg dry matter) and cereal straw *ad libitum* throughout the experiment. Animals with a longer fattening period (bulls and steers) received 3 kg of concentrate (as-fed basis) plus barley silage *ad libitum* (37.9% dry matter, 9.5 MJ ME/kg dry matter) from 14 to 18 months of age. The concentrate was primarily composed of maize (35.0%), barley (22.2%), soybean (7.7%) and gluten feed (8.0%). The calves from the steer group were castrated at 9 months of age by surgical removal of the testes using local anaesthesia and analgesia.

During the last three fattening months of each beef type (when all groups shared the same diet), the individual live weights were recorded at weekly intervals to estimate the average daily gains (ADG) on a monthly basis by a linear regression analysis of the live weight over time.

When the young bulls were 358 d ± 6.1 d old and the bulls and steers were 539 d ± 5.3 d old, the following morphometric variables, which are considered to be quantitative independent variables, were assessed and expressed in cm: height at withers, measured as the distance from the floor to the highest point of the withers, height at rump, measured as the distance from the floor to the highest point of the internal tuberosity of ilion, rump width, measured as the maximum distance between iliac tuberosities, rump length, as the distance from the ischial tuberosity to the external iliac tuberosity, body length, as the distance from the cranial side of the shoulder blades to the caudal side of the ischial tuberosity and chest girth, measured as the circumference immediately behind the shoulder blades in a plane perpendicular to the body axis.

The day before slaughter, ultrasonic measurements were taken of all animals using an Aloka SSD-900 instrument with a 7.5 MHz (5 to 10 MHz), 62-mm wide

multifrequency electronic linear array probe (UST 5710-7.5, Aloka Spain, Madrid, Spain). The measurements were recorded on the left side in all animals over the skin without clipping the fleece by the same operator (Schröder & Staufenbiel, 2006). Although the presence of the hair had an impact on the ultrasound, this was overcome by combing the hair until a completely clean skin surface was achieved. An acoustic gel was used to provide a better contact surface between the probe and the skin of the animal. The animals were immobilized to avoid any abnormal situation that would have stressed the animal. The ultrasound measurements were obtained directly from the screen of the B-mode of the instrument. The dorsal fat and skin thickness was measured on the 13th rib by placing the transducer perpendicularly to the backbone. The measurements were made above the rib at 6 cm from the dorsal midline. The backfat and skin thickness were measured by placing the transducer in the imaginary line between the tuber coxae (hooks) and tuber ischia (pins). The examination site was located in the sacral region between the caudal one-quarter and one-fifth connection line extending from the dorsal part of the pins to the hooks (Schröder & Staufenbiel, 2006).

The young bulls were slaughtered at 12 m old, and the bulls and steers were slaughtered at 22 m old.

Slaughter and carcass characteristics

The animals were slaughtered in a commercial European Union licensed abattoir (MercaZaragoza, Spain) 6 km from the fattening unit. To minimize the pre-slaughter stress, the animals were transported on the day of slaughter without a fasting period. Immediately after arrival, they were slaughtered using a captive bolt pistol and exsanguinated. The hot carcass weight was recorded after slaughter and 2% of the carcass weight was subtracted to calculate the cold carcass weight. The carcasses were chilled for 24 h at 4 °C and split into two halves. Then, the degree of fat cover of the left half of the carcasses and their conformation were graded using the European grading system (EU, 2006). Carcass conformation was based on a visual assessment (SEUROP classification) of the carcass profiles, particularly the essential parts (round, back, and shoulder), using an 18-point scale (1=poorest and 18=best). The degree of fat cover, which takes into account the amount of fat on the outside of the carcass and in the thoracic cavity (1 low; 2 slight; 3 average; 4 high; and 5 very high), was evaluated on a 15-point scale, the score was 15 for 5+ very high to 1 for 1- very low.

The carcass measurements were assessed according to the method of Boer *et al.* (1974) and included the following: carcass length (CL), measured from the anterior edge of the symphysis pubis to the middle of the anterior edge of the visible part of the first rib; length of the hind leg (LL), measured from the medial malleolus of the tibia in a straight line to the anterior edge of the symphysis pubis; and leg width (LW), measured as the horizontal distance between the outermost points on the medial and the lateral surface of the leg. The other shape-related characteristics included the following: breast internal depth (BD), at the level of the fifth rib from the ventral edge of the spinal canal of the posterior aspect of the body of the fifth thoracic vertebra to ventral aspect of the middle of the body of the sixth sternebra; the carcass width (CW), measured from the last sternebra to the superior extreme of the sixth dorsal vertebra; depth of the hind leg (LD), measured as the horizontal distance between the outermost points on the anterior and posterior surface of the leg; and leg perimeter (LP), the maximum measurement of the contour of the leg at the level of the symphysis pubis (Albertí *et al.*, 2005b). The carcass blockiness index (BI) was calculated from these measurements. This index expresses the relationship between the carcass weight (kg) and carcass length (cm). The left half of the carcass was dissected into edible meat, trimmed fat and bone, and the respective percentages were calculated.

The colour of the subcutaneous fat in the dorsal area was measured 24 h after slaughter by avoiding blood spots and included areas between 6th and 13th *vertebrae*. The fat colour was measured using a Minolta CM-2006 d spectrophotometer (Konica Minolta Holdings, Inc., Osaka, Japan) in the CIELAB space (CIE, 1986), with a measured area diameter of 8 mm, including a specular component and a 0% UV, standard illuminant D65, which simulates daylight (colour temperature 6504 K), observer angle of 10° and zero and white calibration. The lightness (L*), redness (a*) and yellowness (b*) were recorded, and the hue angle (H*) and chroma (C*) indexes were calculated as $H^* = \tan^{-1}\left(\frac{a^*}{b^*}\right)\cdot 57.29$, expressed in degrees and $\sqrt{a^{*2}+b^{*2}}$, respectively.

The reflectance spectrum of the fat was collected every 10 nm from 450 to 510 nm. Then, reflectance spectrum was used to calculate the absolute value of the integral of the translated spectrum (SUM) according to the method described by Prache & Thériez (1999).

Sampling procedures, instrumental and fatty acid analyses

The *Longissimus thoracis* (LT) muscle from the 5th to 12th thoracic vertebrae was sliced into steaks. The

ultimate pH was measured with a Crison pH meter (Crison Instruments, SA, Barcelona, Spain) at the level of the 10th vertebra. The fat thickness at the 11th vertebra was measured with a calliper. A steak at the 5th thoracic vertebra was minced to determine the fatty acid (FA) and intramuscular lipid oxidation levels. The FA methyl esters were directly obtained by transesterification using a solution of 2% sulfuric acid in methanol. The FA methyl esters were analysed by gas chromatography with a 30 m × 0.25 mm SP2330 capillary column (Supelco, Tres Cantos, Madrid) and a flame ionization detector, with helium as the carrier gas at 1 mL/min. The oven temperature program increased from 150–225 °C at 7 °C per min, and the injector and detector temperatures were both set at 250 °C (Tor *et al*., 2005). The quantification was performed by area normalization after adding 1,2,3-tri undecanoyl glycerol to each sample as an internal standard. The intramuscular FA composition was calculated as the percentage of each individual acid relative to the amount of total FA and expressed as mg/g FA. The total intramuscular fatty acids were calculated as the sum of each individual FA and expressed as triglyceride equivalents (AOAC, 2000). Intramuscular fat percentage was calculated as the total intramuscular FA expressed as a percentage of fresh muscle. The percentage of polyunsaturated (PUFA), monounsaturated (MUFA) and saturated (SFA) fatty acids were calculated. Intramuscular lipid oxidation was determined according to the method of Ripoll *et al.* (2013b) at 7 d of air exposure. The thiobarbituric reactive substances (TBARS) are expressed as milligrams of malondialdehyde (MDA) per kilogram of muscle.

A steak from the 6th thoracic *vertebra* was used to determine the drip losses. Each sample was hung inside a plastic container at 4 °C. The initial weight of each steak was recorded on the sampling day and after 7 d. The percentage of drip losses were expressed as a ratio of the expelled juice to the initial weight of the sample.

Two 2.5 cm thick steaks of LT muscle (7th and 8th thoracic *vertebrae*) were cut into three pieces. These pieces were randomly placed in 6 polystyrene trays, wrapped with a polyethylene and polyamide film, with an oxygen permeability of 40-50 mL/m^2/24 h and water vapour permeability of 5-7 g mL/m^2/24 h at 23 °C (Cryovac, Barcelona), and stored in the dark at 4 ºC for the colour determination at 1, 2, 5, 8, 12 and 15 days of display. The muscle colour was measured with the same configuration of the spectrophotometer as described for the fat colour measurement, described in section 2.2. The *Longissimus thoracis* samples were placed above a white tile, were measured twice, and the measurements were then averaged.

A 3.5 cm thick steak of the LT muscle from each steer (9th thoracic *vertebra*) was vacuum-packaged and stored in a cooler at 4°C for 7 days of post-mortem ageing and the subsequent Warner-Bratzler shear force determination. The vacuum-packaged steaks were boiled in a water bath (75 °C) to an internal temperature of 70 °C. When they had cooled, no less than ten 10 × 10 mm^2 cross section probes were cut, with the fibres parallel to the long dimension of at least 30 mm. The samples were sheared perpendicular to the long axis of the core using an Instron machine (Model 5543, Instron Limited, Barcelona, Spain) that implemented a Warner-Bratzler device and had a cross-head speed of 150 mm/min. The maximum stress values (maximum load per unit of cross section, measured in N/cm^2) were recorded. The remaining LT muscle from the 10th to 12th *vertebrae* was sliced into 3 cm thick steaks, aged for 1, 7 and 14 days and frozen until the sensory analysis was performed.

Statistical analysis

The slaughter weights, slaughter ages, morphometric measurements, ultrasound tissue thicknesses, carcass characteristics, subcutaneous fat colour, fatty acids, pH, WHC, lipid oxidation (TBARS) and maximum stress values were analysed using one-way ANOVA with the commercial category (YB, B, ST) as the fixed effect.

Instrumental LT muscle colour was analysed using the MIXED procedure for repeated measures based on Kenward-Roger's adjusted degrees of freedom solution. The factors included the commercial category (YB, B, ST) as the between-subject fixed effects, the display time as the within-subject effect and random animal effect as the subject (experimental unit). The closest to zero Akaike Information Criterion (AIC) was used to choose the matrix of the error structure. The least square means were estimated and pair-wise comparisons of the means were obtained by the probability of the differences. For all of the tests, the level of significance was 0.05.

The relationships between morphological measurements of the carcass, the carcass tissue composition and the commercial meat categories were summarized using multivariate analyses. Because there were 17 variables and 20 observations, the edible meat, conformation, fatness degree, leg perimeter and carcass width were selected using the STEPDISC procedure and the stepwise method. These selected variables were analysed by the FACTOR procedure to determine and reduce the number of traits that explain most of the variation in the carcass. VARIMAX was applied to obtain the factor pattern coefficients. The first and

second principal components were plotted. All statistical analyses were performed using SAS 9.1 software (SAS Inst. Inc., Cary, NC, USA).

Results

Morphometric measurements and carcass characteristics

The three commercial categories of beef cattle were defined by the slaughter weight and age (Table 1). The young bulls had the lowest slaughter weight and age ($p<0.001$). The bulls had the greatest slaughter weight and were younger than the steers ($p<0.001$). During the feeding program, the young bulls had greater daily gain than the steers ($p<0.05$), with entire bulls showing an intermediate level ($p>0.05$). The *in vivo* ultrasound thickness of dorsal skin ranged from 4.0 mm to 4.5 mm without differences between commercial categories ($p>0.05$). However, the back skin thickness of young bulls and steers was greater than back skin thickness of bulls ($p<0.01$). In general terms, the ultrasound dorsal fat thickness was smaller than the backfat thickness, and there were no differences between commercial categories ($p>0.05$). The young bulls and steers had similar backfat thickness ($p>0.05$) that was greater than the bulls backfat thickness ($p<0.001$). The ultrasound dorsal fat thickness was highly correlated with the carcass fatness degree (r = 0.55*) and the ultrasound of the backfat thickness (r = 0.61**).

The slaughter weight had a strong influence on the *in vivo* morphometric measurements of the animals (Table 1). In general, the young bulls had the smallest measurements ($p<0.001$), while bulls and steers had similar measurements ($p>0.05$).

Similar to the slaughter weight, the cold carcass weight was significantly different ($p<0.001$) between the commercial categories (Table 2). However, the differences in weight and age were not sufficient to modify the dressing percentage, carcass conformation and fatness degree of the young bulls and bulls. In the same way as those *in vivo* morphometric measurements, the young bulls had the smallest carcass measurements. Bulls and Steers had similar carcass measurements excepting leg width and leg perimeter. Steers had lower values than Bulls for these leg measurements. Regarding the tissular composition of carcass, there was no differences ($p>0.05$) between commercial categories on the percentage of bone. However, Steers had the lowest and percentage of muscle and the greatest percentage of trim fat. Young bulls and Bulls had no differences ($p>0.05$) on these variables. The blockiness index was different among commercial categories ($p<0.001$) and bull carcasses had the greatest blockiness index and young bulls had the lowest blockiness index, while steers had intermediate values.

The principal component analysis of the morphometric measurements of the carcasses, carcass tissular composition and the meat commercial categories are shown in Figure 1. The first principal component (PC1) explained almost 48% of the variability in the data that

Table 1. *In vivo* measurements of young bulls (YB), bulls (B) and steers (ST) of 'Serrana de Teruel' breed.

	YB	B	ST	SEM[1]	Sig.[2]
Number of observations	7	7	6		
Slaughter weight, kg	471.3^{c}	720.3^{a}	660.6^{b}	18.74	***
Age at slaughter, d	372^{c}	606^{b}	639^{a}	5.2	***
ADG[3], g	1.47^{a}	1.23^{ab}	0.99^{b}	0.10	**
In vivo ultrasound thickness, mm					
Dorsal skin	4.5	4.0	4.5	0.23	ns
Back skin	5.2^{a}	4.1^{b}	5.5^{a}	0.24	**
Dorsal fat	5.4	4.7	5.7	0.33	ns
Backfat	7.0^{a}	4.7^{b}	6.8^{a}	0.35	**
In vivo morphometric measurements, cm					
Height at withers	122^{b}	130^{a}	132^{a}	1.8	**
Body length	136^{b}	151^{a}	147^{a}	2.1	***
Height at rump	128^{b}	139^{a}	143^{a}	1.9	***
Rump length	43^{b}	49^{a}	48^{a}	0.6	***
Rump width	38^{b}	44^{a}	44^{a}	0.9	***
Chest girth	172^{b}	192^{a}	192^{a}	2.5	***

[1] SEM: standard error of mean. [2] ns: $p>0.05$, *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$. [3] ADG, average daily gain of the last 90 days before slaughtering calculated by linear regression.

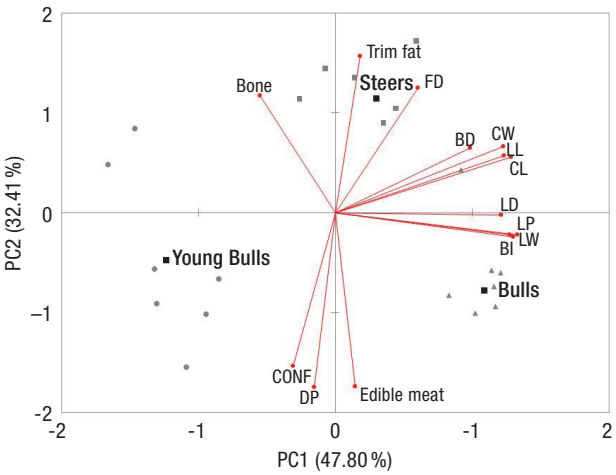

Figure 1. Principal component analysis (PCA) of carcass morphometric measurements and carcass tissular composition of young bulls, bulls and steers of 'Serrana de Teruel' breed. BD, breast internal depth; BI, blockiness index; CL, carcass length; CONF, carcass conformation; CW, carcass width; DP, dressing percentage; FD, fatness degree; LD, leg depth; LL, leg length; LP, leg perimeter; LW, leg width.

summarized the carcass measurements. According to PC1, the older animals (B and ST) had larger carcasses and blockiness indexes and higher values of carcass width, leg length, leg width, leg perimeter and leg depth than the young bulls. The second principal component (PC2) explained more than 32% of the variability and was positively correlated with the fatness degree and percentages of trim fat and bone, and negatively correlated with the dressing percentage, conformation and edible meat. According to PC2, the entire males' carcasses (B and YB) had more edible meat, a better conformation and a lower fatness degree than the steers' carcasses.

Table 3 shows the correlations between the variables related to the carcass classification variables, carcass morphometric measurements, and tissular composition. As expected, the conformation was positively correlated with the edible meat and was inversely correlated with the trim fat and bone. The carcass fatness degree was highly positively correlated with the trim fat (p<0.001). Significant inverse correlations were observed between the carcass conformation and some carcass measurements (CL, CW, BD and LL). The correlation of these same carcass measurements and the fatness degree was positive and significant (p<0.05). When the relationships between these variables were studied within each treatment group, random and inconsistent correlations were found, probably due to the low number of data points in each treatment group.

Meat quality

The effect of commercial category on the measurements of the subcutaneous caudal fat colour and main meat quality traits are shown in Table 4. There were significant differences in the instrumental colour of the fat. The bull carcasses had greater a*, b*, C* and SUM values than the young bull carcasses (p<0.05).

Table 2. Carcass classification, measurements and tissular composition of young bulls (YB), bulls (B) and steers (ST) of 'Serrana de Teruel' breed.

	YB	B	ST	SEM[1]	Sig. [2]
Number of observations	7	7	6		
Cold carcass weight, kg	277.4^{c}	425.7^{a}	365.2^{b}	10.08	***
Dressing percentage	58.89^{a}	59.09^{a}	55.31^{b}	0.411	***
Conformation, 1-18	10.3^{a}	9.7^{a}	8.3^{b}	0.35	**
Fatness degree, 1-15	5.0^{b}	5.7^{b}	8.0^{a}	0.25	***
Carcass measurements					
Carcass length, cm	121.7^{b}	140.6^{a}	137.7^{a}	1.21	***
Carcass width, cm	58.6^{b}	68.2^{a}	67.4^{a}	0.63	***
Breast internal depth, cm	32.7^{b}	38.6^{a}	39.3^{a}	0.92	***
Leg length, cm	78.6^{b}	89.4^{a}	88.0^{a}	0.91	***
Leg width, cm	27.3^{c}	31.5^{a}	29.8^{b}	0.43	***
Leg perimeter, cm	114.8^{c}	129.8^{a}	122.8^{b}	1.24	***
Leg depth, cm	42.9^{b}	47.7^{a}	46.0^{a}	0.63	***
Blockiness index, kg/cm	2.13^{c}	3.03^{a}	2.64^{b}	0.10	***
Carcass tissular composition, %					
Edible meat	74.4^{a}	75.8^{a}	71.4^{b}	0.72	**
Trim fat	5.5^{b}	5.1^{b}	8.4^{a}	0.40	***
Bone	20.1	19.1	20.3	0.53	ns

[1] SEM: standard error of mean. [2] ns: p>0.05, *: p<0.05, **: p<0.01, ***: p<0.001.

Table 3. Pearson correlations among carcass morphometric measurements, SEUROP carcass classification and tissular composition of 'Serrana de Teruel' carcasses.

	Conformation	Fatness degree	Edible meat	Trim fat	Bone
Fatness degree	-0.52*	—			
Edible meat	0.68**	-0.54*	—		
Trim fat	-0.56*	0.73***	-0.88***	—	
Bone	-0.53*		-0.71***		—
Carcass morphometric measurements					
CL	-0.47*	0.51*			
CW	-0.52*	0.57**			
BD	-0.49*	0.56*			
LL	-0.49*	0.48*			
LW					-0.47*
LP					
LD					
BI					-0.48*

CL, carcass length; CW, carcass width, BD, breast internal depth; LL, leg length; LW, leg width; LP, leg perimeter; LD, leg depth; BI, blockiness index. ns: $p>0.05$, *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$.

Table 4. Subcutaneous caudal fat colour and meat quality of young bulls (YB), bulls (B) and steers (ST) of 'Serrana de Teruel' breed.

	YB	B	ST	SEM [1]	Sig. [2]
Number of observations	7	7	6		
Subcutaneous fat colour					
Lightness (L*)	72.84^{a}	71.39^{ab}	69.40^{b}	0.771	*
Redness index (a*)	1.86^{b}	3.81^{a}	2.40^{b}	0.346	***
Yellowness index (b*)	10.50^{b}	13.23^{a}	10.39^{b}	0.439	***
Hue angle (H*)	79.83	73.95	76.95	1.806	ns
Chroma (C*)	10.68^{b}	13.78^{a}	10.73^{b}	0.434	***
SUM [3]	194^{a}	355^{c}	246^{b}	12.0	***
Longissimus thoracis characteristics					
pH 24 h	5.61	5.59	5.58	0.023	ns
Dorsal fat thickness, mm	5.1^{ab}	3.8^{b}	6.9^{a}	0.80	*
Intramuscular fat, % fresh matter	1.80^{b}	1.89^{b}	2.65^{a}	0.570	***
Drip losses, %	3.2	3.2	3.3	0.30	ns
TBARS 7 d, mg MDA/kg muscle	0.57	0.46	0.31	0.104	ns
Max. stress 7 d, N/cm^2	65.58^{a}	60.04^{a}	48.34^{b}	2.72	***

[1] SEM: standard error of mean. [2] ns: $p>0.05$, *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$. [3] SUM: estimator of fat carotenoids (absolute value of the integral of the translated spectrum).

There were no significant differences in the ultimate pH, water holding capacity or lipid oxidation of the LT muscle between the commercial categories (Table 4). The dorsal fat thickness of the bulls was lower than the fat thickness of the young bulls and steers. These results were not consistent with the ultrasound dorsal fat thickness, but they were consistent with the ultrasound backfat thickness. In fact, the ultrasound backfat thickness and dorsal fat thickness were significantly correlated (r=0.58***). The maximum stress of the LT muscle at 7 d of ageing was lower in the steers than in the young bulls and bulls ($p<0.001$). Also, young bulls and bulls had lower intramuscular fat content than steers ($p<0.05$).

In the present study, the dominant fatty acids of the intramuscular fat were oleic, palmitic, cis-linoleic and stearic acids, based on their percentages (Table 5). In general, the young bulls and bulls had similar percentages of the dominant fatty acids, as well as MUFA, PUFA, n-6 and n-3 fatty acids ($p>0.05$), while the steers had significantly lower percentages of stearic, cis-linoleic, PUFA, n-6 and n-3 fatty acids and significantly higher percentages of oleic acid and MUFA. However, there were no significant differences in the percentages of SFA between the commercial categories. The most significant differences between the bulls and steers were in the percentages of oleic, cis-linolenic

Table 5. Fatty acids of intramuscular (%) fat of young bulls (YB), bulls (B) and steers (ST) of 'Serrana de Teruel' breed.

Fatty acids	YB	B	ST	SEM [1]	Sig. [2]
Number of observations	7	7	6		
C10:0	0.19	0.15	0.16	0.005	ns
C12:0	0.09	0.07	0.09	0.007	ns
C13:0	0.05	0.01	0.03	0.011	ns
C14:0	1.95^{ab}	1.72^{b}	2.39^{a}	0.157	*
C14:1	0.39^{b}	0.37^{b}	0.58^{a}	0.051	*
C15:0	0.33	0.33	0.36	0.026	ns
C15:1	0.04	0.01	0.01	0.015	ns
C16:0	24.69^{ab}	22.22^{b}	25.76^{a}	0.869	*
C16:1	2.22^{b}	2.02^{b}	3.14^{a}	0.172	***
C17:0	0.65^{a}	0.52^{b}	0.74^{a}	0.043	**
C17:1	0.68	0.81	0.90	0.115	ns
C18:0	17.59^{a}	18.82^{a}	16.00^{b}	0.490	**
C18:1 n-9t	2.62^{a}	1.50^{b}	2.22^{ab}	0.284	*
C18:1 n-9c	23.58^{b}	22.61^{b}	32.0^{a}	0.826	***
C18:2 n-6t	0.13^{b}	0.13^{b}	0.22^{a}	0.019	**
C18:2 n-6c	16.62^{a}	20.02^{a}	8.92^{b}	1.265	***
C18:3 n-6	0.10	0.08	0.08	0.014	ns
C18:3 n-3	0.49^{a}	0.54^{a}	0.28^{b}	0.017	***
C20:0	0.09	0.03	0.07	0.018	ns
C20:1	0.28^{b}	0.26^{b}	0.45^{a}	0.049	*
C20:2	0.12	0.12	0.11	0.022	ns
C20:3 n-6	1.02	1.21	1.04	0.117	ns
C20:4 n-6	5.27^{ab}	6.16^{a}	4.05^{b}	0.526	*
C20:5 n-3	0.36^{a}	0.29^{a}	0.15^{b}	0.032	***
C22:2	0.09^{a}	0.00^{b}	0.02^{ab}	0.029	ns
C22:6 n-3	0.05	0.02	0.02	0.022	ns
C24:1	0.28^{a}	0.00^{b}	0.20^{ab}	0.089	ns
SFA	45.63	43.86	45.61	1.175	ns
MUFA	30.09^{b}	27.56^{b}	39.48^{a}	1.137	***
PUFA	24.28^{a}	28.57^{a}	14.92^{b}	1.911	***
PUFA n-6	23.55^{a}	27.73^{a}	14.64^{b}	1.862	***
PUFA n-3	0.91^{a}	0.85^{a}	0.45^{b}	0.069	***
PUFA/SFA	5.44^{a}	6.59^{a}	3.31^{b}	0.550	**

[1] SEM: standard error of mean. [2] ns: $p>0.05$, *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$.

and palmitic acids; however, there were differences in most of the fatty acids between these two commercial categories. In summary, the percentages of the n-6 and n-3 PUFA were higher in the bulls compared to the steers, with a concomitant increase in the PUFA/SFA ratio in the bulls.

The instrumental muscle LT colour through 15 d of display is shown in Table 6. There was an interaction between the commercial category and time of display in terms of the lightness ($p<0.05$), and also lightness was affected by the commercial category ($p<0.01$) and time of display ($p<0.01$). The meat of the young bulls and bulls had a similar lightness evolution throughout the time of display ($p>0.05$), while the meat of the steers had lower values ($p<0.05$) at 2 d than on the other days. In general, the lightness of the meat of the bulls was lower than that of the young bulls and steers. With respect to the hue angle, there was an interaction between the commercial category and the time of display ($p<0.001$). Hue angle was also affected by the commercial category ($p<0.001$) and time of display ($p<0.001$). The meat of the young bulls exhibited a decrease in the hue angle from 1 d to 2 d and another decrease ($p<0.05$) from 12 d to 15 d, while the meat of the bulls and steers exhibited a slight increase in the hue angle during the latter period. The meat of the young bulls had greater values of hue angle throughout the time of display than the meat of the bulls and steers ($p<0.05$). The chroma of the three treatments decreased with time of display ($p<0.001$) and also was affected by the commercial category ($p<0.001$). The bulls and steers had a greater chroma than the young bulls at 1d ($p<0.05$), but the three commercial categories reached similar values at 15 d ($p>0.05$).

Table 6. Colour of *Longissimus thoracis* of young bulls (YB), bulls (B) and steers (ST) of 'Serrana de Teruel' breed.

	Commercial category, C [1]			SEM [2]	C	Time, T	C*T
	YB	B	ST				
Number of observations	7	7	6				
Lightness (L*)				0.945	**	**	*
1 d	39.90	37.18	40.31^{x}				
2 d	39.98^{a}	36.84^{b}	36.29^{by}				
5 d	40.59^{a}	37.46^{b}	40.68^{ax}				
8 d	40.01^{a}	35.94^{b}	38.82^{ax}				
12 d	40.73^{a}	36.99^{b}	38.61^{abx}				
15 d	39.71	37.87	40.66^{x}				
Hue angle (H*)				1.900	***	***	***
1 d	46.24^{az}	22.96^{bxy}	25.91^{bx}				
2 d	31.01^{ax}	20.54^{bx}	25.14^{abx}				
5 d	32.04^{ax}	22.85^{bxy}	27.58^{abxy}				
8 d	31.67^{ax}	21.41^{bxy}	23.42^{bx}				
12 d	37.57^{ay}	25.13^{bxy}	26.65^{bxy}				
15 d	29.91^{x}	26.48^{y}	30.27^{y}				
Chroma (C*)				0.671	***	***	ns
1 d	20.92^{bw}	22.40^{az}	22.98^{aw}				
2 d	18.69^{x}	19.95^{x}	19.57^{x}				
5 d	16.87^{xy}	18.16^{x}	18.09^{y}				
8 d	16.12^{ay}	17.57^{abxy}	19.00^{by}				
12 d	15.27^{ay}	16.83^{aby}	18.08^{by}				
15 d	14.82^{z}	15.13^{y}	15.38^{z}				

[1] Different letters (^{a,b,c}) mean differences between commercial categories within a display time ($p<0.05$). Different letters (^{w,x,y,z}) mean differences between display times within a commercial categories time ($p<0.05$). [2] SEM: standard error of mean. ns: $p>0.05$, *: $p<0.05$, **: $p<0.01$, ***: $p<0.001$.

Discussion

Morphometric measurements and carcass characteristics

Castration modifies the ADG due to the anabolic properties of the androgen hormones, among which testosterone has the greatest effect on muscle protein anabolism, given that its intake is not affected by castration (Biagini & Lazzaroni, 2007). Hence, it is often reported that bulls have greater ADG than steers (Purchas *et al.*, 2002; Keane, 2003; Bureš & Barton, 2012). However, steers and bulls of the present study showed statistically the same ADG. Related to this, difference of age at slaughter between young bulls and bulls was not enough to modify the ADG according to Kirkland *et al.* (2006) and Bureš & Barton (2012). Only steers had lower ADG than young bulls due to the concomitant effects of age and castration.

The skin thickness of the adult animals seems to be constant and it is not influenced by the breed. Álvarez-Rodriguez *et al.* (2009) reported that skin thickness of adult Parda de Montaña and Pirenaica cows ranged from 4 to 6 mm, respectively. In accord with this finding, Schröder & Staufenbiel (2006) reported general thickness values from 5 to 6 mm. The ultrasound dorsal fat thickness measurements show that, 'Serrana de Teruel' is an early maturing breed with greater dorsal fatness than other Spanish breeds, such as Parda de Montaña and Pirenaica at similar slaughter weights (Ripoll *et al.*, 2014). It is well known that steers have more subcutaneous fat than entire males, as indicated in a review by Field (1971). Testosterone has an inhibitory effect on the activities of the lipogenic enzymes in adipose tissue, inducing higher basal lipolytic rates (Prior *et al.*, 1983) thus, castrated animals could increase their fat deposits. From our results, it seems that the backfat measurement is a better measurement than dorsal fat area (13th rib) for highlighting the differences in fatness degree among beef types.

The slaughter weight had a strong influence on the *in vivo* and carcass morphometric measurements. When the carcasses increase in weight (Kempster *et al.*, 1988; Albertí *et al.*, 2005b), all carcass dimensions and assessments increased. Additionally, and in agreement with Biagini & Lazzaroni (2007), steers had lower

linear body measurements than entire males. This was because steers have lower muscular development than entire males, but the bone structure is not affected. However, the differences in weight and age were not sufficient to modify the dressing percentage, carcass conformation and fatness degree between young bulls and bulls. The dressing percentage of the steers in this study was similar to the Parda de Montaña and Pirenaica steers (Ripoll *et al.*, 2014) and greater than of the young of Avileña-Negra Ibérica bulls, as reported by Daza *et al.* (2012). In relation to fatness degree and conformation, the 'Serrana de Teruel' young bulls and bulls were closer to the medium meat-producing breeds than the low meat-producing breeds, according to the breed classification described by Albertí *et al.* (2005b). In this work, the entire bulls of Serrana de Teruel breed had carcasses with a greater conformation and lower degree of fatness than the castrated males. Androgens, such as testosterone, have a clear effect on bovine skeletal muscle through its specific receptors, stimulating muscular growth and explaining the sexual dimorphism of muscle growth (Sauerwein & Meyer, 1989).

Albertí *et al.* (2005b) found that the carcass fatness degree of seven breeds slaughtered at the young bull and bull categories was correlated with most of the same measurements of our study. These authors also found a strong and inverse correlation between fatness degree and carcass conformation. In disagreement with our results, Albertí *et al.* (2005b) reported a correlation between the carcass conformation and the measurements related to the leg volume (LW, LP, LD). These disparities could be because the carcasses in our study had great weight differences, and it has been shown that the SEUROP conformation score is influenced by the weight of the carcasses (Díez *et al.*, 2006). When the relationships between these variables were studied in each treatment group, random and inconsistent correlations were found. These correlations were unreliable likely because of the low number of data per treatment group. Carcass linear measurements alone are not very useful to predict the tissular composition of the carcasses (Kempster *et al.*, 1982). However, ultrasound fat thickness has been successfully used to predict carcass meat yield in live animals (Hamlin *et al.*, 1995). The results of the present study of ultrasound fat thickness and fatness degree are not consistent. This inconsistence could be linked to methodological differences. While ultrasound measures fat thickness just at a point, fatness degree considers the whole carcass. Keane (2003) measured the fatness degree and fat depth at 10^{th} rib (with rule) of entire and castrate animals slaughtered at light and heavy weight. They found effect of sex and slaughter weight on fatness degree but just effect of slaughter weight on fat depth. It seems that fatness degree provides more information about subcutaneous fat cover of carcasses than isolated ultrasound measurements.

Young bulls and steers of the present study had duller fat colour than bulls. The colour of bovine subcutaneous fat depends on the age, gender and breed of cattle, but diet is the most important extrinsic factor and its influence depends on the duration of feeding (Dunne *et al.*, 2009). Fat colour is associated with the lipophilic pigments stored in the tissue. In the present study, age at slaughter did not influence carcass fat colour, and bulls and steers were fed silage the same period. Therefore, the differences in the storage of the carotenoid pigments may result from the differences in the dorsal fat thickness. Similar amounts of carotenoids could be diluted by great deposition of fat (Knight *et al.*, 2001). Hence, bulls would have more vivid fat colour than steers and young bulls because it had less fat thickness, measured with rule and ultrasounds, than young bulls and steers.

Meat quality

'Serrana de Teruel' is genetically close to Parda de Montaña and Pirenaica (Martín-Burriel *et al.*, 2007). However, carcasses of 'Serrana de Teruel' young bulls in this study were fatter than those of Parda de Montaña and Pirenaica, with dorsal fat thickness values from 3.4 to 4.6 mm (Ripoll *et al.*, 2014).

In our study, meat from males (young bulls and entire bulls) was tougher than the steers, according with the results of other authors (Field, 1971; Shackelford *et al.*, 1992; Purchas *et al.*, 2002). This lower toughness could be due to lower hydroxyproline content (Boccard *et al.*, 1979; Destefanis *et al.*, 2003) because of the lack of the anabolic effects of testosterone on collagen synthesis. Beside of this, the steers of the present study had greater percentage of intramuscular fat, and it is reported that intramuscular fat is inversely related with shear force (Destefanis *et al.*, 2000). However, other studies have reported a negative effect of intramuscular fat on meat toughness (Fiems *et al.*, 2000) or no relationship at all (Cabaraux *et al.*, 2004; Ripoll *et al.*, 2014).

The oxidation in meat depends on the balance between antioxidant and pro-oxidant agents in the muscle (Morrissey *et al*., 1998). However, we can summarize the balance, on the one hand, the amount of antioxidants and activity of antioxidant enzymes in the muscle; and secondly the quantity and type of fat, and the amount of myoglobin present in the muscle. High content of fat, and great proportion of unsaturated fatty acids contribute to increased oxidation of the meat (Monahan, 2000). Also, older animals have a higher activity of

antioxidant enzymes such as catalase, superoxide dismutase and glutathione peroxidase (Cho *et al*., 2015). However, we did not find differences in TBARS due to intramuscular fat content between steers and entire animals, or due to age between young bulls and bulls. Regarding the threshold value of TBARS to reject the meat, there are no concluyent studies Campo *et al.* (2006) reported that trained panellist found oxidized flavours at 2 mg/kg, while Greene & Cumuze (1982) reported values from 0.6 to 2 mg/kg in an experiment with inexperienced panellists. However, White *et al.* (1988) reported that the threshold of consumers was 6.3 mg MDA/kg of meat. Thus, considering these limits, the meat of the three commercial categories at 7 days of ageing is acceptable to consumers.

According to their percentages, the dominant fatty acids of intramuscular fat were oleic, palmitic, cis-linoleic and stearic acids, which was similar to the results described by Monteiro *et al.* (2006) and Daza *et al.* (2012). The increase in the slaughter weight of the bulls compared to the young bulls did not affect to the mean fatty acid groups or the PUFA/SFA ratio, which was similar to the results described by De Smet *et al.* (2004) and Nogalski *et al.* (2014). The greatest differences between bulls and steers were in the percentages of oleic, cis-linolenic and palmitic acids. However, there were differences in most of the fatty acids between these two commercial categories. In addition, Eichhorn *et al.* (1985) also found that castrates had higher values of C14:0, C15:0, C16:0, C16:1 cis-9 and C18:1 cis-9 and lower values of C18:2 n-6, C18:3 n-3 and C20:4 n-6 than entire males. Several authors (Prior *et al.*, 1983; Monteiro *et al.*, 2006) suggested that testosterone has an inhibitory effect on the activities of the lipogenic enzyme and increases the basal lipolytic rates. This leads to differences in the degree of fatness and associated changes in the triacylglycerol/phospholipid ratio (De Smet *et al.*, 2004; Nogalski *et al.*, 2014).

Regarding the instrumental LT muscle colour through 15 d of display, the heterogeneous first-order autoregressive matrix was selected for the statistical analyses of the lightness, hue angle and chroma, which is in agreement with Ripoll *et al.* (2014). When beef colour is measured over a long period of time of display, the variances of these variables increase over time and the covariances decline exponentially, resulting in a good fit to the aforementioned variance-covariance matrix. The increase in chroma over time of display indicates that the beef colour is duller than it was at the beginning of the measurements. An increase in the hue angle during the last days of meat display is often related to the discoloration of the meat (Albertí *et al.*, 2005a). Using an algorithm that relates the visual appraisal with the instrumental colour (Ripoll *et al.*, 2012), the meat from the young bulls and steers were assessed as very bright red at 1 d, while meat from bulls was assessed as bright red at this time point. Concomitant with the lightness and chroma, the visual appraisal decreased over time of display. The meat from young bulls and steers maintained a red colour until 15 d, while the meat from bulls would be classified as dark red or brown at 12 d and 15 d. In a study that slaughtered seven bovine breeds at three weight-based commercial categories, the results showed that, in general, heavy bulls had a reduced lightness and hue angle than light bulls (Albertí *et al.*, 2003). On the other hand, the meat of bulls is often reported as darker than meat of steers (Martí *et al.*, 2013).

In conclusion, castration increased backfat and *post mortem* fat thicknesses and carcass fatness degree while decreased the weights, dressing percentage, conformation and blockiness index of carcasses. Castration also diminished the carotenoids stored in subcutaneous fat, diminishing concomitantly the chroma. In the same way, PUFA to SFA ratio, maximum stress were diminished due to castration, although odour intensities and acid flavour were increased. The increment of age at slaughter increased the *in vivo* and carcass morphometric measurements, blockiness index while decreased backfat and *post mortem* thicknesses. Carcass classification was not modified influenced by age as maximum stress and fatty acids composition. The increase of age increased chroma and the estimation of carotenoid pigment.

Hence, bulls produced great and well conformed carcasses with more edible meat and less fattened than the other categories. However, steers are recommended to produce great and fattened carcasses. Finally, it seems that bull commercial category is the most suitable to 'Serrana de Teruel' breed.

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