Instituto Nacional de Investigación y Tecnología Agraria y Alimentación (INIA)
Available online at www.inia.es/sjar

Spanish Journal of Agricultural Research 2008 6(4), 546-558
ISSN: 1695-971-X

Intrabreed variability and relationships for 41 carcass and meat traits in Pirenaica cattle

B. Panea[1]*, P. Albertí[1], J. L. Olleta[2], M. M. Campo[2], G. Ripoll[1], J. Altarriba[2] and C. Sañudo[2]

[1] *Unidad de Tecnología en Producción Animal. Centro de Investigación y Tecnología Agroalimentaria del Gobierno de Aragón. Avda. Montañana, 930. 50080 Zaragoza, Spain.*

[2] *Departamento de Producción Animal y Ciencia de los Alimentos. Universidad de Zaragoza. Miguel Servet, 177. 50013 Zaragoza. Spain.*

Abstract

A total of 125 13-month-old, entire males of the Pirenaica breed were selected from among the progeny of nine different sires. They were used to study the intrabreed variability of 41 carcass and meat traits, including weights, lengths, diameters and perimeters, grading parameters, dissection of the sixth rib, pH, colour and meat texture variables, and sensory attributes. Pearson correlations were also calculated. Coefficients of variation ranged from 3.5% for dressing percentage to 47.0% for fat red index, and all of the values could be considered within the normal range for cattle. Carcass traits showed lower variability (11.7% on average) than meat variables (14.8% on average). Hence, to achieve a standardised product, it would be desirable to include in the breeding selection programme a variable that could be measured on the carcass and that can predict meat quality. Nevertheless, from the results of the present study, none of the variables studied fulfil this requirement, and further studies would be necessary to widen our knowledge on this subject.

Additional key words: beef, linear measurements, meat instrumental quality, sensory quality.

Resumen

Variabilidad intra-racial y relaciones entre 41 características de canal y carne en la raza Pirenaica

Se han utilizado 125 animales de raza Pirenaica, machos enteros de 13 meses de edad, descendientes de nueve toros, para medir la variabilidad intra-racial de 41 variables de canal y carne, incluyendo pesos, longitudes, diámetros y perímetros, escalas de clasificación, disección de la 6ª costilla, pH, variables de color y textura y atributos sensoriales. Se han calculado las correlaciones de Pearson. Los coeficientes de variación variaron del 3,53% para el rendimiento de la canal al 47,04% para el parámetro a* de la grasa, y estuvieron dentro del rango normal para el ganado vacuno. Las variables de canal mostraron menor variabilidad (11,75% de media) que las variables de carne (14,84% de media). Por lo tanto, para conseguir un producto más homogéneo, sería deseable incluir en el esquema de selección alguna variable que se pudiera medir en la canal y que fuera capaz de predecir la calidad de la carne. Sin embargo, ninguna de las variables estudiadas reúne estos requisitos, por lo que son necesarios más estudios en este sentido.

Palabras clave adicionales: calidad instrumental de la carne, calidad sensorial, medidas lineales, vacuno.

---

* Corresponding author: bpanea@aragon.es
Received: 11-09-07. Accepted: 24-07-08.

Abbreviations used: CV (coefficient of variation), EU (European Union), SED (standard error), WHC (water holding capacity).

Introduction

Beef production is of great importance throughout Europe. European Agricultural Policy has been developed to encourage the use of local breeds to develop sustainable animal production (Piedrafita *et al.*, 2003). However, the persistence of a population is partially linked to its ability to meet current market requirements, and persistence depends on carcass and meat quality. Consequently, within the scope of the European Union (EU), identifying and describing breed-dependent traits related to carcass and meat quality have gained in interest over recent years because satisfying consumer requirements is essential for producers (Renand *et al.*, 2001). Traditionally, producers have selected sires for their productive and morphological aspects, including live or carcass weight, because these aspects are considered more important than those related to meat quality.

An abundance of literature has been generated on the study of breed effect on carcass and meat characteristics (Chambaz *et al.*, 2003; Keane, 2003; Piedrafita *et al.*, 2003; Özlütürk *et al.*, 2004; Albertí *et al.*, 2005), but there is little information regarding the intrabreed variability of carcass and meat traits, especially in beef cattle. Furthermore, the practical implications of having information about quality parameters related to bull sires has not been extensively studied in the international literature addressing carcass or meat quality (Maher *et al.*, 2004; Altarriba *et al.*, 2005). Intrabreed variability would be of major interest to breeders; to be competitive through an identifiable brand, they have to be able to offer the market a homogeneous product.

The aim of this study was to quantify intrabreed variation in carcass and meat quality characteristics of Pirenaica cattle and also to highlight the differences between carcasses grouped by the corresponding sire's selection index. The selection index was the weight of progeny at 210 days, and it is the current criterion used by the Breeders' Association to determine whether or not to maintain the sires in the selection programme.

Material and methods

Animals

Pirenaica is a beef-specialised breed located on the southern slopes of the Pyrénées in NE Spain. More information on this breed's productive traits and ethnologic characteristics can be found in Sánchez-Belda (2002) and Piedrafita *et al.* (2003). Beef production with the Pirenaica breed is based on maximising the use of grazing lands. Calving generally occurs in the first third of the winter season, and calves suck milk directly from the mother until they are put out for spring grazing. In spring, they accompany their mothers to alternate a milk diet with the consumption of grass. On returning from the summer grazing pastures, calves are weaned (about 5 to 7 months of age) and reared indoors with an *ad libitum* concentrate diet, reaching the market with a 450-kg live weight at around 12 months of age (Sánchez-Belda, 2002).

A total of 125 young males were used (Table 1). All animals were descendants of nine sires, which were those being used for artificial insemination in the Breeders' Association reproduction programme at the time of the study. Once weaned, young bulls were fed at the National Centre of Animal Selection and Reproduction (Zaragoza, Spain) on a rearing concentrate until they were 11 months old, followed by a fattening period of two months with concentrate until slaughter. Concentrate and cereal straw were provided *ad libitum*. During the rearing period, the diet consisted of 90.3% dry matter, 17.6% crude protein, 5.4% fibre, and 5.3% crude fat, with 140.4 g kg^{-1} of digestible protein. For the fattening period, the diet characteristics were 89.9% dry matter, 14.2% crude protein, 4.9% fibre, 5.0% crude fat, and 114.2 g kg^{-1} of digestible protein.

Slaughtering was established at 13 months of age, and the day prior to slaughter, the animals were weighed (live slaughter weight). EU welfare regulations were followed when handling the animals. Animals were slaughtered at the nearest EU-licensed abattoir, at a distance of 30 km, to minimise the transport stress effect. Stunning was performed by captive bolt pistol. Just after slaughter, the left forelimb autopod was removed and weighed and its length and perimeter measured. Carcass dressing was undertaken according to standard commercial practice. Carcasses were chilled at 4 ±1ºC for 24 h.

Carcass quality

The following variables were recorded:

– Hot carcass weight, measured without removing subcutaneous fat and maintaining the testicles and kidney, channel, and pelvic fat. The tail remained on the right half carcass.

Table 1. Means, coefficient of variation (CV), and minimum and maximum values for carcass traits of Pirenaica young bulls (n=125)

	Mean	CV	Minimum	Maximum
Live slaughter weight (kg)	582	11.24	397	760
Autopod weight (kg)	2.6	11.15	1.6	3.2
Autopod length (cm)	34.08	6.28	19.50	39.00
Autopod perimeter (cm)	21.48	5.59	18.30	25.00
Hot carcass weight (kg)	371.86	12.35	240.80	493.90
Dressing percentage	63.81	3.53	58.25	69.68
Blockiness index (kg cm^{-1})	2.87	10.10	2.01	3.50
Conformation (EUROP)	11.40	15.79	7.00	15.00
Fatness (EUROP)	5.21	20.35	3.00	8.00
Carcass length (cm)	129.52	3.78	118.50	145.00
Carcass width (cm)	60.79	3.82	54.00	68.00
Hind limb length (cm)	80.62	3.87	70.00	87.50
Hind limb width (cm)	30.13	7.24	25.00	36.00
Hind limb perimeter (cm)	123.76	4.94	107.50	139.50
Hind limb depth (cm)	45.07	4.84	40.00	52.00
Loin length (cm)	56.43	4.84	43.50	62.00
Loin area (cm^2)	48.61	18.10	27.66	77.40
Loin medial-lateral diameter (cm)	9.29	9.26	7.14	11.33
Loin dorsal-ventral diameter (cm)	6.32	15.19	4.23	9.10
Fat L*	73.43	5.94	46.00	83.67
Fat a*	3.89	47.04	0.43	13.30
Fat b*	5.23	33.27	1.40	11.33
Muscle percentage	74.60	4.93	63.15	82.81
Fat percentage	9.69	28.59	3.51	17.23
Bone percentage	14.39	14.80	9.67	21.96
Other percentage	1.32	25.76	0.59	2.37

- Dressing percentage, calculated as (hot carcass weight/slaughter weight)*100.
- Conformation score was graded according to the EUROP classification (R.(EEC) no. 1208/81, 2930/81, and 1026/91) with a scale ranging from 15 (very good conformation) to 1 (very poor conformation) (Piedrafita *et al.*, 2003).
- Fatness score was measured on a 1–15 scale (1, very low fat; 15, very high fat). With respect to a 1–5 classification, the equivalence of the scale used was 1-, 1, 1+, 2-, 2, 2+, 3-, 3, 3+, 4-, 4, 4+, 5-, 5, and 5+ (Piedrafita *et al.*, 2003).
- Several morphological measurements were taken on the left half carcass, according to the methodology described by De Boer *et al.* (1974): carcass length, carcass width, hind limb length, hind limb width, hind limb perimeter, hind limb depth, and loin length. From these measurements, blockiness index [hot carcass weight (kg)/ carcass length (cm)] was calculated. Higher blockiness index values indicate higher muscular development (Albertí *et al.*, 2001).
- Loin area: the left half of the carcass was quartered, and the area of the *Longissimus thoracis* muscle, at the fifth–sixth rib level, was drawn with a marker used on acetate paper covering the surface of the loin; the area was later measured by planimetry using a digital planimeter, the Placom KP-82. Medium-lateral and dorso-ventral diameters (A and B, respectively) were also measured (Albertí *et al.*, 2007).
- The sixth thoracic rib joint was extracted (24 h *post-mortem*). The weight of the rib joint was recorded, and the *L. thoracis* muscle was weighed and separated for instrumental analysis, while the rest of the rib joint was vacuum-packaged and frozen at -18ºC until dissection. Tissue composition (muscle, bone, fat, and other) was estimated from the thawed rib

joint (Robelin and Geay, 1975). Results are expressed as a percentage of the entire rib weight.

Subcutaneous fat colour and meat quality

The colour of the subcutaneous fat was measured 24 h after slaughter on the carcass using a Minolta CM-200 spectrophotometer with a D65 illuminant and a 10º standard observer in the CIE L*a*b* space (Commission Internationale de l'Eclairage, 1976). Afterwards, the pH of the *L. thoracis* muscle at the lumbar region level was measured with a CRISON pH meter equipped with a penetration electrode. Subsequently, the *L. thoracis* muscle was removed from the left side of the carcass (between the seventh and ninth hemi-vertebrae).

Meat quality parameters were determined according to the guidelines of Honikel (1998) and Cañeque and Sañudo (2000).

The day after slaughter, meat colour was measured in the *L. thoracis* (sixth rib level) muscle, after 2 h of air exposure, with a Minolta CM-2002 spectrophotometer with a D65 illuminant and a 10º standard observer in the CIE L*a*b* space. This sample was then placed on a polystyrene tray wrapped with oxygen-permeable plastic film and kept at 2–4ºC until the seventh day *post-mortem*. The pH at 7 days *post mortem*, haem pigment concentration (Hornsey, 1956), and water-holding capacity were measured using a compression method (Grau and Hamm, 1953).

The rest of the *L. thoracis* muscle was sliced into 3.5-cm–thick steaks for instrumental analysis or 2-cm–thick steaks for sensory analysis. Steaks were vacuum packaged and aged for 7 d at 2–4ºC. All samples were frozen and stored at –18ºC until further analysis.

For texture analysis, steaks were thawed in tap water for 4 h until they reached an internal temperature of 16–19ºC. Samples with a 1-cm^2 cross-section were cut with muscle fibres parallel to their longitudinal axis. The texture of raw meat was analysed with an Instron 4301 using a modified compression device that avoids transversal elongation of the sample (Lepetit and Culioli, 1994). Maximum load (N) and stress at 20% and 80% of maximum compression (N cm^{-2}) were recorded.

Sensory analyses were carried out by an 11-member panel, trained in accordance with ISO 8586-1 (1993), with additional methods specifically for meat. Steaks were thawed inside their vacuum bags with tap water at 16–19ºC and then wrapped in aluminium foil and cooked to an internal temperature of 70ºC on a double plate grill preheated to 200ºC. The internal temperature of the sample was monitored with a data logger using a thermocouple probe, inserted horizontally to the midpoint of the steak. Thawed and cooked steaks were weighed, and cooking losses were calculated. The core portion of the steaks was cut into 11 pieces. Each sub-sample was immediately wrapped in aluminium foil, codified, and kept at 60ºC. Panellists evaluated samples in individual booths under red lights. Three steaks from each animal were assessed. Each sensory evaluation session consisted of 12 randomly selected loin samples. The 12 subsamples were tasted by each panellist in a different order in each session. Panellists were asked to rate beef odour intensity, tenderness, juiciness, and beef flavour intensity, using a 1–100 unstructured line scale, in which 1 represented the lowest and 100 the highest value for the attribute under consideration.

Statistical analysis

Statistical analysis was performed using the SPSS statistical package (13.0). Means, coefficients of variation, minimum and maximum values, and Pearson's correlation coefficients were calculated for all variables.

A k-means cluster analysis was performed to study the cluster of sires based on their descendants' weight at 210 d of age. An ANOVA with the cluster grouping as the fixed effect was carried out to establish if there were any relationships between this common criterion and the meat quality of the descendants. Finally, an ANOVA procedure was performed with the group as the fixed effect, co-varying by slaughter weight.

Results

Means, coefficients of variation (CV), and minimum and maximum values for the variables studied are shown in Table 1 for carcass traits and dissection data and in Table 2 for meat quality characteristics. The average CV for the pooled data was 14.0%, but the spread of the CV depended on the variable considered. The CV for carcass weight was 11.2%, whereas dressing percentage had a low CV (3.5%). The pH showed the lowest CV, both at 24 h and at 7 d (1.8 and 1.4%, respectively). Regarding meat colour, the L* of the muscle was less variable than a* or b*, and muscle b* had a CV that was nearly twice that of a*. Considering water losses, it can be seen that the CV was higher for cooking losses than

Table 2. Means, coefficient of variation (CV), and minimum and maximum values for meat quality characteristics of muscle *Longissimus thoracis* (n=125)

	Mean	CV	Minimum	Maximum
pH 24 h	5.50	1.82	5.36	5.98
pH 7 d	5.53	1.45	5.35	5.87
Muscle L*	37.23	8.35	25.41	46.98
Muscle a*	21.05	12.97	14.84	28.89
Muscle b*	12.12	22.52	7.09	18.67
Myoglobin (mg g^{-1} wet weight)	3.43	19.24	2.20	5.40
Water holding capacity (%)	22.52	12.17	14.70	29.30
Cooking losses (%)	17.29	17.12	11.43	25.72
Maximum load (N)	40.84	3.82	22.84	65.38
Stress at 20% of maximum load (N cm^{-2})	6.38	43.26	3.10	13.84
Stress at 80% of maximum load (N cm^{-2})	27.36	27.78	16.12	54.85
Beef odour intensity (1–100)	52.61	8.29	39.86	63.45
Juiciness (1–100)	47.02	16.74	30.67	70.06
Tenderness (1–100)	54.94	17.58	26.90	79.22
Beef flavour intensity (1–100)	54.36	9.46	24.32	64.57

for water holding capacity (WHC). A higher CV was found for stress at 20% (43.3%) than for stress at 80% (27.8%) and maximum load (23.8%).

Table 3 shows the selection index of each sire and the centroid of each cluster. After clustering, bulls remained in three groups (Table 3). Group 1 included sires with negative indexes, lower than average; group 2 included sires with average indexes; and group 3 included sires with positive indexes. Average values for carcass, subcutaneous fat, and meat quality traits for every group are shown in Table 4. There appear to be statistical differences among the groups for the majority of the variables studied. Thus, animals with a positive selection index had greater carcass traits (conformation score, muscle percentage, morphological measurements, and loin surface) than those from the other two groups.

Table 3. Cluster analysis to group nine different sires by their selection index (descendant weight at 210 days)

Bull number	Selection index
1	3.8
2	-9.1
3	16.7
4	-26.9
5	-28.4
6	-5.0
7	21.1
8	-7.0
9	-12.1
Cluster	**Centroid of each cluster**
1	-27.99
2	-4.85
3	19.80

Correlation coefficients between carcass traits are shown in Table 5, and Table 6 shows the correlation between meat quality characteristics. In general, several significant correlations were found among carcass traits, but they were scarce among meat quality characteristics. The highest correlation coefficient was established between maximum load and compression stress at 80% of compression.

Table 7 shows correlations between carcass and meat characteristics. There were a number of significant correlations, but in general coefficients were low. Animals with heavier and better-conformed carcasses tended to have a lower pH, both at 24 h and at 7 d. On the other hand, hot carcass weight was significant and negatively correlated with L* and positively with the a* of the muscle, although this fact is not so clear in a comparison of the bull sire groups according to the weight of their progeny at 210 days.

Discussion

The current results for all the parameters studied were normal within the Pirenaica breed, and they are in

Table 4. Means, standard error (SED), and significance (p value) for all carcass and meat variables studied, with the index selection group as the fixed effect. Adjusted p value was the significance when data were co-varied by slaughter weight

	Group 1	Group 2	Group 3	SED	p	Adjusted p
Selection index of sire	-24.22	-3.72	19.80			
Slaughter weight (kg)	564.92 [b]	577.90 [b]	616.7 [a]	32.71	0.005	-
Hot weight carcass (kg)	356.22 [b]	368.93 [b]	400.41 [a]	27.63	0.000	0.019
Dressing carcass (%)	63.00 [b]	63.83 [b]	64.91 [a]	1.18	0.003	0.023
Conformation score (1–15)	10.47 [c]	11.47 [b]	12.56 [a]	1.29	0.000	0.001
Fatness score (1–15)	5.24	5.22	5.15	0.06	0.943	0.486
Autopod weight (kg)	2.69	2.64	2.77	0.09	0.159	0.014
Autopod length (cm)	33.79 [b]	33.85 [b]	35.02 [a]	0.85	0.036	0.443
Autopod perimeter (cm)	21.84 [a]	21.13 [b]	21.73 [a]	0.58	0.007	0.000
pH at 24 h	5.53 [a]	5.50 [ab]	5.47 [b]	0.03	0.082	0.032
Carcass length (cm)	128.9	129.3	130.9	1.29	0.234	0.497
Carcass width (cm)	60.0 [b]	60.8 [b]	62.0 [a]	1.27	0.002	0.282
Hind limb length (cm)	80.2 [b]	80.3 [b]	81.9 [a]	1.21	0.042	0.650
Hind limb width (cm)	29.8 [b]	29.9 [b]	31.1 [a]	0.91	0.025	0.529
Hind limb perimeter (cm)	121.9 [b]	123.2 [b]	127.6 [a]	3.66	0.000	0.116
Hind limb depth (cm	44.7 [b]	44.8 [b]	46.2 [a]	1.03	0.008	0.324
Loin length (cm)	55.4 [b]	56.9 [a]	56.8 [a]	1.21	0.015	0.006
Blockiness index (kg cm^{-1})	2.76 [b]	2.85 [b]	3.05 [a]	0.18	0.000	0.044
Loin area (cm^2)	46.70 [b]	46.5 [b]	56.54 [a]	7.21	0.000	0.000
A (cm)	9.07	9.41	9.33	0.26	0.157	0.177
B (cm)	6.40 [b]	5.91 [c]	7.14 [a]	0.83	0.000	0.000
Muscle %	73.24 [b]	74.87 [ab]	75.94 [a]	1.72	0.010	0.023
Fat %	10.48 [a]	9.55 [ab]	5.62 [b]	1.00	0.064	0.029
Bone %	14.81 [a]	14.44 [ab]	13.68 [b]	0.70	0.104	0.518
Other %	1.47 [a]	1.15 [b]	1.49 [a]	0.28	0.000	0.000
L* of subcutaneous fat	74.51	72.82	73.41	1.26	0.176	0.223
a* of subcutaneous fat	4.09	3.64	4.10	0.39	0.386	0.338
b* of subcutaneous fat	5.10	5.13	5.62	0.36	0.411	0.471
L* of muscle	36.93	37.72	36.59	0.83	0.226	0.246
a* of muscle	21.50	20.72	21.18	0.59	0.377	0.263
b* of muscle	11.61	12.32	12.42	0.60	0.375	0.275
pH at 7 d	5.55	5.53	5.49	0.03	0.017	0.168
Myoglobin (mg g^{-1})	3.62 [a]	3.26 [b]	3.52 [ab]	0.28	0.021	0.009
WHC (%)	22.70 [ab]	21.97 [b]	23.49 [a]	1.03	0.051	0.158
Stress at 20% (N cm^{-2})	5.65 [a]	6.30 [a]	3.52 [b]	1.19	0.020	0.119
Stress at 80% (N cm^{-2})	30.10 [a]	25.70 [b]	27.26 [ab]	3.26	0.020	0.022
Maximum load (N)	44.80 [a]	38.66 [b]	40.09 [b]	4.64	0.008	0.028
Cooking losses (%)	12.28 [b]	16.46 [ab]	17.71 [a]	1.41	0.008	0.010
Odour intensity (1–100)	52.36	53.05	52.01	0.75	0.546	0.656
Tenderness (1–100)	54.69	55.01	55.14	0.29	0.981	0.994
Juiciness (1–100)	46.76	47.02	47.40	0.39	0.950	0.946
Flavour intensity (1–100)	55.17 [ab]	53.16 [b]	55.85 [a]	2.02	0.039	0.070
Overall appraisal (1–100)	51.49 [a]	44.82 [b]	48.95 [ab]	5.11	0.003	0.001

Rows with different letters indicate significant differences (at least p≤0.05) between groups.

agreement with the data from several studies of the same breed (Albertí *et al.*, 1995; Campo *et al.*, 1998; Sañudo *et al.*, 2001) or of other European beef breeds (Crouse *et al.*, 1985, in Angus and Simmental; Jurie *et al.*, 1995, in Limusin; Destefanis *et al.*, 1996, in Piemontese and Belgian Blue and White; Chambaz *et al.*,

Table 5. Correlation coefficients (r) between carcass traits. Only significant correlations (at least p≤0.05) are shown

Carcass traits	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Autopod weight (1)	0.55	0.67	0.68		0.56	0.20	0.31	0.73	0.49	0.66	0.42	0.52	0.47	0.51	0.23				0.22		0.22
Autopod length (2)		0.39	0.44		0.37		0.26	0.46	0.44	0.63	0.27	0.37	0.39	0.35	0.18						0.22
Autopod perimeter (3)			0.52		0.43		0.23	0.54	0.33	0.45	0.40	0.36	0.37	0.29	0.19		0.19		0.21		0.23
Hot carcass weight (4)				0.44	0.96	0.61	0.22	0.71	0.61	0.63	0.77	0.81	0.64	0.59	0.51	0.29	0.36	0.19		0.40	
Dressing percentage (5)					0.58	0.62	-0.21				0.54	0.52	0.33		0.42	0.18	0.35	0.59	-0.43	-0.44	
Blockiness index (6)						0.67		0.49	0.55	0.52	0.78	0.82	0.60	0.47	0.52	0.28	0.37	0.28		-0.44	
Conformation (7)								0.21	0.24		0.69	0.68	0.55		0.51	0.19	0.39	0.39	-0.23	-0.38	
Fatness (8)								0.34	0.29	0.20				0.23				-0.38	0.57		
Carcass length (9)									0.54	0.67	0.43	0.47	0.50	0.67	0.31	0.20	0.20		0.23		0.29
Carcass width (10)										0.53	0.34	0.40	0.26	0.46	0.28		0.19				
Hind limb length (11)											0.34	0.45	0.39	0.58	0.19						
Hind limb width (12)												0.76	0.64	0.28	0.55		0.45	0.28		-0.42	
Hind limb perimeter (13)													0.78	0.36	0.48	0.19	0.32	0.35	-0.21	-0.35	
Hind limb depth (14)														0.31	0.42		0.34	0.22	-0.18	-0.19	0.25
Loin length (15)															0.19	0.28			0.23		
Loin area (16)																0.31	0.83	0.27		-0.32	0.25
Medium-lateral diameter (17)																		0.23		-0.18	
Dorso-ventral diameter (18)																				-0.25	0.41
Muscle % (19)																			-0.81	-0.62	-0.27
Fat % (20)																					0.26
Bone % (21)																					
Other % (22)																					

2003, in Angus, Simmental, Charolais and Limousin; and Albertí *et al.*, 2007, in 15 European breeds). Compared with other Spanish cattle breeds, the Pirenaica is a medium-sized breed, with a well-shaped, lean carcass, light subcutaneous fat, light pink meat, and low values for texture variables. It is also characterised by having a tender, mild-flavoured meat (Albertí *et al.*, 1999; Campo *et al.*, 2000; Gil *et al.*, 2001; Panea, 2002; Albertí *et al.*, 2003; Piedrafita *et al.*, 2003).

Variability of carcass quality traits, morphological measurements, and dissection data

The identified CV for carcass weight was very similar to data published by various authors with regard to several European beef breeds (11.2% for Albertí *et al.*, 2005; 6.8% for Biaggini and Lazzaroni, 2005; and 10% for Jurie *et al.*, 1995). In the same way, the present result for CV in dressing percentage was in accordance with those of most of authors (Barton and Pleasants, 1997, in several British breeds; Piedrafita *et al.*, 2003). The similar CV for live and carcass weights and the low CV for dressing percentage suggest homogeneity in live breed performances, considering that the animals were slaughtered at a similar age.

In general, morphological measurements showed a low CV, and the results obtained agree with those reported by other authors (Piedrafita *et al.*, 2003; Özlütürk *et al.*, 2004; Albertí *et al.*, 2005). In the dissection variables, it can be seen that the CV for bone and fat percentages was around three and five times greater than the muscle percentage, respectively. The same pattern has previously been described by other authors (Subrt and Divis, 2002; Piedrafita *et al.*, 2003; Farmer *et al.*, 2004).

The high variability found for conformation and fatness scores was not surprising; Albertí *et al.* (2005) reported a CV of around 30% for both traits, and Piedrafita *et al.* (2003) reported a CV of 16% for conformation and a CV of 20.5% for fatness scores, even when intrabreed variability in carcass weight was low (5%). Nevertheless, the high variability in grading parameters

Table 6. Correlation coefficients (*r*) between meat quality characteristics. Only significant correlations (at least p<0.05) are shown

Meat quality characteristics	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
pH 24 h (1)			0.25	0.38					0.21			-0.24		-0.18	-0.19		
pH 7d (2)						0.21	-0.33	0.20									-0.25
Fat L* (3)			-0.32	-0.19				-0.19									
Fat a* (4)				0.69				0.28									
Fat b* (5)						-0.29	-0.24		0.19								-0.18
Muscle L* (6)						-0.50		-0.47							-0.29		
Muscle a* (7)							0.41	0.38				0.21	0.19		0.36		
Muscle b* (8)																	
Myoglobin (9)											0.28		0.20				-0.20
Water holding capacity (10)										0.22		0.20		-0.29			
Cooking losses (11)																-0.51	
Maximum load (12)												0.22	0.84				
Stress at 20% (13)													0.40				
Stress at 80% (14)															0.26		
Beef odour intensity (15)																	
Juiciness (16)																0.31	0.23
Tenderness (17)																	0.47
Beef flavour intensity (18)																	

may indicate that an additional tool should be taken into account to correctly classify carcasses, chiefly when very similar carcasses are compared. The use of a blockiness index for this purpose has already been suggested by Díez *et al.* (2006) and Albertí *et al.* (2007). According to Albertí *et al.* (2005), these inter-animal differences in shape and morphological measurements are mainly due to variability in transversal measurements of the carcass more than to the variability of longitudinal measures. Thus, it could be assumed that transversal measurements are those that actually define conformation scores. Additionally, the most variable morphological measurement was specifically hind limb width, which could also help to explain the high variability found for the conformation score.

Diameters of the *L. thoracis* muscle are scarce in the literature, but the area of muscle is often measured. A CV of around 14% for the rib area was described by Jones and Tatum (1994) in commercial cattle; a CV of 5% to 8% was shown by Özlütürk *et al.* (2004); and values of around 17% were calculated from data presented by Piedrafita *et al.* (2003). In some European markets such as Spain, carcass price depends on conformation; well-rounded, well-conformed carcasses are the most sought by wholesalers (Bello and Calvo, 2000), who use roundness of limb and shoulder and thickness of loin to estimate the proportion of prime cuts of saleable meat. Carcass fat colour is an important attribute for the beef market. It can be observed that the L* of fat was much less variable than the a* or b* parameters. In lean carcasses, such as in the present study, it is difficult to find areas with enough fat thickness to reliably measure the fat colour.

Physical, chemical, and sensory variables

The very low CV for pH represents good pre-slaughter management and underlines the fact that the Pirenaica breed is rarely affected by stress and pH problems (Albertí *et al.*, 1991, 1995).

The same ratio calculated in the present study among the L*, a*, and b* parameters can be calculated from data presented by other authors (Albertí *et al.*, 1999; Gil *et al.*, 2001; Serra *et al.*, 2004). The b* values depend on diet (Bidner *et al.*, 1986), pH (Albertí *et al.*, 1999), and the chemical state of myoglobin (Lindahl *et al.*, 2001). Furthermore, the CV for myoglobin content was higher

Table 7. Correlation coefficients (*r*) between carcass traits and meat quality characteristics

	pH 24	pH7	Fat L*	Fat a*	Fat b*	Muscle L*	Muscle a*	Muscle b*	Mb[1]	WHC	Cooking	Max[2]	C20[3]	C80[4]	Odour	Juiciness	Tenderness	Flavour
Autopod weight						-0.19	0.20		0.24		0.21							
Autopod length															-0.29			
Autopod perimeter						-0.33	0.24		0.32		0.22							0.26
Hot carcass weight		-0.32				-0.19	0.33	0.18					0.28					
Dressing (%)	-0.27	-0.40		-0.18				0.39	-0.32			-0.18	0.20					
Blockiness index		-0.37					0.33	0.26					0.29					
Conformation	-0.19	-0.30	0.26	-0.22			0.22					-0.30	0.27				0.18	
Fatness			-0.22	0.18			0.27		0.36			0.21						0.23
Carcass length						-0.22	0.20		0.32						-0.20			0.19
Carcass width		-0.19				-0.29	0.28		0.25				0.18		-0.20			
Hind limb length									0.19	0.20					-0.24			
Hind limb width		-0.29					0.30						0.37					
Hind limb perimeter		-0.32					0.21			0.22		-0.26	0.20					
Hind limb depth		-0.30					0.19			0.20		-0.27						
Loin length																		
Loin area		-0.36																0.22
Loin medial-lateral diameter											-0.20							
Loin dorsal-ventral diameter		-0.29												0.24	-0.18			0.23
Muscle %			0.23			0.19		0.18	-0.36	0.20		-0.34		-0.27				
Fat %	-0.22		-0.25			-0.28	0.33		0.44	-0.19		0.38		0.33				0.25
Bone %	0.20						-0.24	-0.23					-0.24					-0.20
Other %									0.22					0.19	-0.26			0.24

[1] Mb: myoglobin; [2] Max: Maximum load; [3] C20: stress at 20%; [4] C80: stress at 80%.

than for the a* parameter, which is in accordance with Albertí *et al.* (1999) but contrary to Serra *et al.* (2004). Because the samples did not have problems with pH and all animals employed in the experiment were fed on the same diet, there appear to have been greater differences between samples in relation to sensitivity to the oxidation process during the blooming period, in agreement with Maher *et al.* (2004), who reported that there are individual differences in the blooming process.

The current results for water losses are in accordance with those of most authors (Albertí *et al.*, 1999; Serra *et al.*, 2004). Comparison of water losses is not easy because of differences in methodology between laboratories. Thus, different authors have employed different methods to measure WHC (Albertí *et al.*, 1991; Irie *et al.*, 1996; Failla *et al.*, 2004). WHC is a result of events both prior to slaughter and following the *post mortem* changes, and it depends on several factors, including the nature of the force applied, which causes the displacement of the water (Rao *et al.*, 1989; Palka and Daun, 1999), the extent of *post mortem* myofibrillar shrinkage, and changes in the extracellular water compartments (Offer and Knight, 1988). Furthermore, different cooking methods are described in the literature: water bath (Destefanis *et al.*, 1996; Failla *et al.*, 2001; Lopes *et al.*, 2003), grill (Chambaz *et al.*, 2003; Lopes *et al.*, 2003; Failla *et al.*, 2004), pan (Jeremiah and Gibson, 2003), and oven (Crouse *et al.*, 1985; Jeremiah and Gibson, 2003; Lopes *et al.*, 2003; Serra *et al.*, 2004), as well as different cooking times. It is clear that cooking losses are influenced by the same factors as WHC, plus cooking method and time, which could explain the higher variability for cooking losses than for WHC.

The current CV results for texture variables were higher than those found in the literature (Campo *et al.*, 1999; Monson *et al.*, 2004; Failla *et al.*, 2004). Stress at 20% is related to the myofibrillar component (Lepetit and Culioli, 1994), and it is concerned with pre- and mainly post-slaughter handling, such as cooling or storage conditions. Improvement at this stage would thus be desirable to reduce variability.

Finally, the variability reported in the present study for sensory analysis variables is in accordance with results reported by Campo *et al.* (1999) or Sañudo *et al.* (2003) in their studies of Spanish cattle. Furthermore, Campo *et al.* (1999) showed that the evolution of sensory characteristics depends on the genotype of the animals and that each breed required a specific ageing period to reach its optimum state.

General effects of selection index

Animals with a positive selection index had greater carcass traits than those from the other two groups, in accordance with the conclusions offered by Altarriba *et al.* (2005). Weight at 210 d could therefore be an indicator of carcass quality. Also, meat quality parameters were significantly different, but the tendencies were not so clear because on most occasions, there was no increase or decrease of the variables in line with the selection index. Thus, sires with the best selection index were found to have the lowest rates at 20% of compression, but in other meat quality parameters, they showed average values. Furthermore, descendants of sires with an average selection index (group 2) showed lower myoglobin content, cooking losses, WHC, maximum load, and compression test at 80% values (which would desirable for consumers), but they also presented higher compression at 20% values and the lowest overall appraisal scores. Finally, the animals in group 1, which were those with the lowest indexes and poor carcass quality, nevertheless had desirable values in terms of overall appraisal. From these results, it has to be concluded that there is as yet no variable that can be measured online on carcasses to predict meat quality. Consequently, more studies are necessary to further our knowledge on this subject.

In general, there is not much literature relating selection index and meat quality in beef, although a better conformation score is not related to a superior meat quality in Charolais (Maher *et al.*, 2004). In pigs, however, most authors have reported that an improvement in carcass traits or lean meat produced a decrease in meat quality (Cameron *et al.*, 1990; Knapp *et al.*, 1997).

When p was adjusted by co-variate by slaughter weight, the significance of the effect remained mainly stable, except for 10 variables. For autopodus weight, the level of significance increased from p=0.159 to p=0.014, whereas in autopodus length, carcass width, hind limb length, hind limb width, hind limb perimeter, hind limb depth, pH at 7 days, WHC, and stress at 20%, the significance of the effect disappeared. Therefore, the effect of the selection index could be considered a consistent result.

Relationships between variables

Among carcass trait relationships, an especially important relationship was that between loin area and minimum diameter (r=0.83), demonstrating that variability in loin area is due to variability in dorso-ventral diameter rather than to any variability in medium-lateral diameter. It is also important to point out that muscle percentage was negatively related to both fatness and bone percentages, but that the relationship was greater with the former than with the latter. Therefore, it can be inferred that the heavier the carcass, the better conformation, more muscle, less fat, and less bone it has, as would be expected (Kempster *et al.*, 1982; Barton and Pleasants, 1997).

Considering relationships between meat quality characteristics, the identified relationship between maximum load and compression stress at 80% of compression has already been defined in previous works, showing its similar biological significance (Campo *et al.*, 2000; Panea, 2002). Myoglobin content was positively related to a* and negatively related to L*, indicating that a high myoglobin concentration was associated with redder, darker meat (Gil *et al.*, 2001; Insausti *et al.*, 2001; Serra *et al.*, 2004).

With regard to sensory traits, there was a positive correlation between juiciness and tenderness, which is frequent in the sensory analysis. The more tender the meat, the more quickly the juices are released by chewing and the juicier the meat appears (Cross, 1988). Additionally, a negative correlation was found between cooking losses and tenderness, in accordance with the findings of other authors (Silva *et al.*, 1999; Destefanis *et al.*, 2000; Serra *et al.*, 2004).

From the results of the present study, it can be concluded that there is great intrabreed variability for most of the traits studied and that this variability is greater in meat characteristics than in carcass traits. Thus, to achieve a standardised product, some meat quality characteristics should be included in selection programmes. Nevertheless, as indicated above, further studies seem necessary to identify a carcass measurement that can predict meat quality.

Acknowledgements

We would like to thank Juan José Pardos and Fidel Lahoz for their technical assistance, the ASPINA breeders' society for providing the animals, and the staff of

CENSYRA (Centre of Artificial Insemination and Animal Reproduction) of the Government of Aragón for their collaboration. This project has been financially supported by an agreement between University of Zaragoza, the National Confederation of Associations of Pyrenean Cattle, and the Government of Aragón.

References

ALBERTÍ P., SAÑUDO C., SANTOLARIA P., 1991. Características de la canal y calidad de la carne de terneros cebados con dietas forrajeras. ITEA 11, 425-427. [In Spanish].

ALBERTÍ P., SAÑUDO C., SANTOLARIA P., NEGUERUELA I., OLLETA J.L., MAMAQUI E., CAMPO M.M., ALVAREZ F., 1995. Calidad de la carne de terneros de raza Parda Alpina y Pirenaica cebados con pienso rico en gluten feed y mandioca. ITEA 16, 630-632. [In Spanish].

ALBERTÍ P., SAÑUDO C., OLLETA J.L., CAMPO M.M., PANEA B., FRANCO J., LAHOZ F., 1999. Color del músculo y de la grasa subcutánea de terneros de siete razas españolas. ITEA 20, 80-82. [In Spanish].

ALBERTÍ P., LAHOZ F., TENA R., JAIME S., SAÑUDO C., OLLETA J.L., CAMPO M.M., PANEA B., PARDOS J.J., 2001. Producción y rendimiento carnicero de siete razas bovinas españolas faenadas a diferentes pesos. Informaciones Técnicas nº 101. Ed. Departamento de Agricultura y Medio Ambiente de la Diputación General de Aragón. Zaragoza Spain. [In Spanish].

ALBERTÍ P., SAÑUDO C., MENDIZÁBAL J., RIPOLL G., OLLETA J.L., PANEA B., MARTÍN A., INDURÁIN G., 2003. Characterization of seven beef breeds by principal component analysis of fatty tissue development and chemical, instrumental and sensory measurements. Proc 49th Int Congress of Meat Sci and Tech, pp.149-150. 31th August-5th September. Campinas, Brazil.

ALBERTÍ P., RIPOLL G., GOYACHE F., LAHOZ F., OLLETA J.L., PANEA B., SAÑUDO C., 2005. Carcass characterisation of seven Spanish beef breeds slaughtered at two commercial weights. Meat Sci 71, 514-521.

ALBERTÍ P., PANEA B., SAÑUDO C., OLLETA J.L., RIPOLL G., ERTBJERG P., CHRISTENSEN M., GIGLI S., FAILLA S., GADDINI A. *et al.*, 2007. Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. Liv Sci 114, 19-30. doi:10.1016/j.livsci.2007.04.010.

ALTARRIBA J., VARONA L., MORENO C., YAGÜE G., SAÑUDO C., 2005. Consequences of selection for growth on carcass and meat quality in Pirenaica cattle. Liv Prod Sci 95, 103-114. doi:10.1016/j.livprodsci.2004.12.008.

BARTON R.A., PLEASANTS A.B., 1997. Comparison of the carcass characteristics of steers of different breeds and preweaning environments slaughtered at 30 months of age. New Zeal J Agr Res 40, 57-68.

BELLO L., CALVO D., 2000. The importance of intrinsic and extrinsic cues to expected and experienced quality: an empirical application for beef. Food Qual Pref 11, 229-238. doi:10.1016/S0950-3293(99)00059-2.

BIAGGINI D., LAZZARONI C., 2005. Carcass dissection and commercial meat yield in Piemontese and Belgian Blue double-muscled young bulls. Liv Prod Sci 98, 199-204. doi:10.1016/j.livprodsci.2005.05.007.

BIDNER T.D., SCHUPP A.R., MOHAMAD A,B., RUMORE N.C., MONTGOMERY R.E., BAGLEY C.P., MCMILLIN K.W., 1986. Acceptability of beef from Angus-Hereford or Angus-Hereford-Brahman steers finished on all-forage or a high-energy diet. J Anim Sci 62, 381-387.

CAMERON N.D., WARRISS P.D., PORTER S.J., ENSER M.B., 1990. Comparison of Duroc and British Landrace pigs for meat and eating quality. Meat Sci 27, 222-247.

CAMPO M.M., SAÑUDO C., PANEA B., ALBERTÍ P., SANTOLARIA P., 1998. Breed and ageing time effect on textural sensory characteristics of beef strip loin steaks. Proc 44th Int Congress of Meat Sci and Tech, pp. 898-900. 30th August-4th September. Barcelona, Spain.

CAMPO M.M., SAÑUDO C., PANEA B., ALBERTÍ P., SANTOLARIA P., 1999. Breed type and ageing time effects on sensory characteristics of beef strip loin steaks. Meat Sci 51, 383-390. doi:10.1016/S0309-1740(98)00159-4.

CAMPO M.M., SANTOLARIA P., SAÑUDO C., LEPETIT J., OLLETA J.L., PANEA B., ALBERTÍ P., 2000. Assessment of breed type and ageing time effects on beef meat quality using two different texture devices. Meat Sci 55, 371-378. doi:10.1016/S0309-1740(99)00162-X.

CAÑEQUE V., SAÑUDO C. (coord.), 2000. Metodología para el estudio de la calidad de la canal y de la carne en rumiantes. Monografías INIA: Ser. Ganadera nº 1. Ministerio de Ciencia y Tecnología, Madrid. 255 pp. [In Spanish].

CHAMBAZ A., SCHEEDER M.R.L., KREUZER M., DUFEY P.A., 2003. Meat quality of Angus, Simmental, Charolais and Limousin steers compared at the same intramuscular fat. Meat Sci 63, 491-500. doi:10.1016/S0309-1740(02)00109-2.

COMMISSION INTERNATIONALE DE L'ECLAIRAGE, 1976. Commission Internationale de l'Eclairage. 18th Session, London, 1975. CIE Publication, 36.

CROSS H.R. (ed.), 1988. Factors affecting sensory properties of meat. In: Meat science, milk science and technology. Elsevier Science Publishers BV, Amsterdam. pp. 158–161.

CROUSE J.D., CROSS H.R., SEIDEMAN S.C., 1985. Effects of sex condition, genotype, diet and carcass electrical stimulation on the collagen content and palatability of two bovine muscles. J Anim Sci 60, 1228-1234.

DE BOER H., DUMONT B.L., POMEROY R.W., WENIGER J.H., 1974. Manual of EAAP reference methods for the assessment of carcass characteristics in cattle. Liv Prod Sci 56, 225-259.

DESTEFANIS G., BARGE M.T., BRUGIAPAGLIA A., 1996. Meat quality in four muscles of hypertrophied Piamontese and Belgian Blue and White young bulls. Proc the 42nd Int Congress of Meat Sci and Tech, pp. 298-299. September. Lillehammer, Norway.

DESTEFANIS G., BARGE M.T., BRUGIAPAGLIA A., TASSONE S., 2000. The use of principal component analysis PCA to characterize beef. Meat Sci 56, 255-259. doi:10.1016/S0309-1740(00)00050-4.

DIEZ J., ALBERTÍ P., RIPOLL G., LAHOZ F., FERNANDEZ I., OLLETA J.L., PANEA B., SAÑUDO C., BAHAMONDE A., GOYACHE F., 2006. Using machine learning procedures to ascertain the influence of beef carcass profiles on carcass conformation scores. Meat Sci 73**,** 109-115. doi:10.1016/j.meatsci.2005.11.015.

FAILLA S., IACURTO M., MORMILE M., GIGLI S., 2001. Meat quality of three Italian breed young bulls. Proc 47th Int Congress of Meat Sci and Tech, pp. 2-3. Auguts 26th-31th. Krakow, Poland.

FAILLA S., GIGLI S., GADDINI A., SIGNORELLI F., SAÑUDO C., PANEA B., OLLETA J.L., MONSÓN F., HOCQUETTE J.F., JAILLER R. *et al.*, 2004. Physical quality of several European beef breeds: preliminary results. Proc. 50th Int Congress of Meat Sci and Tech**,** pp. 401-404. 8th–13th August. Helsinki, Finland.

FARMER L., MOSS B.W., HAGAN T., MAJURY L., KIRKPATRICK G., STEEN R.W.J., PATTERSON D.C., KIRKLAND R.M., KILPATRICK D., DAWSON S., 2004. Effect of carcass weight on sensory quality of young bulls Holstein bulls. Proc. 50th Int Congress of Meat Sci and Tech**,** pp. 405-409. 8th–13th August. Helsinki, Finland.

GIL M., SERRA X., GISPERT M., OLIVER M.A., SAÑUDO C., PANEA B., OLLETA J.L., CAMPO M., OLIVÁN M., OSORO K. *et al.,* 2001. The effect of breed-production system on the myosin heavy chain 1, the biochemical characteristics and the colour variables of *longissimus thoracis* from seven Spanish beef cattle breeds. Meat Sci 58, 181-188. doi:10.1016/S0309-1740(00)00150-9.

GRAU R., HAMM R., 1953. Eine einfache methode zur bestimmung der waserbindung in mukel. Naturwissenschaften 40, 29. [In German]. doi:10.1007/BF00595734.

HONIKEL K.O., 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci 49, 447-457. doi:10.1016/S0309-1740(98)00034-5.

HORNSEY H.C., 1956. The colour of cooked cured pork. I. Estimation of the nitric oxide-haem pigments. J Sci Food Agr 7, 534-540. doi:10.1002/jsfa.2740070804.

INSAUSTI K., BERIAIN M.J., PURROY A., ALBERTÍ P., GORRAIZ C., ALZUETA M.J., 2001. Shelf life of beef from local Spanish cattle breeds stored under modified atmosphere. Meat Sci 57**,** 273-281. doi:10.1016/S0309-1740(00)00102-9.

IRIE M., IZUMO A., MOHRI S., 1996. Rapid method for determining water-holding capacity in meat using video image analysis and simple formulae. Meat Sci 42, 95-102. doi:10.1016/0309-1740(95)00009-7.

ISO, 1993. Sensory analysis- General guidance for the selection, training and monitoring of assessors. Part 1: selected assessors. International Organization for Standardization, ISO, 8586-1, Genève, Switzerland. 26 pp.

JEREMIAH L.E., GIBSON L.L., 2003. The effects of post-mortem product handling and aging time on beef palatability. Food Res Int 36, 929-941. doi:10.1016/S0963-9969(03)00102-9.

JONES B.K., TATUM J.D., 1994. Predictors of beef tenderness among carcasses produced under commercial conditions. J Anim Sci 72**,** 1492-1501.

JURIE C., ROBELIN J., PICARD B., RENAND G., GEAY Y., 1995. Inter-animal variation in the biological characteristics of muscle-tissue in male Limousin cattle. Meat Sci 39, 415-425. doi:10.1016/0309-1740(95)90393-N.

KEANE M.G., 2003. Beef production from Holstein-Friesian bulls and steers of New Zealand and European/American descent, and Belgian Blue x Holstein-Friesians, slaughtered at two weights. Livest Prod Sci 84, 207-218. doi:10.1016/S0301-6226(03)00092-7.

KEMPSTER T., CUTHBERSTON A., HARRINGTON G., 1982. Carcase evaluation in livestock breeding, production and marketing. Granada Publishing Ltd., London. 304 pp.

KNAPP P., WILLIAMS A., SÖLKNER J., 1997. Genetic parameters for lean meat content and meat quality traits in different pig breeds. Livest Prod Sci 52, 69-73. doi:10.1016/S0301-6226(97)00120-6.

LEPETIT J., CULIOLI J., 1994. Mechanical properties of meat. Meat Sci 36, 203-237. doi:10.1016/0309-1740(94)90042-6.

LINDAHL G., LUNDSTROM K., TORNBERG E., 2001. Contribution of pigment content, myoglobin forms and internal reflectance to the colour of pork loin and ham from pure breed pigs. Meat Sci 59, 141-151. doi:10.1016/S0309-1740(01)00064-X.

LOPES N.M.B., SOUZA P.A., SILVA A.G., SOUZA H.B.A., PELICANO E.R.L., LEONEL F.R., LIMA T.M.A., BOIGAO M.M., 2003. Methods of cooking and its influence on meat quality of lamb. 49th Int Congress of Meat Sci and Tech**,** pp. 189-190. 31th August-5th September. Campinas, Brazil.

MAHER S.C., MULLEN A.M., MOLONEY A.P., DRENNAN M.J., BUCKLEY D.J., KERRY J.P., 2004. Colour, composition and eating quality of beef from progeny of two Charolais sires. Meat Sci 67, 73-80. doi:10.1016/j.meatsci.2003.09.007.

MONSON F., SAÑUDO C., SIERRA I., 2004. Influence of cattle breed and ageing time on textural meat quality. Meat Sci 68, 595-602. doi:10.1016/j.meatsci.2004.05.011.

OFFER G., KNIGHT P., 1988. The structural basis of water-holding in meat. Part 2. Drip losses. In: Developments in meat science (Lawrie R., ed.). vol.4. Elsevier Applied Science, London, pp173-243.

OJ, 1981. Directive 81/1208/CEE of the Council of April 28. Official Journal of the European Union L 123 7/5/81. p. 3.

OJ, 1981. Directive 81/2930/CEE of the Council of October 21. Official Journal of the European Union L 293 13/10/81. p. 6.

OJ, 1981. Directive 91/1026/CEE of the Council of April 22. Official Journal of the European Union L 106 26/4/91. p. 2.

ÖZLÜTÜRK A., TUZEMEN N., YANAR M., ESENBUGA N., DURSUN E., 2004. Fattening performance, carcass traits and meat quality characteristics of calves sired by Charolais, Simmental and Eastern Anatolian Red sires mated to Eastern Anatolian Red dams. Meat Sci 67**,** 463-470. doi:10.1016/j.meatsci.2003.11.022.

PALKA K., DAUN H., 1999. Changes in texture, cooking losses, and myofibrilar structure of bovine M-semitendinosus during heating. Meat Sci 51**,** 237-243. doi:10.1016/S0309-1740(98)00119-3.

PANEA B., 2002. Influencia de la raza-sistema productivo sobre el tejido conjuntivo y la textura de la carne bovina. PhD thesis. Facultad de Veterinaria, Universidad de Zaragoza, Spain. 226 pp. [In Spanish].

PIEDRAFITA J., QUINTANILLA R., SAÑUDO C., OLLETA J.L., CAMPO M.M., PANEA B., RENAND G., TURIN F., JABET S., OSORO K. *et al.,* 2003. Carcass quality of 10 beef cattle breeds of the Southwest of Europe in their typical production systems. Livest Prod Sci 82, 1-13. doi:10.1016/S0301-6226(03)00006-X.

RAO M.V., GAULT N.F.S, KENNEDY S., 1989. Variations in water-holding capacity due to changes in the fibre diameter, sarcomere-length and connective-tissue morphology of some beef muscles under acidic conditions below the ultimate pH. Meat Sci 26, 19-37. doi:10.1016/0309-1740(89)90054-5.

RENAND G., PICARD B., TOURAILLE C., BERGE P., LEPETIT J., 2001. Relationships between muscle characteristics and meat quality traits of young Charolais bulls. Meat Sci 59, 49-60. doi:10.1016/S0309-1740(01)00051-1.

ROBELIN J., GEAY Y., 1975. Estimation de la compositon de la carcasse des taurillons à partir de la compositon de la 6ème côte. Bulletin Technique CRZV. Theix. INRA 22. pp. 41-43. [In French].

SÁNCHEZ-BELDA A., 2002. Razas ganaderas españolas bovinas. Ed. FEAGAS-MAPA. pp. 275-282. [In Spanish].

SAÑUDO C., MACÍE E.S., PANEA B., OLLETA J.L., CAMPO M.M., ALBERTÍ P., 2001. The effect of breed-type and slaughter weight on meat texture throughout ageing. Proc. 47th Int Congress of Meat Sci and Tech, pp. 24-25.

SAÑUDO C., MACÍE E.S., OLLETA J.L., VILLARROEL M., PANEA B., ALBERTÍ P., 2003. The effects of slaughter weight, breed type and ageing time on beef meat quality using two different texture devices. Meat Sci 6, 925-932.

SERRA X., GIL M., GISPERT M., GUERRERO L., OLIVER M.A., SAÑUDO C., CAMPO M.M., PANEA B., OLLETA J.L., QUINTANILLA R., PIEDRAFITA J., 2004. Characterisation of young bulls of the Bruna dels Pirineus cattle breed (selected from old Brown Swiss) in relation to carcass, meat quality and biochemical traits. Meat Sci 66**,** 425-436. doi:10.1016/S0309-1740(03)00131-1.

SILVA J.A., PATARATA L., MARTINS C., 1999. Influence of ultimate pH on bovine meat tenderness during ageing. Meat Sci 52**,** 453-459. doi:10.1016/S0309-1740(99)00029-7.

SUBRT J., DIVIS V., 2002. The effect of individual Charolais sires on beef production of their crossbred progeny. Animal Science Papers and Reports 20, 25-32.