CIHEAM Options Méditerranéennes

Performance at slaughter and beef quality characteristics of some Mediterranean beef breeds compared to Central and North European breeds (GemQual EU Project)

Gigli S., Failla S., Iacurto M., Contò M., Sañudo C., Olleta J.L., Albertí P., Panea B., Hocquette J.F., Ertbjerg P., Christensen M., Nute G.R., Richardson I., Williams J.L.

in

Olaizola A. (ed.), Boutonnet J.P. (ed.), Bernués A. (ed.).
Mediterranean livestock production: uncertainties and opportunities

Zaragoza : CIHEAM / CITA / CITA
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 78

2008
pages 173-182

Performance at slaughter and beef quality characteristics of some Mediterranean beef breeds compared to Central and North European breeds (GemQual EU Project)

S. Gigli*, S. Failla*, M. Iacurto*, M. Contò*, C. Sañudo, J.L. Olleta**, P. Albertí***, B. Panea***, J.F. Hocquette****, P. Ertbjerg*****, M. Christensen*****, G.R. Nute******, I. Richardson**** and J.L. Williams*******

*CRA-Istituto Sperimentale per la Zootecnia, Tor Mancina Via Salaria 31, 00016 Monterotondo (RM), Italy

**Dpto de Producción Animal y Ciencia de los Alimentos, Facultad de Veterinaria, Universidad de Zaragoza, Miguel Servet 177, 50013 Zaragoza, Spain

***Unidad de Tecnología en Producción Animal, Centro de Investigación y Tecnología Agroalimentaria, Gobierno de Aragón, Apdo. 727, 50080 Zaragoza, Spain

****Unité de Recherches sur les Herbivores, Centre de Clermont-Ferrand/Theix, INRA, 63122 Saint-Genès Champanelle, France

*****Dept of Dairy and Food Science, Royal Veterinary and Agricultural University, Bülowsvej 17 DK-1870 Frederiksberg C, Denmark

******Division of Food Animal Science, Dept of Clinical Veterinary Science, University of Bristol, Langford House, Langford, North Somerset, BS40 5DU, UK

*******Roslin Institute, Midlothian EH25 9PS, Scotland, UK

SUMMARY – This work is part of a European Project called GemQual (Genetics of Meat Quality), which aims to define genetic components of meat quality, taking into consideration measurements on different European breeds. In Europe, consumers show different preferences regarding beef quality characteristics in accordance with geographical areas. The study of these quality characteristics is therefore of importance. Young bulls were reared and slaughtered in 5 countries by the GemQual partners using standardized protocols. In this paper, only performance and quality meat data of beef cattle subdivided in two groups are presented. The first group corresponds to Mediterranean breeds (Med: Asturiana de los Valles, Charolais, Limousin, Marchigiana, Piemontese and Pirenaica) and the second group to North European breeds (NorthE: Aberdeen Angus, Simmental and South Devon). The fatness score was lower in the Med animals ("2+" *vs* "3") particularly for the double muscle animals ("1+"). The less fatty animals showed on the contrary a higher meat percentage (+7.3%). Med group showed a good lightness (44.02 *vs* 40.25) and higher values of redness and yellowness of their meat (15.62 *vs* 12.22, 15.13 *vs* 12.71 respectively). Total pigments showed higher value for Med group (approximately +4%), particularly due to oxymyoglobin content significantly higher compared to NorthE group (+2.1%). In conclusion, quality meat appears different between groups, Mediterranean breeds being characterized by a lower fat percentage in the carcass and a light meat.

Key words: Beef, meat quality, breed, carcass.

RESUME – "Performances à l'abattage et caractéristiques de la viande de quelques races bovines méditerranéennes par rapport aux races du Centre et de l'Est de l'Europe (Projet UE GemQual) ". Ce travail s'inscrit dans le cadre d'un projet européen intitulé GemQual (Génétique de la Qualité de la Viande), dont l'objectif est d'étudier le déterminisme génétique de la qualité de la viande bovine à partir de mesures sur différentes races bovines européennes. En Europe, les consommateurs manifestent des préférences concernant les caractéristiques de la qualité de la viande bovine en fonction des régions géographiques. L'étude de ces critères de qualité est donc de toute première importance. Des taurillons ont été élevés et abattus dans 5 pays par les différents partenaires du projet GemQual selon des protocoles standardisés. Dans cet article, seules les performances zootechniques et les données de qualité de viande de deux groupes de races bovines seront rapportées. Le premier groupe correspond aux races bovines méditerranéennes (Med : Asturiana de los Valles, Charolais, Limousin, Marchigiana, Piemontese et Pirenaica) et le second aux races bovines du Nord de l'Europe (NorthE : Aberdeen Angus, Simmental et South Devon). L'état d'engraissement est plus faible pour les races du groupe Med ("2+" vs ***"3") en particulier pour les animaux "culards" ("1+"). Les animaux les moins gras ont au contraire les valeurs de rendement en viande les plus élevées (+7,3%). La viande du groupe Med est claire (44,02*** vs ***40,25) et avec des valeurs de rouge et de jaune plus élevées (15,62*** vs ***12,22, 15,13*** vs ***12,71 respectivement). Les teneurs en pigments totaux dans la viande sont plus élevées pour le groupe Med (environ***

+4%), en particulier en raison de teneurs en oxymyoglobine élevées par rapport au groupe NorthE (+2,1%). En conclusion, la qualité de la viande est différente entre les deux groupes de races bovines étudiés, les races méditerranéennes produisant des carcasses maigres et une viande claire.

Mots-clés : *Bovin, qualité de la viande, race, carcasse.*

Introduction

This work is part of a European Project named GemQual (Genetics of Meat Quality), which aims to define genetic component of meat quality, taking into consideration measurements on different European breeds, and also evaluating candidate genes influence on pointed out variations.

Basic research goals were:

(i) To determine possible differences in genetic component as to relate them with meat quality variation of different breeds reared in comparable conditions.

(ii) To identify loci and single nucleotide polymorphisms (SNPs) of candidate genes which could influence meat quality.

(iii) To test and select candidate genes for their influence on meat quality variation.

Analysis of meat quality aimed to detect differences among breeds reared in each European country, taking into account meat quality aspects that are considered important by consumers. Another objective of the project (not reported in the present paper) was to look for associations between gene polymorphisms and quality characteristics.

Five European States (Denmark, France, Italy, Spain and United Kingdom) were involved in the present research. The most representative breeds for each country were chosen reaching a total of fifteen beef or milk specialized breeds and/or local breeds.

The reported results concern only the following European beef breeds: Aberdeen Angus, Asturiana de los Valles, Charolais, Limousin, Marchigiana, Piemontese, Pirenaica, Simmental and South Devon.

Among them, Piemontese, Asturiana de los Valles, Charolais, Limousin and Aberdeen Angus are high specialised breeds; the first two bearing the muscular double muscle character and being very lean, particularly Piemontese breed. The Charolais and the Limousin have an excellent development in the back of the body, while Aberdeen Angus is characterized by a greater intramuscular fat amount despite the good muscular development.

South Devon and Simmental are milk/beef double purpose with a higher tendency to meat production; on the contrary Marchigiana and Pirenaica originally draught breeds, nowadays are reared for beef. These breeds show lower dressing percentage in comparison with the previous ones but have good productive characteristics.

The influence of breed on beef quality has been analyzed and compared in a lot of studies (Crouse *et al.*, 1989; Whipple *et al.*, 1990; Destefanis *et al.*, 1996; Wulf *et al.*, 1997), but this study is among the first which analyses so many different breeds in the same experiment.

In Europe consumers show different preferences regarding the quality characteristics in accordance with geographical areas as underlined by Sañudo *et al*. (1998). In fact, in the Mediterranean area, consumers prefer young animals slaughtered between 12 and 24 months of age with lean and clear meat (Monsón *et al.*, 2005) unlike British traditional beef (Lawrie, 1979).

The aim of this paper is to compare some carcass characteristics and meat quality parameters between breeds reared in North Europe and some others reared in Mediterranean areas to underline the differences between these two groups of breeds.

Materials and methods

In this paper, the data of 258 young bulls subdivided in two groups were studied: Asturiana de los Valles (AV), Charolais (CH), Limousin (LI), Marchigiana (MG), Piemontese (PD) and Pirenaica (PI) which were considered as Mediterranean breeds (Med) and Aberdeen Angus (AA), Simmental (SM) and South Devon (SD) which were meant as North European breeds (NorthE).

The animals were reared and slaughtered in 5 countries by the GemQual partners using standardized rearing systems and slaughtering protocols, so that quality characteristics were evaluated using standardized procedures.

Each country has carried out specific measurements on all samples, which were frozen and transported in the proper way.

At the age of about 8-9 months, all animals were included in the experimental test and recovered in multiple boxes with 7-8 heads for group, using intensive rearing system. Whole rearing period's diet consisted mostly of concentrates, barley 82% and soybean 8%, with 7.5% of straw which brought the requisite integration of long fibre; in addition animals were fed on a mineral vitamin integrator and bicarbonate, in order to avoid rumen acidosis due to the large part of concentrates in the diet, (Sañudo *et al.*, 2004). Since the above mentioned countries didn't produce the same feeds, this diet was chosen to standardize the rearing techniques.

The animals were slaughtered at about 15 months of age, or rather when they had reached 75% of an adult beef's standard weight, with an average live weight showed in details in Table 1.

Table 1. Average live weight and slaughtering age values per breed

Breed	Weight (kg)	Age (d)
Aberdeen Angus	597.7±25.1 bcd	428.6±48.0 bc
Asturiana de los Valles	557.7±48.5 ef	460.6±30.4 a
Charolais	634.0±40.0 a	460.6±21.6 a
Limousin	565.4±30.3 ed	428.0±22.8 bc
Marchigiana	523.5±38.0 g	459.2±19.4 a
Piemontese	527.3±40.1 g	461.0±19.0 ab
Pirenaica	602.4±52.7 abc	444.8±32.3 ab
Simmental	621.8±93.3 ab	455.9±10.8 a
South Devon	591.7±32.5 bcd	398.5±46.9 d

a, b, c, d, e, f, g: Significant differences between breeds ($p<0.05$).

The North European breeds have the final live weight above the mean together with Pirenaica and Charolais Mediterranean breeds (Table 1) while the other Mediterranean breeds are below the mean.

The final age is 427.7 days for the North European breeds and 452.4 days for the Mediterranean ones.

Young bull cattle were slaughtered in EEC label abattoirs following only one experimental protocol for all the breeds. Before slaughtering, animals were kept for about 12 hours without feed.

The following research institutes performed rearing and slaughtering: Roslin Institute, Scotland; Den Kongelige Veteræn og Landbohøjskol, Frederiksberg Denmark; Centro de Investigación y Tecnología Agroalimentaria de Aragón, Spain; CRA - Istituto Sperimentale per la Zootecnia, Italy; Institut National de la Recherche Agronomique (Theix), France.

After slaughter, carcasses were divided in two half sides which were stored in a cold room at 2°C for ageing. After 3 and 24 hours the pH at the 10th thoracic rib was measured in *Longissimus thoracis* muscle in order to identify DFD carcasses.

The right half side after 24 hours was weighed to calculate dressing percentage and it was also assessed by an expert both for conformation and fatness based on to SEUROP grid; the evaluation was converted in 18 classes for conformation and in 15 for fatness degree.

A sample was cut at the 6th thoracic rib and the percentages of meat, bone, fat and other tissues were determined after dissection in order to evaluate tissue composition. On cut between 5th and 6th thoracic rib the *Longissimus* area was evaluated by drawing the perimeter and calculating the area.

The *Longissimus thoracis* muscle was dissected from the frozen half side (between 6th and 13th rib), from which analysis were carried out in two different times: after 48 hours and after 10 days from slaughter. It was established a definite area of this muscle for each analytical measurement as described in Fig. 1, (www.gemqual.com) to minimize variability of the results due to qualitative intramuscular variation.

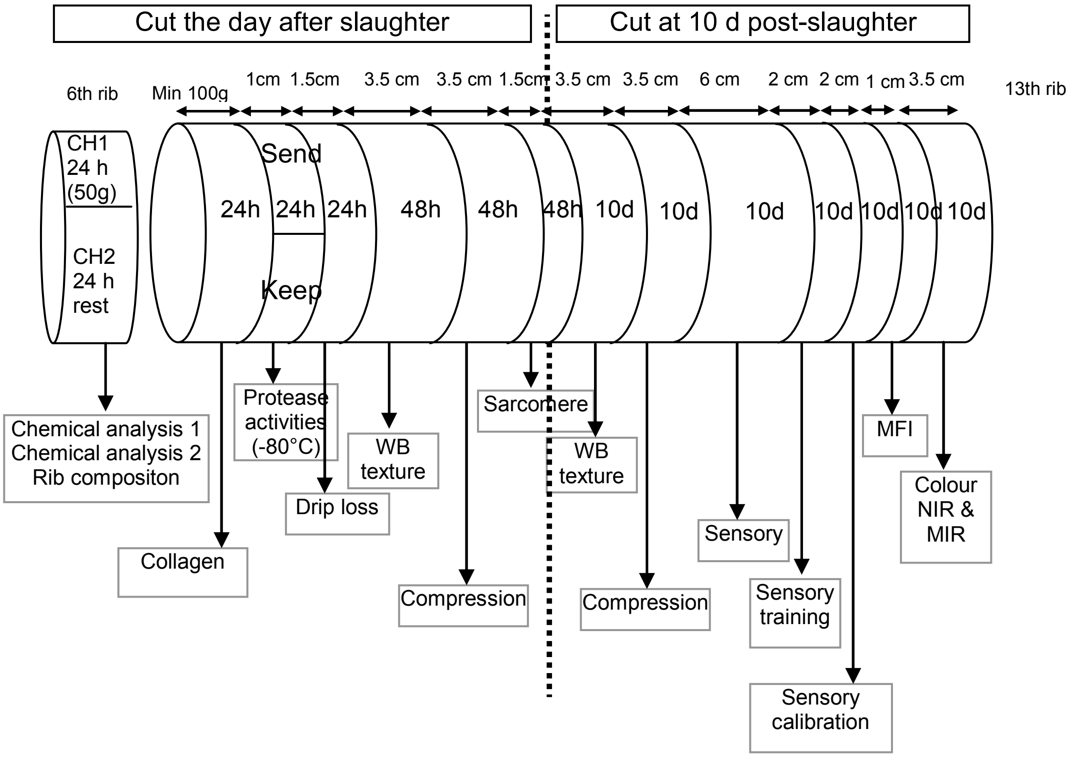

Fig. 1. Sampling of *Longisssimus thoracis.*

Longissimus samples were kept at 4°C until the established day for taking samples and after they were stored vacuum-packed and frozen at -18°C till analysis time.

As far as project analysis protocol was concerned, all physical analyses were considered: texture determination on raw and cooked meat after 10 days ageing, colour and spectrophotometrical analysis to define myoglobinic pigments. In addition, pH at 10 days and drip loss at 24 hours on fresh meat were measured.

Samples were weighed both first and after overnight thawing at 4°C. Thaw loss and pH were estimated to evaluate the freezing process in order to identify sample anomaly or deteriorations. The shear force was carried out with the Warner Bratzler Shear (WBS) on an Instron 1011 machine. The test was made both on raw sample at 10 days of ageing and on cooked sample ageing 48 hours and 10 days.

Shear force was measured on raw and cooked meat. Samples were cooked in a water bath at 80°C to an internal temperature of 78°C, then cooled in running tap water for 45' and stored in a refrigerator for 4 hours. Cooking losses were later calculated as percentage.

On ten samples, 1 cm^2 of cross section, with fibre direction paralleled to length (long axis), maximum load, stress at 20% and at 80%, and also maximum compression were measured with an Instron 4301 machine, using a modified device which avoids transverse elongation of the sample (Campo *et al*., 2000).

The drip loss measurement was made after 24 hours from slaughtering in accordance with Barton-Gade *et al.* (1994).

Colour coordinates were measured at ten points on the surface of slices, 3 cm thick according to Cassens *et al.* (1995). After exposure to air for 1 hour, lightness (L*), redness (a*), yellowness (b*), chroma (C) and hue (H) were calculated with CIEL*a*b* System using D65 illuminant and using spectrophotometer Minolta CM-2600d; reflectance spectra between 360 and 740 nm (by steps of 10 nm) was also measured.

The ratio between absorption and dispersion (K/S) was calculated using meat reflectance values, in accordance with the following formula:

$K/S = (1-R)^2/2R$

R = reflectance at different wavelengths.

Different fragments of myoglobin were measured from K/S according the AMSA (1991) formulas using isosbestic points of oxymyoglobin and metmyoglobin.

DeMb (%) = (K/S 474 nm) / (K/S 525 nm);
MetMb (%) = (K/S 572 nm) / (K/S 525 nm);
OxyMb (%) = (K/S 610 nm) / (K/S 525 nm).

pH was evaluated from the average of 4 surveys at the 10th thoracic rib, with a pHmeter with temperature compensation.

The statistic analysis of variance was performed on GLM procedure of SAS software (SAS, 1985) using a monofactorial model:

$Y = M + A_j + E_{jk}$
M = average
A_j = breed group type effect; (j = 1,2)
E_{jk} = error

To evaluate relationships among the groups and variables, the principal component analysis was performed on standardized data, using Princomp procedure of SAS software.

Results and discussion

The live weight of the two groups showed remarkable differences (Table 2). In fact although NorthE animals were younger than the Med ones of about 24 days, they had a live weight exceeding 33.8 kg. The best performances of NorthE group were evidenced also from the elevated average daily gain (ADG), principally due to Aberdeen Angus and South Devon breeds that showed a growth compensation gain, recorded during the first experimental period (Albertí *et al*., 2006, in press). During the last period of breeding (from 12 months to slaughter), ADG was indeed lower, namely 1.51 kg for South Devon and 1.3 kg for the Aberdeen Angus as reported in the same paper.

However the double-muscled animals (Piemontese and Asturiana de los Valles) showed a lower live weight (542.5 kg) than the other animals specialized for meat production as Charolais and Limousin for Med group (599.1 kg on average) and Aberdeen Angus for NorthE group (597.6 kg).

The carcass weight of Mediterranean animals was approximately 11 kg greater than that of the others, because of a better dressing percentage (61.9 *vs* 56.9%). The higher value in the first group of animals was due mainly to the double-muscled breeds, in fact Piemontese and Asturiana de los Valles which showed 63.11% of dressing percentage as reported in other works (Albertí *et al*., 1998; Lazzaroni *et al.*, 1999). However, excluding these two breeds, animals of Mediterranean origin still showed a better dressing percentage (+3.4%). The Med group showed also good conformation score

("U+" *vs* "U-"), this difference depending almost exclusively on double-muscled animals (13.33, "E-" on average). In fact, without these two genotypes, the conformation scores were similar between the two groups of breeds (10.65 *vs* 9.83).

Table 2. Performances at slaughter

Groups	Live weight (kg)	Carcass weight (kg)	ADG (kg/d)	Dressing percentage (%)	Conformation score	Fatness score
Med	569.1 b	352.4 a	1.35 b	61.94 a	11.5 a	5.8 b
NorthE	601.9 a	341.9 b	1.80 a	56.86 b	9.8 b	8.1 a
Means	578.9	349.2	1.49	60.42	11.0	6.5
sd	56.3	36.1	0.26	2.95	2.3	2.6

a, b: Significant differences bteween breeds (p<0.05)

The fatness score was lower in the Med animals (5.8 *vs* 8.1, Table 2, class "2+" *vs* "3") particularly for the double-muscled animals (3.83, class "1+"), while the two French breeds showed similar values than NorthE breeds (8.69 *vs* 8.14 about class "3"); the other animals (Pirenaica and Marchigiana) had intermediate values (4.94, class "2" on average for the two genotypes).

Tissue composition (Fig. 2), estimated by the dissection of the rib samples emphasized fat accumulation for NorthE animals (16.44 *vs* 9.73%) in particular if compared to double-muscled animals (5.50%), while the difference with French animals was limited (+2.2%).

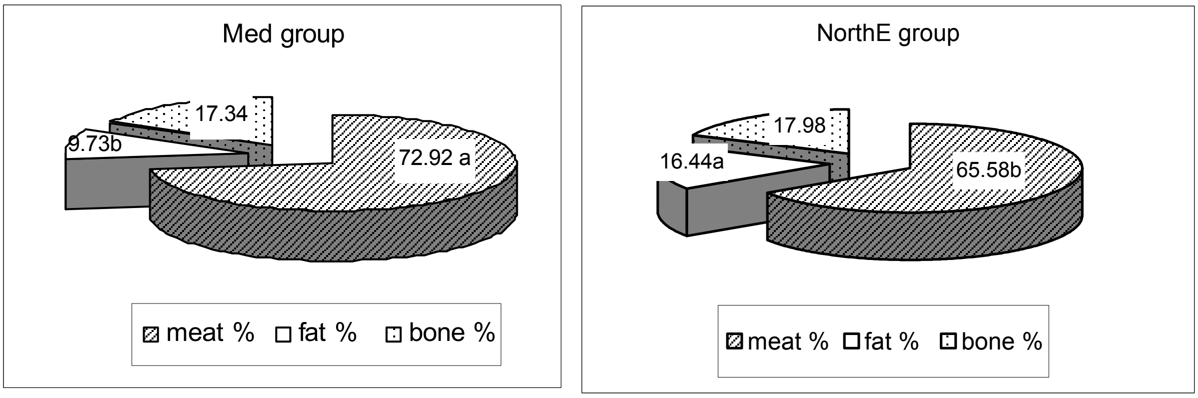

Fig. 2. Tissue composition percentage.

The leaner animals showed an elevated meat percentage (72.92 *vs* 65.58%, Fig. 2) being the bone percentage similar in both groups (17.66% in average). Generally Spanish and Italian breeds (double-muscled or not) showed a greater proportion of lean tissue, while the French breeds were similar to NorthE breeds (69.8 *vs* 65.58%). Moreover, the different productive performances between two groups didn't depend on different slaughter weights: using a covariate analysis with slaughter weight as covariate, the differences between breeds remained indeed substantially unchanged.

The *Longissimus thoracis* pH (Table 3) was similar at 24 hours but showed different values at 10 days of ageing between the two groups, marbling in NorthE group determined probably a limited increase of pH (Lawrie *et al.,* 1974). In fact, pH was positively correlated with fat percentage ($r = 0.18$; $P < 0.01$) and negatively with meat amount ($r = -0.22$; $P < 0.001$), while it didn't show any correlation with texture values. Therefore, pH difference did not seem to be linked to muscle proteolysis, also because the differences between groups for drip loss and thaw loss were not significant, while cooking loss in NorthE animals was higher (+1.5%), due to intramuscular fat cooking mobility.

Both raw and cooked meat of NorthE animals (Table 4) were tougher than meat from Med animals

(40.56 *vs* 44.97 N; 53.10 *vs* 60.00 N respectively), although the maximum load and stress at 20% (that estimates myofibrillar break) were similar (Lepetit and Culioli, 1994), while stress at 80% in NorthE group was higher. Double-muscled animals showed lower shear force on raw meat, maximum load and stress at 20% and at 80% (37.08, 3.99, 30.20 respectively for WBS raw, stress 20% and stress 80%), although some authors reported that these animals had tough myofibres (Clinquart *et al.*, 1998).

Table 3. pH and water loss at different times

Groups	pH at 24 h	pH at 10 days	Drip loss 24 hours (%)	Thaw loss % at 10 days	Cooking loss % at 10 days
Med	5.64	5.54 b	2.98	7.34	25.56 b
NorthE	5.65	5.61 a	2.57	6.93	27.09 a
Means	5.64	5.56	2.86	7.22	26.01
sd	0.174	0.09	1.68	1.86	2.23

a, b: Significant differences between breeds ($p<0.05$).

Table 4. Texture determination on raw and cooked meat at 10 days (N)

Groups	WBS raw	WBS cooked	Max laod	Stress 20%	Stress 80%
Med	40.56 b	53.10 b	52.05	4.27	35.41 b
NorthE	44.97 a	60.00 a	55.23	4.51	38.29 a
Means	41.88	55.09	53.00	4.34	36.27
sd	9.91	11.90	13.00	1.22	8.76

a, b: Significant differences between breeds ($p<0.05$).

Generally, the genetic type has an influence on shear force on cooked meat. In particular it was noticed that Simmental breed showed tougher meat. On the opposite, it was showed that double-muscled animals had a more tender raw meat (Lazzaroni *et al.,* 1994; Campo *et al.,* 2000; de Smet *et al.*, 1998; Sarti *et al.*, 2005), which became during cooking stringy because this meat is poor of fat and losses a lot of water, increasing shrinkage during cooking (Seideman *et al.*, 1987).

All texture values were correlated with cooking loss (especially maximum load $r = 0.33$, $P < 0.001$), confirming the more water losses the tougher meat became (Silva *et al.*, 1999).

Med group (Table 5) evidenced a good lightness and higher values of redness and yellowness, Chroma (+23, 2%) and Hue (-4, 8%), that means a colour more near to ideal red with a good intensity.

Table 5. Colour parameters at 10 days

Groups	L*	a*	b*	C	H	Total pigment
Med	44.02 a	15.62 a	15.13 a	21.80 a	44.26 b	4.63 a
NorthE	40.25 b	12.22 b	12.71 b	17.70 b	46.50 a	4.45 b
Means	42.89	14.61	14.41	20.58	44.93	4.57
sd	3.10	2.29	1.36	2.16	4.45	0.27

a, b: Significant differences between breeds ($p<0.05$).

Low values of lightness have been found by various authors for these breeds (Sami *et al.,* 2004). Among genotypes of the Med group, French breeds, in particular the Charolais, showed a greater lightness (45.67), while a* and b* index were similar to the others breeds. The parameters of colour were negatively correlated with shear force on cooked meat and pH (Wulf *et al.*, 1997), particularly lightness (r = -0.34, r = -0.31, p<0.001 respectively) and yellowness (r = -0.36, r = -0.37, p<0.001 respectively), while positively correlated with drip loss (r = 0.21, p<0.01 for L and b*). Therefore higher pH and lower drip loss values were significantly associated with lower lightness, higher redness confirming the strong relationship between pH and meat colour.

Total pigments showed higher values for the Med group (about +4%) in particular (Fig. 3) due to oxymyoglobin content significantly higher compared to the NorthE group (+2.1%). Different percentage of oxymyoglobin and metmyoglobin determine the bright or dark coloration of muscle. In fact, Med animals had brighter meat. Within this group, the lower values of oxymyoglobin have been noticed in French breeds, in particular for Limousin (57.22%), the higher value being observed for Asturiana (60.13%). Metmyoglobin instead was higher in NorthE group, especially for South Devon breed (19.05%). Apart from colour parameters (L*, a* and b*), these pigments were also correlated with thaw loss, in fact excessive water loss was positively correlated with metmyoglobin (r = 0.22, p<0.01) and negatively with oxymyoglobin (r = -0.25, p<0.001), indicating the conservation state between the two pigments.

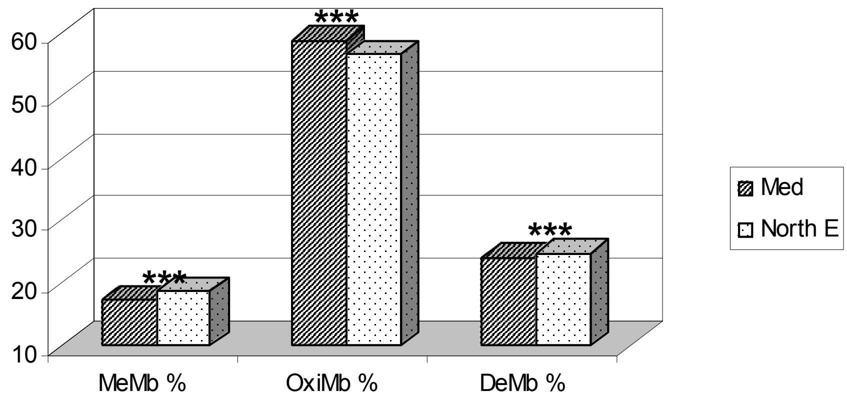

Fig. 3. Percentage composition of pigment.

The 1st and 2nd principal components (Fig. 4) explained about the 70% of the variability, particularly myoglobin pigments and meat colour explained the principal differences between the two groups of breeds. Analyzing altogether qualitative parameters, the meat colour was opposed to pH and toughness. Med and NorthE groups were divided in two separate areas even if not clearly. In fact same parameters of French breed appeared similar to NorthE.

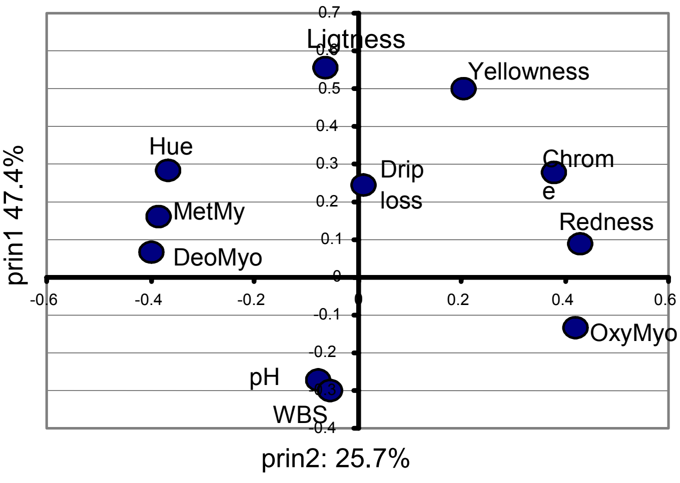

Fig. 4. Principal component analysis: projection of variables.

The NorthE group was characterized by a greater toughness and a low lightness (Fig. 5), while a light lightness was a characteristics of the Med group together with redness and yellowness.

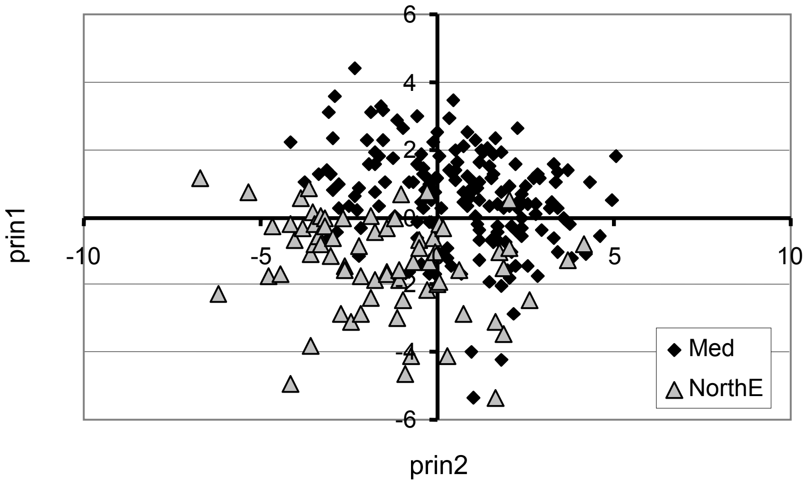

Fig. 5. Principal component analysis: projection of individuals and distribution of groups.

Conclusions

Mediterranean breeds were characterized by a lower fat percentage in the carcass and in the meat, and also by a light meat rich in colour pigments. This group showed a more tender meat even if the differences became small in compression tests thanks to high marbling. Obviously, pH and water loss variability pointed out the different muscle biochemical characteristics.

However, it has to be underlined that North European consumers tastes are very different than that of the Mediterranean's ones: the former prefer a marbled meat, mostly obtained from castrated animals while the latter would prefer a lean and light meat obtained from younger animals.

References

Albertí, P., Sañudo, C., Campo, M.M., Panea, B., Olleta, J.L., Santolaria, P. and Nute, G. (1998). Influence of breed on the sensory meat quality of Spanish yearlings bulls. *Revista portuguesa de Zootecnia*, 1, 39-46.

Albertí, P., Panea, B., Sañudo, C., Olleta, J.L., Ripoll, G. , Ertbjerg, P., Christensen, M., Gigli, S., Failla, S., Concetti, S., Hocquette, J.F., Jailler, R., Rudel, S., Renand, G., Nute, G.R., Richardson, R.I. and Williams, J.L. (2006). *Live weight, body size and carcass characteristics of young bulls of fifteen European breeds. Livestock Science*. In press.

AMSA (1991). Guidelines for meat color evalution. In: *Proceedings of the Reciprocal Meat Conference*, Vol. 44, Chigago: Amer. Meat Science Ass. and National Livestock Meat Board, pp. 3-17.

Barton-Gade, P.A., Demeyer, D., Honikel, K.O., Joseph, R.L., Puolanne, E., Severini, M., Smulders, F.S.M. and Tornberg, E. (1994). Final version of reference methods for water holding capacity in meat and meat products: Procedures recommended by an OECD working group. In: *Proceedings of the 40th International Congress of Meat Science and Technology (ICoMST)*, The Hague (The Nederlands), 28 August-2 September 1994, S-V.05.

Campo, M.M., Santolaria, P., Sañudo, C., Lepetit, J., Olleta, J.L., Panea, B. and Albertí, P. (2000). Assessment of breed type and ageing time effects on beef meat quality using two different texture devices. *Meat Science*, 55, 377-378

Cassens, R.G., Demeyer, D., Eikelenboom, G., Honikel, K.O., Johansson, G., Nielsen, T., Rennere, M., Richardson, I. and Sakata, R. (1995). Recommendation of a reference method for assessment of meat colour. In: *Proceedings of the 41st International Congress of Meat Science and*

Technology (ICoMST), San Antonio, Texas (USA), 20-25 August 1995, Vol. II, C86, pp. 410-411.
Clinquart, A., Hornick, J.L., van Eenaeme, C. and Istasse, L. (1998). Influence du caractère culard sur la production et la qualité de la viande des bovines Blanc Bleu Belge. *INRA Productions Animales*, 11: 285-297.
Crouse, J.D., Cundif, L.V., Koch, R.M., Koohmaraie, M. and Seideman, S.C. (1989). Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. *Journal of Animal Science*, 67: 2661-2669.
de Smet, S., Claeys, E., Buysse, G., Lenaerts, C. and Demeyer, D. (1998). Tenderness measurements in four muscles of Belgian Blue normal and double-muscled bulls. In: *Proceedings of the 44th International Congress of Meat Science and Technology (ICoMST)*, Barcelona (Spain), 30 August-4 September 1998, pp. 288-295.
Destefanis, G., Barge, M.T. and Brugiapaglia, A. (1996). Meat quality in four muscles of hypertrophied Piemontese and Belgian Blue and White young bulls. In: *Proceedings of the 42nd International Congress of Meat Science and Technology (ICoMST)*, Lillehammer (Norway), 1-6 September 1996, pp. 298-299.
Lawrie, R.A. (1974). *Ciencia de la carne*, 337-351. Ed. Acribia. Zaragoza.
Lawrie, R.A. (1979). The storage and preservation of meat in moisture control. *Meat Science* (3rd ed.), Pergamon Press), Oxford.
Lazzaroni, C., Bigini, D., Toscano Pagano, G. and Iacurto, M. (1999). Meat production in pure and crossbred Piemontese cattle. In: *Book of Abstracts of the "50th Annual Meeting of the European Association for Animal Production"*, Zurich (Swiss), 22-26 August 1999, Paper C3.17, 179 (Abstract).
Lazzaroni, C., Semprini, D., Abrate, M., Pagano, M. and Toscano-Pagano, G. (1994). Morphological characteristics of muscles fibres in double muscled and normal cattle. In : *Proceedings of the 40th International Congress of Meat Science and Technology (ICoMST),* The Hague (The Netherlands), 28 August-2 September 1994, S-III, 25.
Lepetit, J. and Culioli, J. (1994). Mechanical properties of meat. *Meat Science*, 36: 203-237.
Monsón, F., Sañudo, C. and Sierra, I. (2005). Influence of breed and ageing time on the sensory meat quality and consumer acceptability in intensively reared beef. *Meat Science*, 71: 472-479.
Sami, A.S., Augustini, C. and Schwarz, F. (2004). Effects of feeding intensity and time on feed on performance, carcass characteristics and meat quality of Simmental bulls. *Meat Science*, 67, 195-201.
Sañudo, C., Panea, B., Olleta, J.L., Monsón, F., Sierra, I., Albertì, P., Ertbjerg, P., Christiansen, M., Failla, S., Gigli, S., Gaddini, A., Hocquette, J.F., Jailler, R., Nute, G.R. and Williams, J.L. (2004). Carcass quality of several European cattle breeds: Preliminary results. In: *Proceedings of the 50th International Congress of Meat Science and Technology (ICoMST)*, Helsinki (Finland), 8-13 August 2004, pp. 516-519.
Sañudo, C., Sánchez, A. and Alfonso, M. (1998). Small ruminant production systems and factors affecting lamb meat quality. *Meat Science*, 49, 529-564.
Sarti, F., Lasagna, E., Maidani, M., dal Bosco, A., lo Martire, C. and Filippini, F. (2005). Qualità della carne in vitelloni marchigiani ipertrofici. In: 4th World Italian Beef Cattle Congress, Gubbio (Italy), 29 April-1 May 2005, pp. 573-576.
SAS (1985). *User's guide*. SAS Institute, Cary, NC.
Silva, J.A., Patarata, L., Martins, C. (1999). Influence of ultimate pH on bovine meat tenderness during ageing. *Meat Science*, 52, 453-459.
Seideman, S.C., Koomaraie, M. and Crouse, J.D. (1987). Factors associated with tenderness in young bulls. *Meat Science*, 20: 281-291.
Whipple, G., Koohmaraie, M., Dikeman, M.E., Crouse, J.D., Hunt, M.C. and Klemm, R.D. (1990). Evaluation of attributes that affect *Longissimus* muscle tenderness in *Bos taurus* and *Bos indicus* cattle. *Journal of Animal Science*, 68: 2716-2728.
Wulf, D.M., Shannon O'Connor, F., Tatum, J.D. and Smith, G.C. (1997). Using objective measures of muscle colour to predict beef *Longissimus* tenderness. *Journal of Animal Science*, 75: 684-692.