

MEAT QUALITY OF TEN CATTLE BREEDS OF THE SOUTHWEST OF EUROPE

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ABSTRACT

A sample of about 70 young bulls of each of ten beef cattle breeds reared in their typical production systems has been characterised with respect to meat quality traits. Breeds included were Asturiana de los Valles, Asturiana de la Montaña, Avileña-Negra Ibérica, Bruna dels Pirineus, Morucha, Pirenaica and Retinta from Spain, and Aubrac, Gasconne and Salers from France.

As was previously showed regarding carcass traits, there exist large differences both between and within breed – systems. In general, rustic breeds tended to present darker and redder meats with higher haematin contents, whereas less precocious and more specialised breeds showed brighter meats with bigger water losses. Protein content was similar, whereas intramuscular fat presented the larger variations both between and within breeds. ICDH content was higher in the more rustic breeds, showing the predominantly oxidative character of their fibres. Texture measurements showed in general large within breed-system variations, the differences between breeds being less evident.

Within breed-system, daily gain weight was positively associated with brighter and tender meats. In the range studied, increasing slaughter weight within breed did not have influence on meat quality. Conformation was related to lower water holding capacity and less dry matter and intramuscular fat, as well as to a lower haematin content giving brighter meats. The increase in fatness scores was related to an augment of toughness in meat

specialised breeds, although in Avileña-Negra Ibérica breed fatness carcasses were related to more tender meats.

Redness parameter a^* was positively related to fatter animals and opposed to conformation, the opposite being true for the L^* (lightness) parameter. There was a small trend of fatter carcasses to be related to oxidative fibres, whereas the muscular fibres of the more conformed carcasses were more glycolytic. Texture measurements maximum load, maximum stress and toughness were very closely related. Shear force was opposed to tenderness. Losses at cooking were opposed to juiciness, but only in the Spanish breeds. No consistent trends regarding relationships between carcass characteristics and tenderness could be observed. Overall acceptability was primarily related with tenderness and flavour, and later on juiciness.

INTRODUCTION

Beef meat production is an important sector in the world economic system, surrounding five million Tm of meat per year. The European Union (15) represents the second main world producer after USA, but consists of a high variability of local production systems, less homogenous than the highly intensive feedlot system, which is mainly used in USA. Consequently, the general cost of production is higher in these traditional systems, which means that farmers have to find out different strategies for selling their meat without increasing production costs.

In general, beef meat market depends upon the ability of the industry to diminish production costs and to increase beef meat consumption. In spite of the importance of beef meat, its consumption has followed a decreasing tendency in Europe in this decade. Several aspects can cause this fall, including other cheaper meats or meat products, which beef meat has to compete with, changes in consumption habits due to an increasing elderly population, vegetarians tendencies or healthy and frauds problems with a high mass media diffusion (Aguado and González, 1997).

On the other hand, the current agricultural policy of the European Union considers a new reorientation of meat bovine market, fomenting diversification of agricultural production and promotion of specific products (R/CEE 2081/92 and R/CEE 2082/92). This is especially important in unfavourable areas, where this restructuring would contribute to an increase of farmer's incomes and favour the establishment of rural population. Furthermore, that would increase the number of animals of certain breeds that could disappear due to the direct competence with more specialised breeds, since local breeds are always highly related to the environment.

In general, the system of production of beef meat differs upon the purpose of the herds. In dairy cows, weaning happens few days after birth and calves follow an intensive feeding with no grazing. In meat herds, calves depend on the production system, as they normally graze with their mothers until weaning and later are reared indoors or outdoors until slaughter.

Nowadays, the traceability of the meat from the farmer to the consumer guarantees its quality. This is the main aspect that consumers look for while purchasing any product. Creation of meat quality labels, normally under a geographical situation and with a specific genotype and production system, has been the symbol of this guarantee, since all these factors can affect meat quality. The improvement of this quality is based upon what the consumer expects and perceives (Issanchou, 1996). After hygienic and nutritional aspects, organoleptic perception would be the main criterion on purchase decision. Besides colour (Wood *et al.*, 1998), tenderness is considered the main quality attribute of meat (Love, 1994). All these characteristics can be measured either directly by consumers or taste panels or through instrumental methods that can be related to consumer appraisals.

Meat quality criteria are affected by a wide variability of factors such as intrinsic, pre-slaughter and post-slaughter ones. For this reason, researchers have been controlling every aspect of the production-slaughtering-conditioning differing just one for its study. When the animals were submitted to the same conditions, the breed was an important production factor affecting carcass quality (Wheeler *et al.*, 1996; Albertí *et al.*, 1997, 1998), as well as meat quality (Barton and Pleasants, 1993; Wheeler *et al.*, 1994; Zembayashi *et al.*, 1995; González *et al.*, 1997; Campo *et al.*, 1999; Sañudo *et al.*, 1998, 1999). It has been shown the different tissue composition in animals from rustic breeds related to more specialised beef meat breeds, and the different sensorial perception of meat of animals from double muscled breeds related to other breeds (De Smet *et al.* 1998).

Also, within a breed and its production system, the knowledge of the relationships among several productive, carcass quality and meat quality variables can help to the improvement by genetic selection, as well as to understanding the properties of the final product and its acceptability.

On the other hand, what can be purchased in the market under a quality label has their own productive characteristics, different from other labels and differing in more than one aspect. For this reason, we have studied different beef meat production systems related to local breeds and its influence on meat quality. Specific objectives of this FAIR1 CT95 0702 project have been the following: 1) to study meat characteristics of several Spanish and French local beef breeds; 2) to analyse their intra-breed variability and the effect of breed - production system; and 3) to establish relationships of meat traits with other growth, carcass and meat quality traits.

MATERIALS AND METHODS

Animals

Seven Spanish local beef breeds: Asturiana de los Valles (AV), Asturiana de la Montaña (AM), Avileña-Negra Ibérica (A-NI), Bruna dels Pirineus (BP), Morucha (Mo), Pirenaica (Pi) and Retinta (Re), and three French local beef breeds: Aubrac (Au), Gasconne (Ga) and Salers (Sal) were studied in two consecutive years.

Growth and slaughter conditions

All animals were reared under local production systems and slaughtered in their areas of origin in commercial abattoirs. In Spain, fattening started at about 5 to 7 months of age and calves were fed *ad libitum* a diet based on concentrated meal and straw or hay. Average slaughter weight was breed specific, depending upon the degree of maturation and market preferences. The range for the Spanish breeds was 450-550 kg (table 1).

In France, young Au bulls started fattening at an average age of 19 months, and were fed maize silage and hay *ad libitum*, complemented with concentrates, during 4-6 months. In the Ga breed, fattening started when young bulls were about 7 months old, being fattened during 9 months with maize silage *ad libitum* complemented with concentrates. Animals of Sal breed started fattening at 9-10 months being fed grass and maize silage *ad libitum* complemented with concentrates during 10 months.

After slaughter, carcass conformation and fatness (CEE 390/81 and 1208/81) were evaluated using the EUROP scale divided in 15 points (1-very bad conformation; 15-very good conformation) and a 1-15 fatness scale (1-very low fatness; 15-very high fatness). The number of animals studied for meat quality characteristics in each breed-production system is shown in table 1.

Sample preparation

From the left side of the carcass, 24 hours after the slaughter the 6th rib was excised with an electrical cutter for its dissection, in order to assess carcass tissue composition and *Longissimus* muscle characteristics. Additionally, a piece was taken between the 7th and 11th ribs. Small pieces were taken from the *Longissimus* muscle core at the 7th rib level, frozen in liquid nitrogen and stored at –80°C for characterisation of muscle fibre and enzyme activity. The rest of the loin between the 7th and the 11th rib was kept vacuum packaged at 4°C until meat reached 7 days of ageing to assess sensory meat quality.

Chemical determinations and measurement of pH and colour

After 48 hours from the slaughter, half of the *Longissimus* muscle from the 6th rib was used for the determination of dry matter (ISO 1442) and water holding capacity (Sierra, 1973) in fresh meat. The rest was minced and kept at –18°C until assessment of haem pigments (Hornsey, 1956), protein content (ISO 937), intramuscular fat (ISO 1443) and total and soluble collagen (Bonnet and Kopp, 1984). The sample for total collagen was immediately frozen while the soluble collagen sample was first hydrolysed and then frozen (Kopp, 1971)

When the strip loin reached 7 days of ageing, a 3-cm thick chop located in the 7th-8th ribs of the *Longissimus* muscle was cut and placed in a polyexpan tray, covered with plastic film permeable to O₂ and stored for 24h at 4°C for measuring meat colour development. Meat colour was measured by a spectrophotometer Minolta CM 2002 in Spanish breeds and Minolta CM 508i in French breeds (C/2°C) in the CIE L* a* b* space (CIE, 1976). pH was then measured by a penetration electrode (CRISON 507 in Spanish breeds, INGOLD 406DXK in French breeds). A 3.5-cm thick chop from the 8-9th ribs was taken, vacuum packaged and kept at 4°C during 7 additional days until meat reached 14 days of ageing, being frozen and kept at –18°C after it for texture analysis.

The rest of the muscle *Longissimus* was sliced into 2-cm thick chops for sensorial analysis. Samples were vacuum packaged and aged at 4°C during seven more days, until meat reached 14 days of ageing, being frozen and kept at –18°C until the analyses were done.

Texture determination

Texture was measured in a INSTRON 4301 equipment. Steaks were defrosted in tap water for 4 hours until reaching an internal temperature of 17-19°C. Each steak was then cut transversally into two halves to be studied either as raw or cooked meat. Meat was vacuum packaged prior to cooking in a water bath at 75°C until the internal temperature reached 70°C. Samples, 1 cm² in cross-section, were cut with muscle fibres parallel to the longitudinal axis of the sample. Maximum load, yield and toughness were recorded using a Warner Bratzler (WB) device shearing until the total break of the sample. Texture of raw meat was analysed using a modified compression device that avoids transversal elongation of the sample. The stress was assessed at the maximum rate of compression, and at 20 % and 80 % maximum compression.

Biochemical determinations

Slow myosin heavy chain (MHC I) in the muscle was characterised by enzyme-linked immunosorbent assay (ELISA) with a specific MHC I monoclonal antibody (Picard *et al.*, 1994). Metabolic traits of the muscle were determined by measuring lactate dehydrogenase

activity (LDH) according to Ansay (1974) and isocitrate dehydrogenase activity (ICDH) according to Briand *et al.* (1981).

Taste panel

For assessing sensory characteristics, samples were defrosted in tap water during 4 hours until they reached an internal temperature of 17-19°C. Final defrosted weight was recorded for assessing water losses. The samples were analysed by teams in different laboratories: Zaragoza analysed AV, AM, Pi and Re; Monells analysed A-NI, BP and Mo; and Villers Bocage analysed Au, Ga and Sal. Meat was cooked inside aluminium paper in a double plate grill in Zaragoza and Villers Bocage, and in the oven in Monells, until all the samples reached an internal temperature of 55°C in Villers Bocage and 70°C in Monells. Every steak was then weighted for recording cooking losses, trimmed of any external connective tissue, cut into 2-cm² samples, wrapped in codified aluminium paper and stored (approximately 5 min) in warm pans at 60°C until tasted. Samples were randomly served to a trained ten-member sensory panel in Monells and Villers Bocage, and to a trained eleven-member sensory panel in Zaragoza, placed in individual booths under red lighting for mask differences in meat colour.

Panellists assessed beef and livery odour intensity, tenderness, juiciness, beef and livery flavour intensity and overall appraisal in a ten-point scale. A score of 0 stood for no odour or flavour, very tough and no juicy and very poor appraisal, and a score of 10 stood for high odour or flavour, very tender and juicy and very good appraisal.

Statistical analysis

Means and within year (residual) standard deviations have been computed for every breed - production system. The within year (residual) variances have been compared for the Spanish and French breeds by means of a Bartlett test.

Linear regressions have been assessed within each breed-production system between meat quality traits and daily gain weight, slaughter weight, carcass conformation and fatness scores as independent variables, although only significant slopes are shown.

For the study of the within breed variability, data (Y_{ijk}) was previously corrected for the effect of the test-group since animals were fattened and slaughtered in two annual batches that might induce some environmental differences. The phenotypic variability was therefore studied on the residuals (y_{ijk}) after fitting for the effects of breeds and years, and the interaction between both according to the linear model:

$$\begin{aligned} Y_{ijk} &= \text{test-group}_{ij} + y_{ijk} \\ &= \text{breed}_i + \text{year}_j + \text{breed} \times \text{year}_{ij} + y_{ijk} \end{aligned}$$

Traits were analysed in different clusters according to their incidence on beef production or meat quality (growth, carcass characteristics, muscle characteristics, colour measures, water holding capacity, physical measure of texture and also eating quality). The relationships were studied within these clusters to see whether some variables were sufficiently correlated and could be aggregated in synthetic variables that were further used to analyse the relationships with variables of other clusters. These synthetic variables were obtained by taking the first component of a principal component analysis (PCA) in which only the variables to be aggregated were included.

These relationships between variables of the same or different clusters were first estimated on all animals whatever the breed seeking for general biological association between traits. Correlation coefficients were calculated between all variables (residuals). These relationships were analysed by the mean of principal component analyses (PCA) that provided synthetic information on the joint variability of different variables of interest. Since some animals were lacking some of the trait measures, the PCA were performed on the correlation coefficient matrix calculated using all animals.

However, relationships to eating quality variables was analysed in three groups according to the laboratory carrying out the taste panel, since the tasting protocols were somewhat different and might have induced differences in the joint variability of traits. The first group included the breeds evaluated in Zaragoza: Asturiana de los Valles, Asturiana de la Montaña, Pirenaica and Retinta. The second group included the breeds evaluated in Monells: Bruna dels Pirineus, Avileña and Morucha. The third group included the three French breeds, Aubrac, Gasconne and Salers that were evaluated in Villers-Bocage.

All data has been analysed with the SAS package (1998).

RESULTS AND DISCUSSION

MEAT QUALITY

Animals with DFD meats (pH > 6.0) after 24 hours from the slaughter were eliminated for the study of meat quality traits. High pH values would have produced a dark meat colour because of a high mitochondria oxygen consumption (Bendall and Taylor, 1972), and a high water-binding capacity which would produce greater light penetration and absorption (MacDougall, 1982). Furthermore, since several enzymatic systems work faster at high pHs (Roncalés *et al.*, 1995), high pHs could produce as well changes in sensory attributes such as a higher tenderness. All these factors could have affected meat quality traits more than the production system (Beltrán *et al.*, 1997).

There was a very low variability both between and within each breed-production system regarding pH at the 7th day (table 2). This low variability might be partly due to a good handling of animals, since pre-slaughter induced stress is the main cause of high pHs in beef animals (Beltrán *et al.*, 1997).

Colour measurements

The International Commission on Illumination (CIE, 1986) system transforms the object's reflectance into a three-dimensional space, the most used is known as $L^* a^* b^*$, which would define each colour. Table 2 shows L^* coordinate values or lightness. The haem pigment myoglobin is the main responsible for the colour of the meat (MacDougall, 1982). On exposure to air the purple ferrous deoxygenated form rapidly oxygenates on the surface to the brighter red covalent complex oxymyoglobin. During display this oxidises to brownish red and finally to brownish green metamyoglobin (MacDougall, 1982). In beef meat, oxygenation is almost complete after 1 day of blooming, which has been the period of time used in our study.

Within breeds, the coefficient of variation was around 7-8% for the Spanish breeds and 5% for the French breeds. The lower variability in the French breeds could be due either to differences in the analytical device or to the higher weight they were slaughtered, which would produce less differences among animals of the same breed because of the high time that they spent under the same productive conditions. AM and Mo breeds showed the darker meat (32.24 and 32.60 respectively), while AV and Pi, the most meat specialised Spanish breeds, and Ga, among the French breeds, showed the brighter meat (38.81, 38.87 and 39.64 respectively). Variability has been reported among breeds of cattle and their crosses, with Holstein animals having a higher oxygen consumption rate and poorer colour stability than muscle from crossbreeds (Lanari and Cassens, 1991), which would show lower L^* values corresponding to darker meat. But age at slaughter also affects meat lightness, since older and more precocious animals would present a higher myoglobin content (Renner, 1986) and, consequently, lower L^* values. This could explain the darker meat in Au and Sal related to Ga breed among the French breeds, and Mo and AM among the Spanish breeds.

Mean values for redness (a^* co-ordinate values) are presented in table 2. Redness is highly correlated to the haem pigment content (Renner, 1986). We could separate two groups of animals, the Spanish breeds and the French ones, according to their a^* values, probably due to the different optical instrumentation used in the measurements. Spanish breeds showed values over 20, and French breeds below 15. Since the age at slaughter of the French animals was older and they were supposed to show redder meat, these differences could be due to the different equipment used in the measurement in different laboratories. The most rustic breeds showed the highest a^* values (Mo 23.95, AM 23.42, and

Re 22.92) while A-NI, another rustic breed, showed the lowest value among the Spanish breeds (20.58) and AV also had a low a^* value (20.93). The double muscled condition, characteristic of some of the AV animals, has been previously reported with lower a^* values than normal genotypes (Destefanis *et al.*, 1994). Among French breeds, Ga showed a higher value (14.58) than Au and Sal (14.12 and 14.14, respectively).

The b^* coordinate mean values are presented in table 2. This characteristic showed a higher variation related to L^* or a^* values, with coefficients of variation ranging from the 19% (Mo breed) to 34% (AV breed). The higher values corresponded to AM and Mo breeds whereas A-NI and AV presented the lowest values. These results are consistent with previous reports, as normal genotypes have shown slightly higher b^* values than double muscled genotypes (Destefanis *et al.*, 1994). Among French breeds Sal presented the lowest b^* value (9.32) whereas Ga the higher (10.54).

Water holding capacity

Thawing losses measure the capacity that the muscle has to hold water. If the muscle has a high loss percentage during thawing, its capacity is low. The coefficient of variation ranged from 13% to 35% depending upon the breed-production system (table 2). The higher mean values for thawing losses have been observed in Pi breed (8.09 %) and the lowest in Ga (6.17 %) and BP (6.25 %). Although double muscled animals have been reported to present higher drip losses values than normal genotypes (Destefanis *et al.*, 1994), AV did not show the highest thawing value among all studied breeds.

Cooking losses were measured in the chops assigned to sensorial assessments. As this analysis took place in three different laboratories with three different methodologies of cooking, the between groups differences in losses are more related to the cooking method used than to genetic differences. Meats that were cooked in an oven, pertaining to the BP, A-NI and Mo breeds, showed more than 20% of losses, whereas meats from AV, AM, Pi and Re breeds, that were cooked in a grill until 70°C of internal temperature, showed intermediate losses. In their turn, meats from French breeds, cooked in a grill until 55°C of internal temperature, had the lowest losses (7.40 - 9.31%). We can compare breeds within each group of cooking. Although double muscled animals have been reported with lower cooking losses than normal genotypes (Clinquart *et al.*, 1994; Destefanis *et al.*, 1994), in our study Re animals showed lower water losses than AV. Mo showed the highest losses in the oven-cooked meat, and Ga within the French breeds.

Water holding capacity was measured directly with a compression test. We can observe two groups of breeds, depending upon the laboratory that performed the analysis, as French breeds showed lower values than Spanish breeds (table 2). Among the Spanish breeds, the higher losses corresponded to the most meat-specialised breeds, Pi (23.10 %)

and AV (22.69 %). This phenomenon has been also reported by Destefanis *et al.* (1994), although double muscled animals were not found with the higher losses by Clinquart *et al.* (1994). Albertí *et al.* (1995) also found similar values to those reported here for Pi.

WHC results are the most variable reported in the bibliography, probably because of the high number of methods of measurement that can be used (Honikel, 1998), although not all of them discriminate completely different effects (Honikel, 1997). Different factors affect this capacity of binding water, since the amount of water in the muscle varies inversely to its fat content (Callow, 1947), and is highly related to the pH. In this study, however, we have found differences in intramuscular fat content not related to the average WHC mean of each breed.

Chemical composition

Dry matter content of the muscle is shown in table 3. The highest variability corresponded to A-NI (12.8 %) and Re breeds (10.0 %), and the lowest to Ga (2.3 %) and AV breeds (3.0 %). Means are quite similar in all breeds, ranging between 24.13 % (Pi) and 24.25 % (AV) to 25.44 % (Sal) and 25.40 % (BP). These values are similar to those found by Clinquart *et al.* (1994) and Fiems *et al.* (1998) in double muscled Belgian Blue cattle, and by Sañudo *et al.* (1999a) in some of the breeds included in this study. This suggest a constant content of dry matter of *Longissimus* muscle across breeds, although different muscles could content a different amount of dry matter (Lawrie, 1998)

Protein content of *Longissimus* muscle is also shown in table 3. A-NI (4.50 %) and Pi (3.8 %) showed the higher variation, and AM (2.1 %) and AV (1.92 %) the lowest. This variation can be considered very low, probably due to the fact that muscle is a middle speed deposition tissue (Lawrie, 1998) which would represent a similar content in the same muscle of different animals.

The higher protein content has been found in AV (22.84 %) and the lower in BP (21.70 %). Similar values have been reported for the Belgian Blue White double muscled (Fiems *et al.*, 1998). The higher protein content in double muscled animals could be due to its higher amount of muscular cells (Hanset *et al.*, 1982) in relation to normal genotypes.

Intramuscular fat content shows the highest variation among the meat quality attributes (table 3). This fact is mainly due to the late deposition rate within the tissue development rate, and because intramuscular fat is an energetic depot that the animal keeps for its consumption in low feeding conditions. So, depending on several intrinsic factors, such as age, gender or breed, and extrinsic ones, such as feeding system or walking conditions, the amount of intramuscular fat will vary (Robelin, 1986; Barker *et al.*, 1995).

The highest variability has been shown in AV breed (62.6 %). Given the lower intramuscular fat content of that breed (0.99 %), that figure implies a higher variation per unit

of stored fat. This is a characteristic of double muscled animals (Arthur, 1995), and it has been largely reported in other double muscle breeds such as Belgian Blue White (Clinquart *et al.*, 1994, 1997) and Piemontese (Destefanis *et al.*, 1996). In all these reports, the percentage of intramuscular fat did not reach 1%. The highest amount of fat appeared in Re (3.48 %), A-NI (2.72 %) and Mo (2.62 %) rustic breeds, which normally present a higher fat content than meat specialised breeds in the same productive conditions. Regarding the French breeds it is worth mentioning the lower value of intramuscular fat of the Au breed (1.09 %), in spite of its high age and weight at slaughter. There has been reported an important genetic effect on muscle composition; for example, dairy cattle have higher marbling than beef cattle (Fisher *et al.*, 1983).

For total collagen, the highest values have been observed in A-NI (3.41), BP (3.14), Sal (3.12), and AV (3.06). The values are slightly higher than those found by Campo (1999) and lower than those found by Seideman *et al.* (1986) in Angus and Hereford. For the French breeds, the average values are lower than those found by Jeremiah and Martin (1982) found higher values than ours for double muscle breeds of similar age (6.83 and 6.25 mg/g for Charolais and Chianina breeds).

Kopp (1971) reported that the biggest increase of collagen content happens in the range between 9-13 months, being that increase proportionally more important than the development of muscular tissue. This author reported that 5-10% of variability is normal in collagen content. Our values however were higher, around 20% and 13 % for the Spanish and French breeds, respectively, agreeing with results from De Smet *et al.* (1998) in the Belgian Blue White breed.

The higher values for insoluble collagen are those of A-NI (2.29) and French breeds. The lowest values were shown by Pi (1.68) and AM (1.53) breeds. Variability was similar in all Spanish breeds, around 20% of the mean, and lower in French breeds, ranging from 10 to 14% of the mean. Insoluble collagen average values were in accordance to those found by Campo (1999) for similar breeds. Bocard and Bordes (1986) reported an effect of precocity on collagen content, being higher for the breeds that arrived sooner at 45% of adult live weight. That trend, however, has not been observed in our data.

Quality of collagen has been reported as the relationship between total and insoluble collagen, named solubility percentage. Our solubility percentage values were higher than those found in the literature (Jeremiah *et al.*, 1980; Seideman *et al.*, 1986; Lizaso *et al.*, 1997) but are in accordance to those found by Sañudo *et al.* (1996) and Campo (1999). It is important to consider the solubilisation method: most of the authors use a standard of 70°/75 min, whilst we have used 90°/2 hours following the method described by Kopp (1971). It has been reported that time and temperature of solubilisation affects results (Kopp, 1971). On the other hand, the sampling method also would affect solubility results since there would be an

overestimation when samples are solubilised before freezing (Jeremiah *et al.*, 1980), something that we have avoided. Variation in solubility was according to that of Kopp (1971).

Solubility of collagen in French breeds was lower than in Spanish breeds, but similar to those reported by Jeremiah and Martin (1982). Kopp reported that collagen solubility reaches its maximum at 13 months of age, decreasing after it until the animals became 19 months old. This fact could explain partly the differences between Spanish and French breeds since French animals were slaughtered at an older age.

It is well established that the amount and properties of collagen are important in determining toughness of meat (Cross *et al.*, 1973; Seideman *et al.*, 1986; Vanderhaeghe *et al.*, 1989). A higher collagen content of the meat is associated with higher toughness. But collagen content itself cannot explain meat tenderness variability, because its properties change with age (Vanderhaeghe *et al.*, 1989). These changes are related to collagen thermal stability (Kopp, 1971; Judge and Mills, 1986). That stability depends on the amount and nature of crosslinks (Judge and Aberle, 1982; Damergi *et al.*, 1998) that increase with age (Shimokomaki *et al.*, 1972; Bosselmann *et al.*, 1985) being greatest at 15 months of age (Kopp, 1971).

Biochemical composition of muscle

Haematin content is shown in table 4. The maximum average value corresponded to AM (186.21 µg/g), Mo (180.83µg/g), and Au (181.99 µg/g) and the minimum to A-NI (135.94 µg/g) and AV (136.73 µg/g). Paleness of double muscled animals has been reported and explained mainly by their low myoglobin concentration (Boccard, 1982; Arthur, 1995; Clinquart *et al.*, 1994). Within breed residual variability differed in Spanish breeds, reaching its maximum for the AV breed (23.1%) and its minimum (14.0%) for the BP breed. Variability in French breeds did not differ between breeds, being approximately 14% of the mean.

At the same percentage of adult live weight, differences in meat pigmentation would be non-existent (Renerre, 1986). But at the same slaughter weight, the most precocious animals would present the highest pigment content, as found by Maltin *et al.* (1998) in Angus crossbred (154.98 µg/g) related to Charolais crossbred (139.43 µg/g). This is why AM and Mo showed the highest values among the Spanish breeds. Mo had been previously reported with a very high myoglobin content related to other Spanish breeds grown in the same conditions (Albertí *et al.*, 1995).

Chasco *et al.* (1995) found values for Pi yearlings of 170.89 µg/g, lower than Renerre and Valin (1979) for Limousin. Dairy cattle (Beriaín and Lizaso, 1997) and older animals (Morita *et al.*, 1969) would also present a higher pigment content under the same productive conditions. This could explain the higher content in Au (181.99 µg/g) related to the Sal

(176.78 $\mu\text{g/g}$) and Ga (164.09 $\mu\text{g/g}$). In general, French breeds showed higher haematin content than Spanish breeds, probably due to its older age.

Muscle is composed by different types of muscular fibres that can be classified according to different criteria. It is accepted, however, that there are three types of fibres (β R type I; α R type II A; α W type II B) according to their red or white colour, physical and metabolic characteristics (Ashmore and Doerr, 1971). Red fibres of slow twitch (type I) would show an oxidative metabolism, with isocitrate dehydrogenase (ICDH) as the characteristic enzyme, whereas white fibres of fast twitch (type II B) would show a glycolytic metabolism, with lactate dehydrogenase (LDH) as a characteristic enzyme. There are few muscles that can be considered composed only by one of those fibre types. *Longissimus* muscle is considered a mixed muscle with red fibres of fast twitch with an oxidative-glycolytic metabolism, although muscle fibre type may change with selective breeding, diet or exogenous growth promoters among other factors (Buttery *et al.*, 1997). Distribution of fibre types changes with age by conversion of fast oxidative glycolytic fibres into fast glycolytic fibres (Seideman *et al.*, 1986). And since it has been observed a negative correlation between the oxidative activity of the muscles (ICDH) and overall muscle growth in cattle (Jurie *et al.*, 1995a), it would exist a positive correlation between glycolytic metabolism and protein retention (Jurie *et al.*, 1995b).

LDH results are shown in Table 4. Among the Spanish breeds the highest amount of enzyme has been found in AV breed (1204.16 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$) followed by the BP breed (1171.29 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$), whereas the lowest mean value corresponds to the Pi breed (1022.30 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$). The French breeds presented higher values for LDH content than the Spanish breeds. Double muscled animals have a higher number of white fibres (Boccard, 1982), which would be related to LDH activity. This would explain the higher value in AV breed.

The variability expressed in relation to the mean ranged between 11.7% and 15.3% for the breeds AV and Pi, being the differences statistically significant. There were no differences among French breeds, being the coefficient of variation around 20%.

The highest ICDH content appeared in the more rustic breeds Re, Mo, AM and A-NI (2.07 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$, 1.90 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$, 1.78 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$ and 1.77 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$, respectively), whereas the lowest mean values corresponded to the meat specialised breeds Pi (1.36 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$) and AV (1.47 $\mu\text{mol min}^{-1}\cdot\text{g}^{-1}$). These breeds would be slightly younger at the same slaughter weight than rustic breeds, which would decrease its ICDH content.

According to Jurie *et al.* (1995b) ICDH activity would decrease until the age of 12 months. After this age, it would increase, which would coincide with a slowing down of the conversion of fast oxidative glycolytic fibres into fast glycolytic fibres. Hence, the period of

growth and development would be characterised by fibre conversion, and the increase of ICDH activity may be considered as the first feature of ageing (Jurie *et al.*, 1995b).

The variability of ICDH has been higher than the variation of LDH values, ranging from 39.0% (A-NI) to 23.8 % (BP), probably because of the different precocity of the different breeds. The variability of French breeds was also high and similar between breeds, around 34%.

Myosin is the biggest myofibrillar protein and the main component, together with actine, involved in muscle contraction. Type I fibres express the myosin heavy chain I (MHC I) isoform (Termin *et al.*, 1989) which is a useful marker for this type of oxidative fibres (Picard *et al.*, 1994). Pi had the biggest MHC I percentage (41.49%) and A-NI the lowest (26.70 %) (table 4). In the French breeds the MHC I content was lower than in the Spanish breeds. No relation can be found between this variable and production or genetic characteristics, since Mo and AM breeds, with 39.24% and 35.45% of MHC I respectively, had medium values between the meat specialised breeds Pi and AV. Variability was similar to that showed by the ICDH enzyme. Mo showed the lowest variation among animals (21.9%) and A-NI and Re the highest (48.16% and 46.28% respectively).

Texture determinations

Meat texture is of utmost importance to consumer acceptance. In sensorial terms, it can be defined as the composite of structural elements of meat and the manner in which it registers with the physiological senses (Tornberg, 1996). Meat texture is correlated with several muscular structures and its components: myofibrils, connective tissue and water (Lepetit *et al.*, 1986). In physical terms, meat toughness could be the work of deformation and failure but also the consideration of forces involved and the anisotropy of the whole muscle. Mechanical forces acting on meat can include shear, compression and tensile forces and they should be defined in the mechanical test in use (Tornberg, 1996).

Depending upon the mechanical test used results will show contribution of one or other meat component (Campo, 1999). Instrumental methods can be divided into empirical and fundamental ones. For the assessment of the texture of whole meat, the empirical method of the Warner-Bratzler shear device is the most widely used. In fundamental tests, uniaxial compression is one of the most popular. A well-defined compression test for evaluating the tenderness of both raw and cooked meat has been developed in France. This method is capable of discriminating the role of each meat component to overall meat toughness. So, at low stress (20%), it would assess myofibrillar effect, and at high compression rates (80%), it would assess the connective tissue contribution (Lepetit and Culioli, 1994). Fibre direction is also important. When shear force is applied perpendicular to the direction of fibres, maximum force is correlated with myofibrillar components of meat.

For maximum load of cooked meat (table 5), higher values were those presented by AV (5.02), possibly due to the presence of the double muscle condition. It has been observed that the presence of muscular fibres of rapid contraction is positively correlated to myofibrillar contribution to toughness (Campo *et al.*, 1999). Intermediate values are those of Mo (4.90) and Re (4.65). However, the lowest values corresponded to the breed Au (3.48), a rustic breed reared on a grazing system and slaughtered at the oldest age among the breeds studied. All texture values were according to those of Sañudo *et al.* (1996) and Campo (1999). Variation coefficients of maximum load were different between breeds, ranging from 23.5% in the Pi breed to 30.4% in Mo. Variability was lower in French breeds (18.6%, 19.2% and 24.5% for Ga, Au and Sal, respectively). Kopp (1971) reported that variability of Warner-Bratzler method is high. Variability was similar to that of data recorded by Albertí *et al.* (1995) for textural parameters.

Regarding toughness (table 5), the highest values corresponded to Sal (1.95), Mo (1.77) and AV (1.76), followed by Pi (1.67), Au (1.63), Ga (1.62) and Re (1.52). The lowest values were those of BP (1.47), A-NI (1.44) and AM (1.41). Albertí *et al.* (1995) reported that there is no breed effect in this parameter and Kopp (1971) that there is no age effect on it. The highest variability was found in A-NI (42.36%) and the lowest in Sal breed (22.56%).

Stress at 20% values, representing resistance of myofibrillar component, was higher in AV (5.11) and Pi (5.45) meat breeds and in French breeds. The rest of the breeds showed similar values. Variability was also higher in meat specialised breeds (AV, 32.48%, Pi, 31.92%) than in others.

Stress at 80% would represent resistance offered by connective tissue. The highest values were those of Sal (42.65), AM (41.18) and A-NI (39.42). Surprisingly, the animals of the breed Au that were slaughtered at the oldest age, with time enough to increase in collagen cross-links, showed very low values. Variability was very similar in all French breeds, around 22%. The variability was different in the Spanish breeds, ranging from 20.0% to 31.9% for the BP and Pi, respectively.

The highest values for maximum load were shown by the breeds Sal (69.51) and AM (65.48) whereas the lowest values corresponded to AV (55.38). Variability in maximum load in compression was very similar to that of stress at 80%.

REGRESSIONS OF INSTRUMENTAL MEAT QUALITY VARIABLES ON PRODUCTION AND CARCASS CLASSIFICATION TRAITS

Daily gain weight

Significant slopes in the lineal regressions attending at Daily Weight Gain (DGW, kg/day) as the independent variable are shown in table 6. No significant regressions have been found between DGW and pH in any breed. As previously reported by Minet *et al.* (1998) in double muscled animals, DGW has been positively related to the L^* value in AM, BP and Ga breeds (4.52, 2.31 and 5.43 respectively), and to an increase in b^* value in Pi (3.51) and Ga (1.67). However, DGW has been negatively correlated to the a^* value in AV and A-NI breeds (-2.14 and -2.07 respectively), probably because the a^* co-ordinate is highly correlated to haem pigment content. Since fast growth rates would imply a lower haeminic deposition, that would also represents a lighter meat and a higher L^* value.

Thawing losses have presented positive slopes in BP (2.72) and negative in A-NI (-2.93), cooking losses showed negative slopes in A-NI and Ga (-6.77 and -2.20 respectively) while water holding capacity measured with a compression test presented a negative slope in AV (-1.87) and positive in AM (3.76). No coincident slopes and tendencies have been found among the different ways of measuring water holding capacity, as predicted by Honikel (1998) with different methodologies, related to DGW. Dry matter and total and insoluble collagen showed positive slopes in different breeds, especially AM and Re. This would imply an increase on the amount of collagen, and consequently of dry matter, as DGW increases. Allingham *et al.* (1998) found an increased collagen synthesis as growth rate increases, although the new collagen was more soluble than the previous one. On the other hand, negative significant slopes have been found in AV (-0.34) and Mo (-1.09), maybe because of an increasing deposition of fat with DGW in these breeds, which would reduce protein deposition.

As found in the a^* value, haematin content showed negative significant slopes in some breeds (Ga, -93.17; AM, -87.87; A-NI, -49.39; Sal, -31.21 and Re, -14.88) related to DGW, which would represent lighter meat as DGW rises. In animals with high weight gain, it has been found a shift towards production of fibres with greater glycolytic activity, which have a faster *postmortem* maturation rate and hence produce more rapidly tender meat (Jurie *et al.*, 1995b). However, LDH showed a large negative slope in AV (-176.77) and slightly positive in Mo (5.05), which would represent an increment of the oxidative activity in double muscled breed AV as DGW rises. Double muscled animals, however, usually do not have high DGW because of some physical characteristics related to their lower digestive development and low food intake (Arthur, 1995).

Texture variables have shown negative significant slopes on DGW in all breeds with significant values but Pi, who presented the only positive slope for stress at 20% compression (3.04). This would represent decreasing toughness values as DGW rises, coinciding with Allingham *et al.* (1998), who found a higher soluble collagen deposition and, consequently, a possible lower toughness as DGW increases. Young animals, as those of the Spanish breeds, would show higher toughness than older animals intensively fed up to a limit age. And this could explain why French breeds showed less significant slopes than Spanish breeds, especially Au, since they were slaughtered at a higher age, and DGW at older ages is lower than at early steps.

Slaughter weight

Significant slopes of the meat quality traits on slaughter weight (SW), expressed in kilograms, are presented in table 7. Only Pi showed a slightly significant slope of pH related to SW, which would support the previous idea that pre-slaughter stress pH due to management has more influence on pH than production factors.

As in Minet *et al.* (1998), colour co-ordinates, while significant, showed positive slopes in all breeds but b* in BP (-0.033). According to these results, a higher SW would represent a lighter meat in Au (0.015) and Ga (0.018) and redder in Pi (0.015), which would be related to the significant and positive haematin slope.

As previously reported in DGW, water holding capacity did not show homogenous tendencies through the different methodologies of measurement. Thawing losses were not significantly related to SW in any breed, cooking losses only in AM (0.037) and Sal (0.006) breeds, and WHC measured with a compression test showed a negative slope in Re (-0.038).

Dry matter had similar, but slight slopes, in Pi, Mo and Ga, probably related in this last breed to an increase in intramuscular fat with SW. In intensively fed animals, high energy diets would produce an increase in fat deposition, especially as age and weight rise. But we have not found significant slopes in any breed but Ga, probably due to the fact that, within breed, the degree of maturity was similar for all animals. Total collagen only showed significant slopes in AM (-0.0045) and Re (0.0047). The different tendency could be due to different energy content in the diet, since Damergi *et al.* (1996) have reported a diet effect on collagen characteristics. A restriction would increase total content in young animals and decrease it in the older ones, decreasing solubility in both cases.

Although haematin content would increase with age and consequently with SW, we found negative slopes in AV (-0.32) and A-NI (-0.51). No explanation can be found in A-NI, although AV presents lean and pale meat related to its double muscled condition. LDH only showed a significant positive slope in BP (1.05) and ICDH showed negative slopes in AM

(-0.006), A-NI (-0.013), Re (-0.005) and Ga (-0.006). Jurie *et al.* (1995b) also described a decreasing ICDH activity and an increasing LDH activity as age of Limousin males rose until 12 months old, due to an increment of glycolytic metabolism. Myosin presented negatively slopes in AV, BP, A-NI and Re breeds, and positive in Pi breed.

Regarding instrumental texture characteristics, when slopes were significant, AV, AM and Pi showed positive tendencies, whereas in BP, A-NI and French breeds the slopes were negative. These results could be related to the different development steps at the slaughter weight in different breeds studied in this project. The differences in development could explain the deposition of soluble collagen in meat specialised breeds and AV, and an increasing stable cross-linking in the rest of breeds, since age is one of the factors that influences insoluble cross-link formation and this is highly related to meat toughness (Monin, 1991).

Carcass conformation

Significant slopes in the lineal regressions attending at carcass conformation score as the independent variable are shown in table 8. As conformation increases, pH would decrease in AV and Mo breeds, and increase in BP. Higher conformation scores would be related to higher lightness in AV, AM, Pi, Au and Ga, probably related to a higher muscle development and a lower myoglobin concentration. The slopes of a^* and b^* co-ordinates showed different tendencies in different breeds, positive in Pi (0.31 and 0.54 respectively) and in Au ($a^*=0.16$), and negative in AV and Ga for a^* , and Re in b^* .

Thawing and water holding capacity showed positive and significant slopes in most of the breeds, probably related to a higher muscle development as conformation score increase, which would include a higher water content easier to release, since conformation is based in muscle development instead of fat deposition. Cooking losses only showed a negative slope in BP.

While significant, dry matter showed negative slopes in all breeds but Re, related to the higher water content of the muscle as conformation and muscle development increase. Protein showed positive slopes in AV, Re and Ga, whereas the slopes of intramuscular fat on conformation scores were negative in AV, BP, Mo, Re, Au and Ga. Given that carcass conformation and fatness are inversely correlated and conformation is based on muscle development, slopes related to protein were positive and those related to fat negative. Collagen content also presented negative slopes in half of the breeds. An increase of conformation score caused a decrease in total collagen content in A-NI, Au, Ga and Re (as reported by Vanderhaeghe and Deroanne, 1989). Given that all these animals have been intensively fed, as previously explained, high growth rates would produce more soluble collagen.

As expected, haematin content showed negative slopes in AV, AM, BP, Au and Ga, since higher muscle development would represent lighter meats with lower myoglobin concentration. LDH only had a positive slope in Re while ICDH showed negative slopes in Mo, Re and Au breeds, as previously reported in DGW and SW since higher DGW and SW are normally related to higher conformation scores.

Regarding texture characteristics measures of raw meat, maximum load and stress at 80% compression showed negative slopes. As they are related mainly to connective characteristics and collagen content, and since total and insoluble collagen showed negative slopes, they presented as well negative slopes. However, compression at a rate of 20 %, a measure of myofibrillar characteristics, only showed a positive slope in AV. The AV breed, due to its double muscled condition, would show a higher number of muscular cells (Hanset *et al.*, 1982; Lazzaroni *et al.*, 1994; Wegner *et al.*, 1997) with a higher number of white fibres (Wegner *et al.*, 1997) which are inversely related to tenderness (Maltin *et al.*, 1998).

Fatness score

Table 9 shows significant slopes of lineal regressions regarding at carcass fatness score as the independent variable. Only AV and Pi showed significant slopes in pH (0.007 and 0.011 respectively). While significant, L* slope was negative (-0.58 in AV breed) and a* and b* were positive. Meat from younger animals is paler and less red than from older animals, and fatness score increases with age. This could explain the direction of the slopes.

Only Pi showed a significant and positive slope in thawing losses (0.28). Water holding capacity measured with a compression test showed a negative slope in AV (-0.25) and positive in A-NI (0.64) and Re (0.98). This lack of significance with fatness has to be understood by the fact that fatness score measures external fatness. Any direct relation between water releases and fatness should exist with intramuscular fatness. As fatness score increased, positive slopes appeared with dry matter, intramuscular fat and collagen content, and negative with protein content. Fat and protein in the muscle are negatively correlated, that is why slopes had different senses. At this age of slaughter, as external fatness increases, intramuscular fat also would increase, and although it is a late development tissue it would be deposited at the same time as subcutaneous fat.

Haematin content showed the same significant and positive slopes as a* co-ordinate in the same breeds, plus Pi. Older animals would show higher fatness scores besides higher myoglobin concentration, producing positive relations between these variables. LDH showed a slight negative slope AV (-0.76) and positive in AM (29.83); ICDH only showed a low significant slope in Au (0.075), while no significant slopes were found for myosin content. This would suggest low correlation between fatness score and these biochemical variables.

Our results agree with those of Jurie *et al.* (1995b) that did not find any relation between biological characteristics of the muscle and carcass composition, i.e., fat percentage.

When significant, the slopes for texture variables have been divided into two groups according to their sign. Meat specialised breeds, AV and Pi, plus AM, showed positive slopes in all significant variables. As no significant slope was found in compression at 20%, those significant slopes in maximum load and stress at 80 % would indicate an increasing connective toughness while fatness score increases in these two meat specialised breeds. Only A-NI breed showed a negative slope in compression variables, which would imply a positive influence of fatness score on tenderness on this breed.

RELATIONSHIPS BETWEEN TRAITS

Relationships among muscle characteristics and carcass traits

The existing relationships between muscle characteristics and carcass traits as derived from a Principal Component Analysis are presented in figure 1. To characterise carcasses several carcass quality indexes were defined. A synthetic carcass conformation (SCC) index was calculated from measures of conformation (conf), hind-limb width (hw) and area of muscle *Longissimus* (area). That index is as follows:

$$\text{SCC} = 0.56 \text{ conf} + 0.55 \text{ dp} + 0.47 \text{ hw} + 0.41 \text{ area, for all Spanish animals, and}$$

$$\text{SCC} = 0.60 \text{ conf} + 0.57 \text{ dp} + 0.55 \text{ hw, for the French animals without area.}$$

As showed in a previous chapter, the different fatness measures taken on the 6th rib (total fat, tf%; intermuscular fat, imf%; muscle, m%; subcutaneous fat, sf%) and on the carcass (fattening score, fat; kidney and knob channel fat, kkcf), were closely related and opposed to muscle content estimated from the 6th rib. A synthetic carcass fatness (SCF) index was calculated for further analyses as follows:

$$\text{SCF} = 0.51 \text{ tf\%} + 0.47 \text{ imf\%} - 0.45 \text{ m\%} + 0.32 \text{ fat} + 0.32 \text{ kkcf} + 0.32 \text{ sf\%, for all animals except AM,}$$

$$\text{SCF} = 0.54 \% \text{ tf} + 0.50 \text{ imf\%} - 0.48 \text{ m\%} + 0.34 \text{ fat} + 0.34 \text{ sf\%, for AM animals which were lacking the carcass internal fat content.}$$

In addition, the two carcass (cl) and hind-limb (hl) lengths measures were close and a synthetic carcass length (SCL) variable was calculated as:

$$\text{SCL} = 0.71 \text{ cl} + 0.71 \text{ hl, for the all animals.}$$

The opposition between the two carcass synthetic variables, conformation and fatness, explained most of the variation among animals and determined therefore the first axis. There was a group of muscle characteristics that were positively related to carcass fatness and opposed to carcass conformation on that first axis: contents of lipids (lip), dry

matter (dm), pigments (hem) and collagen (coll), as well as the size of muscle fibres (mfa). The protein content (prot) had opposite relationships. However, it should be mentioned that the haematin content of the Mo breed was surprisingly positively related to carcass conformation and negatively to carcass fatness (not shown in the figures).

The second axis was primarily explained by some opposition between fibre type characteristics. Higher glycolytic activity (ldh) was opposed to higher oxydative activity (icdh) and to higher content of slow myosine heavy chain (myos).

These muscle fibre characteristics were lowly related to other muscle variables, except a significant relationship between the icdh oxydative activity and the pigment content. There was a slight trend: animals with fatter carcass had muscles whose energy metabolism was more oxydative and animals with better conformation had muscles whose energy metabolism was more glycolytic.

Relationships with colour measures

The Principal Component Analysis of spectrophotometer variables and muscle and carcass characteristics are reported in figure 2. The lightness L^* parameter was clearly opposed to the intensity of the red a^* parameter, while the yellow b^* parameter was positively associated to that red a^* intensity. The a^* parameter was clearly associated to fatter animals and opposed to conformation, while the opposite was true for the L^* parameter, since fatter animals had higher content of haematin and that latter was primarily associated to the a^* red colour and opposed to L^* lightness.

The same pattern for the relationship between colour parameters (L^* , a^*) and haematin content was found within the different breeds, except in the Mo and AM breeds where very low relationships were observed (figures not shown).

The same pattern was also found within the different breeds for the relationships between colour parameters (L^* , a^*) and carcass conformation or carcass fatness, although in the A-NI, Mo, Re and Sal breeds these colour parameters were poorly related to carcass characteristics.

Relationships among texture measures

The Principal Component Analysis of texture measures obtained with the Warner-Bratzler device or the compression device are reported in figure 3. The three parameters measured, maximum load (lmx), maximum stress (smx) and toughness (tgh) were very closely related. A synthetic shear force variable (SSHF) was calculated:

$$\text{SSHF} = 0.59 \text{ smx} + 0.58 \text{ lmx} + 0.56 \text{ tgh, for all animals.}$$

The measures of the maximum compression force (cmx) or at 80% deformation (c80) were also closely related. A synthetic maximum compression variable (SCMX) was calculated as:

$$\text{SCMX} = 0.71 \text{ cmx} + 0.71 \text{ c80, for all animals.}$$

These two groups of measures of the texture were not related to each other. The compression force at 20 % deformation (c20) was lowly positively related to both groups, slightly closer SCMX than SSHF.

Relationships among eating quality evaluations

Taste panels in Zaragoza, Monells and Villers evaluated the following sensory traits: acceptability (Acc), tenderness (Tend), juiciness (Juic), beef flavour (b.Fl), beef odour (b.Od), liver flavour (l.Fl), and liver odour (l.Od). Each panel was in charge of evaluating separately a group of breeds. Since it was not possible to assess meat quality in the same conditions in the three laboratories, the analyses were performed separately for breeds tested in Zaragoza (AV, AM, Pi and Re), Monells (BP, A-NI and Mo) or Villers (Au, Ga and Sal).

Results in the three laboratories (figure 4) show that the overall acceptability score was primarily dependent on tenderness and beef flavour, then on juiciness. In the two Spanish laboratories where liver flavour and odour were evaluated, they were poorly related to overall acceptability. In the three laboratories, juiciness was closely related with tenderness. Beef flavour was positively related to tenderness and juiciness in the French laboratory but unrelated to both evaluations in both Spanish laboratories.

Relationships with tenderness and texture measures

The Principal Component Analysis between tenderness and texture measures (SSHF, SCMX, c20), carcass and muscle characteristics were performed within each laboratory (figure 5).

In the three laboratories, shear force measured with the Warner-Bratzler device (SSHF) appeared clearly opposed to tenderness score. Both compression measures were poorly related to tenderness. They were, even surprisingly, positively related to tenderness in Monells laboratory. Except in the Mo breed, the synthetic maximum compression variable (SCMX) was positively related to the collagen content of the muscle.

In the breeds tested in Zaragoza tenderness and shear force tended to be related to the carcass characteristics: fatter carcasses with worse conformation tended to be related with tender meat, although they had higher content of collagen. However in the Pi breed, animals with fatter carcass tended to give tougher meat. On the other hand, in the breeds

tested in Monells tenderness and shear force were lowly related to carcass conformation and fatness: leaner animals with well shaped carcass only tended to have slightly tougher meat.

No clear relationship appeared between carcass characteristics and tenderness or texture of animals tested in Villers. In the Sal breed, tenderness was lowly but positively related to fatness similarly to most of the Spanish breeds. In the two other French breeds tested in Villers (Au and Ga) the opposite relationship was found, principally for the Au animals: leaner animals with well shaped carcasses tended to have tender meat. These last results are not shown in figures.

Relationships with juiciness and water loss measures

Principal Component Analyses including juiciness and water loss measures (at thawing, wl.t, or cooking, wl.c) or water holding capacity (whc), and carcass and muscle characteristics were performed within each laboratory (figure 6).

Among the three measures of water loss only water loss at cooking was clearly opposed to juiciness in the four breeds evaluated in Zaragoza. Water loss at cooking was higher in fatter animals of AM and Pi breeds (results not shown). Juiciness was lower in fatter animals of Pi breed.

Within the three breeds evaluated in Monells juiciness was closely related to water loss at cooking and slightly less with loss at thawing, but unrelated to the measure on fresh meat. In the three breeds, water loss at cooking was higher and juiciness lower in fatter animals with poorer shaped carcass.

Within the three French breeds evaluated in Villers, there was no clear relationship between juiciness scored by the taste panel and the three measures of water loss. Only in the Au breed a relationship could be found between juiciness and carcass characteristics: juiciness was higher in leaner animals with better shaped carcass.

Relationships with flavour and odour evaluations

A graphic representation of the principal component analysis developed on data of flavour and odour evaluations, as well as carcass and muscle characteristics was drawn for each laboratory (figure 7).

Within the breeds evaluated in Zaragoza, beef flavour and beef odour scores were closely related, as were liver flavour and liver odour evaluations. The latter were also close to the former. In the AV, Pi and Re breeds beef flavour was positively related to carcass fatness and to intra muscular lipid content. The AM breed was peculiar since beef flavour was independent of carcass fatness or lipid content and was slightly related positively to carcass conformation (again, results specific for each breed are not shown in tables).

For the breeds evaluated in Monells, the four sensory traits were also closely correlated to each other. Beef flavour was higher in fatter animals in the BP and Mo breeds, in relation with higher lipid contents. In the A-NI breed, beef flavour was slightly opposed to carcass fatness and lipid content, and was positively related to carcass conformation.

In the three French breeds beef flavour was positively related to lipid content and LDH activity. In the Ga and Sal breeds the correlation with lipid content was higher than with LDH activity. Beef flavour was therefore higher in fatter animals with poorer shaped carcass. In the Au breed both relationships were equivalent and, consequently, beef flavour was independent of carcass characteristics.

CONCLUSIONS AND IMPLICATIONS

Ten beef meat breed - systems of the Southwest of Europe have been thoroughly characterised regarding meat quality variables. Breed and production system affects meat quality characteristics. The large differences between breed - systems observed may justify specific designations or meat quality marks. Within breed and in the range of variation studied, the increase of slaughter weight, daily gain or conformation score does not imply meat quality losses in terms of colour, texture or chemical composition.

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Table 1. Sample size (N) and averages and ranges for age at slaughter, daily gain weight, slaughter weight, carcass conformation score (EUROP), and carcass fatness score (1-15) in ten local breed-production systems of the Southwest of Europe.

Breed	N	Slaughter age (days)	Daily gain (kg/day)	Slaughter weight (kg)	Conformation score	Fatness score
AM	70	541.0 (433 – 715)	1.03 (0.50 – 1.38)	444 (399 – 566)	7.5 (R–) (2 – 11)	6.7 (3–) (4 – 11)
AV	70	415.7 (327 – 519)	1.41 (0.9 – 2.17)	509 (463 – 622)	11.8 (U+) (7 – 15)	4.1 (2–) (1 – 9)
A-NI	70	363.6 (296 – 432)	1.64 (1.10 – 2.11)	481 (435 – 531)	8.5 (R) (5 – 11)	8.0 (3) (5 – 11)
BP	67	380.6 (334 – 453)	1.63 (1.04 – 2.14)	542 (440 – 602)	11.2 (U) (10 – 14)	6.7 (3–) (4 – 11)
Mo	70	438.9 (343 – 508)	1.11 (0.57 – 1.66)	458 (340 – 545)	6.0 (O+) (4 – 9)	8.1 (3) (7 – 10)
Pi	55	382.8 (289 – 463)	1.65 (1.13 – 2.41)	552 (413 – 731)	9.9 (U–) (6 – 14)	5.5 (2) (2 – 9)
Re	68	417.7 (345 – 503)	1.41 (0.65 – 2.33)	498 (420 – 560)	9.4 (R+) (7 – 12)	8.8 (3+) (6 – 12)
Au	78	722.8 (675 – 787)	1.25 (0.83 – 1.70)	753 (686 – 830)	9.5 (U–) (5 – 13)	7.7 (3) (4 – 12)
Ga	82	492.3 (392 – 577)	1.37 (1.02 – 1.81)	610 (539 – 670)	9.5 (U–) (5 – 13)	8.0 (3) (6 – 11)
Sal	82	582.1 (488 – 720)	1.29 (0.91 – 1.86)	714 (615 – 795)	8.3 (R) (6 – 11)	8.7 (3+) (5 – 14)

AV: Asturiana de los Valles, AM: Asturiana de la Montaña, Pi: Pirenaica, BP: Bruna dels Pirineus, A-NI: Avileña-Negra Ibérica, Mo: Morucha, Re: Retinta, Au: Aubrac, Ga: Gasconne, Sal: Salers.

Table 2. Colour determinations and water holding capacity in ten local beef cattle breed - systems of South-western Europe: means and (within year standard deviations).

	AM	AV	A-NI	BP	Mo	Pi	Re	Au	Ga	Sal
N	70	70	70	70	70	55	68	78	82	82
PH7d	5.59 (0.07)	5.53 (0.07)	5.54 (0.05)	5.54 (0.09)	5.53 (0.09)	5.51 (0.05)	5.53 (0.09)	5.59 (0.08)	5.62 (0.04)	5.61 (0.07)
L*	32.24 (3.00)	38.81 (3.61)	37.73 (2.73)	36.03 (2.70)	32.60 (2.52)	38.87 (3.08)	35.45 (2.44)	38.90 (1.71)	39.64 (1.79)	38.16 (1.72)
a*	23.42 (2.91)	20.93 (2.95)	20.58 (1.87)	21.29 (2.36)	23.95 (2.69)	21.14 (2.88)	22.92 (1.85)	14.12 (1.22)	14.58 (1.31)	14.14 (1.67)
b*	13.20 (3.25)	11.67 (2.17)	10.74 (2.42)	11.20 (3.13)	12.54 (3.70)	12.28 (2.64)	11.08 (1.85)	10.02 (0.93)	10.54 (1.24)	9.32 (1.42)
Thawing losses (%)	6.81 (2.37)	6.84 (1.68)	6.83 (1.76)	6.25 (2.64)	7.69 (1.42)	8.09 (1.96)	7.41 (1.39)	7.92 (1.38)	6.17 (0.81)	7.62 (0.97)
Cooking losses (%)	14.72 (4.53)	14.42 (3.27)	23.40 (5.63)	22.91 (5.18)	24.61 (5.80)	15.29 (3.92)	13.50 (3.50)	8.69 (1.20)	9.31 (1.39)	7.40 (0.76)
WHC (%)	20.86 (2.22)	22.69 (2.21)	20.16 (1.90)	21.04 (2.53)	19.13 (1.91)	23.10 (2.18)	19.66 (5.71)	16.86 (1.51)	16.09 (1.71)	15.12 (1.94)

Table 3. Chemical composition of meat in ten local beef cattle breed - systems of South-western Europe: means and (within year standard deviations).

	AM	AV	A-NI	BP	Mo	Pi	Re	Au	Ga	Sal
Dry matter (%)	24.39 (0.82)	24.25 (0.72)	24.99 (3.19)	25.40 (0.85)	25.32 (0.91)	24.13 (1.13)	24.81 (2.48)	24.79 (0.81)	25.16 (0.58)	25.44 (0.97)
Protein content (%)	22.33 (0.46)	22.84 (0.44)	21.76 (0.99)	21.70 (0.83)	21.93 (0.94)	22.25 (0.84)	22.48 (0.66)	22.36 (0.58)	22.6 (0.60)	21.79 (0.70)
Intramuscular fat (%)	1.91 (1.01)	0.99 (0.62)	2.72 (0.72)	2.43 (0.81)	2.62 (0.60)	1.94 (0.91)	3.48 (1.78)	1.09 (0.50)	1.81 (0.73)	2.42 (1.14)
Total collagen (mg/g)	2.66 (0.57)	3.06 (0.65)	3.41 (0.55)	3.14 (0.52)	3.02 (0.68)	2.90 (0.54)	3.07 (0.59)	2.71 (0.35)	2.49 (0.31)	3.12 (0.39)
Insoluble collagen (mg/g)	1.54 (0.40)	1.69 (0.39)	2.29 (0.44)	1.86 (0.32)	1.91 (0.42)	1.68 (0.32)	1.82 (0.43)	2.39 (0.26)	2.15 (0.27)	2.80 (0.39)
Solubility of collagen (%)	42.43 (9.45)	43.10 (9.42)	32.94 (8.03)	39.97 (8.16)	35.44 (9.26)	42.08 (7.21)	40.43 (10.87)	11.60 (6.56)	13.32 (7.38)	10.64 (6.72)

Table 4. Muscle fibre characteristics in ten local beef cattle breed - systems of South-western Europe: means and (within year standard deviations).

	AM	AV	A-NI	BP	Mo	Pi	Re	Au	Ga	Sal
Haematin ($\mu\text{g/g}$)	186.21 (27.72)	136.73 (31.49)	135.94 (23.74)	147.81 (20.72)	180.83 (31.74)	143.99 (30.74)	165.80 (27.78)	181.99 (23.09)	164.09 (27.68)	176.78 (23.93)
LDH ($\mu\text{mol piruvate}$)	1084.36 (138.96)	1204.16 (184.37)	1153.18 (175.40)	1171.29 (143.59)	1166.71 (135.84)	1032.96 (121.27)	1042.69 (154.73)	1489.34 (271.29)	1549.56 (309.49)	1348.56 (245.16)
ICDH ($\mu\text{mol isocitrate}$)	1.78 (0.61)	1.48 (0.48)	1.77 (0.69)	1.64 (0.39)	1.90 (0.68)	1.35 (0.45)	2.07 (0.58)	1.58 (0.56)	1.65 (0.56)	1.80 (0.64)
Myosin (%)	35.45 (9.18)	32.10 (10.60)	26.70 (12.86)	27.87 (8.74)	39.24 (8.59)	41.49 (16.07)	31.01 (14.35)	22.91 (7.78)	29.63 (9.30)	27.33 (9.78)

Table 5. Texture measurements in ten local beef cattle breed - systems of South-western Europe: means and (within year standard deviations).

	AM	AV	A-NI	BP	Mo	Pi	Re	Au	Ga	Sal
Maximum load (kg)	4.02 (1.07)	5.02 (1.25)	4.09 (1.04)	4.36 (1.26)	4.90 (1.49)	4.00 (0.94)	4.65 (1.27)	3.48 (0.67)	3.93 (0.73)	4.41 (1.08)
Toughness (kg/cm ²)	1.42 (0.31)	1.76 (0.56)	1.44 (0.61)	1.47 (0.35)	1.77 (0.57)	1.67 (0.51)	1.52 (0.35)	1.63 (0.27)	1.62 (0.23)	1.95 (0.37)
Maximum load compression (N)	65.48 (17.33)	55.38 (13.42)	63.36 (10.20)	59.21 (13.30)	59.85 (9.97)	59.02 (11.07)	59.16 (10.06)	64.84 (12.19)	62.98 (13.34)	69.51 (16.76)
Stress at 20% (N/cm ²)	4.61 (1.21)	5.11 (1.66)	4.54 (1.20)	4.21 (0.84)	4.19 (0.88)	5.45 (1.74)	4.29 (1.12)	5.53 (1.24)	5.51 (1.23)	4.92 (1.29)
Stress at 80% (N/cm ²)	41.18 (10.20)	34.45 (8.18)	39.42 (8.21)	37.64 (8.15)	36.24 (6.80)	37.07 (7.16)	36.82 (7.48)	36.99 (7.97)	35.35 (6.54)	42.65 (9.23)

Table 6. Significant slopes for each beef breed-system of the linear regressions relating each variable with the Daily Weight Gain (DWG) as the independent variable.

	AV	AM	Pi	BP	A-NI	Mo	Re	Au	Ga	Sal
pH 7 days										
L*		4.520		2.310					5.430	
a*	-2.140				-2.070					
b*			3.510						1.670	
Thawing losses				2.720	-2.930					
Cooking losses					-6.770				-2.200	
WHC	-1.870	3.760								
Dry matter		0.930	1.160						1.100	
Protein	-0.340					-1.090				
Intramuscular fat										
Total collagen		0.750					0.460			
Insoluble collagen		0.450				0.400	0.430			
Haematin		-87.870			-49.390			-14.880	-93.170	-31.210
LDH	-176.770					5.050				
ICDH					-1.950		-0.580			1.800
Myosin	-10.200		25.310		-29.190					
Max. Load WB									-1.510	
Toughness WB				-0.300	-0.850				-0.370	
Max. Load C				-12.340		-10.960				
Stress 20% C	-1.710		3.040	-0.830						-0.960
Stress 80% C				-8.780						

Table 7. Significant slopes for each beef breed-system of the linear regressions relating each variable with Slaughter Weight (SW) as the independent variable.

	AV	AM	Pi	BP	A-NI	Mo	Re	Au	Ga	Sal
pH 7 days			0.0002							
L*								0.015	0.018	
a*			0.015							
b*	0.023		0.012	-0.033					0.011	
Thawing losses										
Cooking losses		0.037								0.006
WHC							-0.038			
Dry matter			0.006			0.005			0.005	
Protein										
Intramuscular fat									0.006	
Total collagen		-0.004					0.005			
Insoluble collagen							0.004			
Haematin	-0.320		0.180		-0.510					
LDH				1.050						
ICDH		-0.006			-0.013		-0.005		-0.006	
Myosin	-0.089		0.087	-0.097	-0.260		-0.120			
Max. Load WB	0.018								-0.006	-0.011
Toughness WB					-0.011				-0.002	
Max. Load C			0.044	-0.15				-0.140		
Stress 20% C		0.012	0.008	-0.006	-0.016					
Stress 80% C			0.034	-0.096						

Table 8. Significant slopes for each beef breed-system of the linear regressions relating each variable with Conformation score as the independent variable.

	AV	AM	Pi	BP	A-NI	Mo	Re	Au	Ga	Sal
pH 7 days	-0.006			0.038		-0.017				
L*	0.480	0.490	0.480					0.290	0.270	
a*	-0.380		0.310						-0.260	
b*			0.540				-0.280	0.160		
Thawing losses			0.240							0.240
Cooking losses				-1.290						
WHC	0.270	0.440						0.280	0.230	
Dry matter	-0.114						0.420		-0.086	-0.180
Protein	0.087						0.140		0.110	
Intramuscular fat	-0.160			-0.270		-0.110	-0.390	-0.095	-0.190	
Total collagen	-0.089						-0.120	-0.005	-0.004	
Insoluble collagen	-0.046				-0.098			-0.007		-0.006
Heamatin	-2.670	-5.050		-6.060				-5.590	-4.630	
LDH							0.800			
ICDH						-0.190	-0.088	-0.076		
Myosin	0.770									
Max. Load WB				0.440		-0.250				
Toughness WB				0.099						
Max. Load C	-2.250			-3.150				-2.010	-2.820	
Stress 20% C	0.140									
Stress 80% C	-1.350		-1.020					-1.740	-1.070	

Table 9. Significant slopes for each beef breed-system of the linear regressions relating each variable with Fatness score as the independent variable.

	AV	AM	Pi	BP	A-NI	Mo	Re	Au	Ga	Sal
pH 7 days	0.007		0.011							
L*	-0.580									
a*	0.360			0.470					0.360	
b*			0.490					0.128		
Thawing losses			0.280							
Cooking losses										
WHC	-0.250				0.640		0.980			
Dry matter	0.136			0.190		0.340			0.130	0.150
Protein	-0.070						-0.120			
Intramuscular fat	0.170			0.180			0.580		0.210	0.160
Total collagen	0.092		0.110						0.006	
Insoluble collagen	0.057		0.060			0.190			0.008	
Haematin	6.160		4.730	3.000					5.180	
LDH	-0.760	29.830								
ICDH								0.075		
Myosin										
Max. Load WB			0.184							
Toughness WB		0.050	0.119					-0.040		
Max. Load C	3.260		2.750		-3.570					
Stress 20% C				-0.117					0.260	
Stress 80% C	1.880		1.757		-2.030					

Figure 1. Relationships between muscle characteristics and carcass synthetic variables.

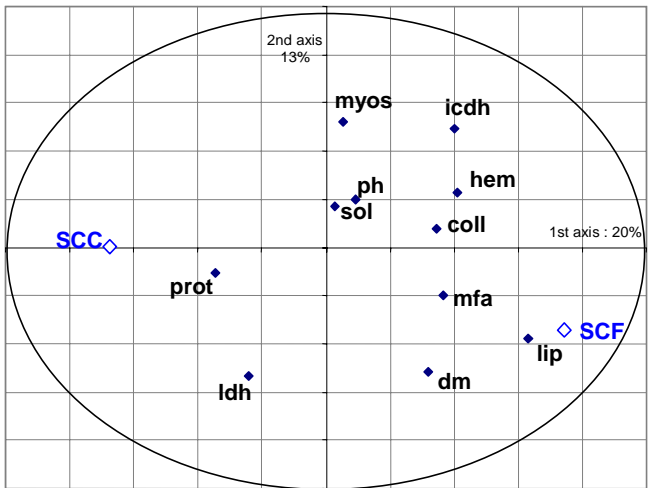


Figure 2. Relationships between colour parameters, carcass synthetic and muscle variables.

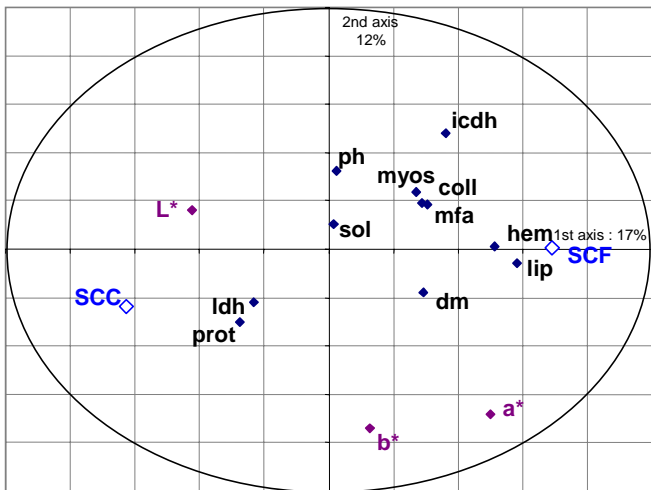


Figure 3. Relationships between texture measures of all animals.

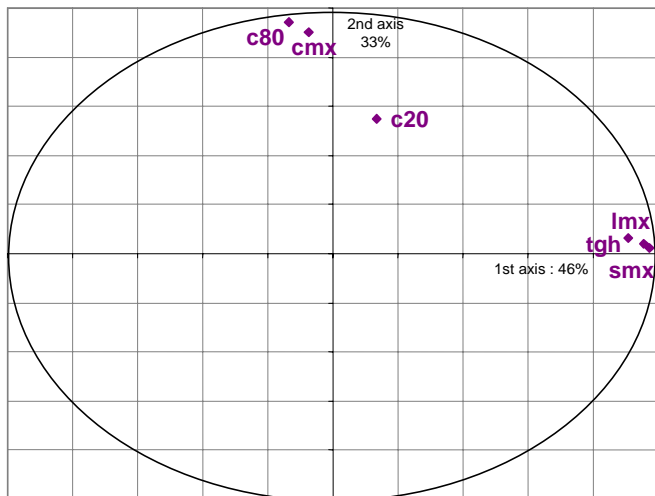


Figure 4. Relationships among sensory traits presented by laboratories (Zaragoza, Monells and Villers).

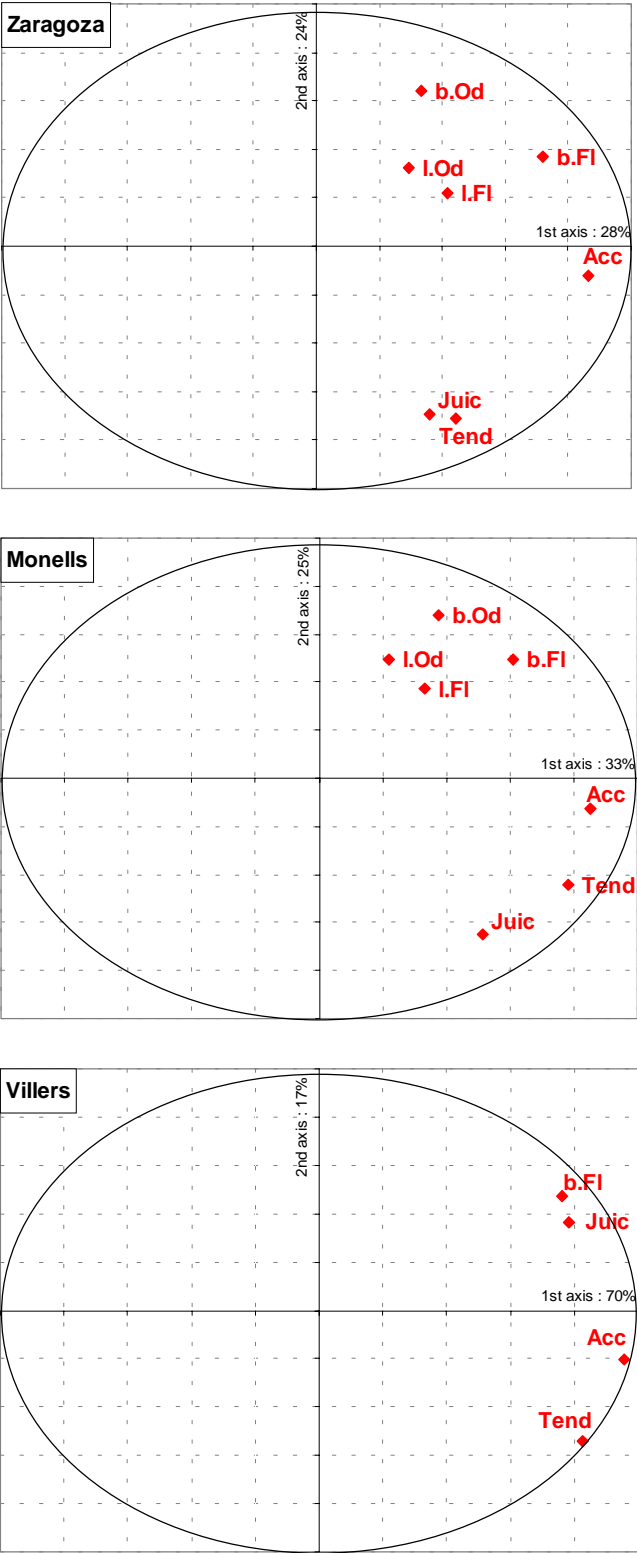


Figure 5. Relationships of carcass and meat instrumental traits with texture and tenderness presented by laboratories (Zaragoza, Monells and Villers).

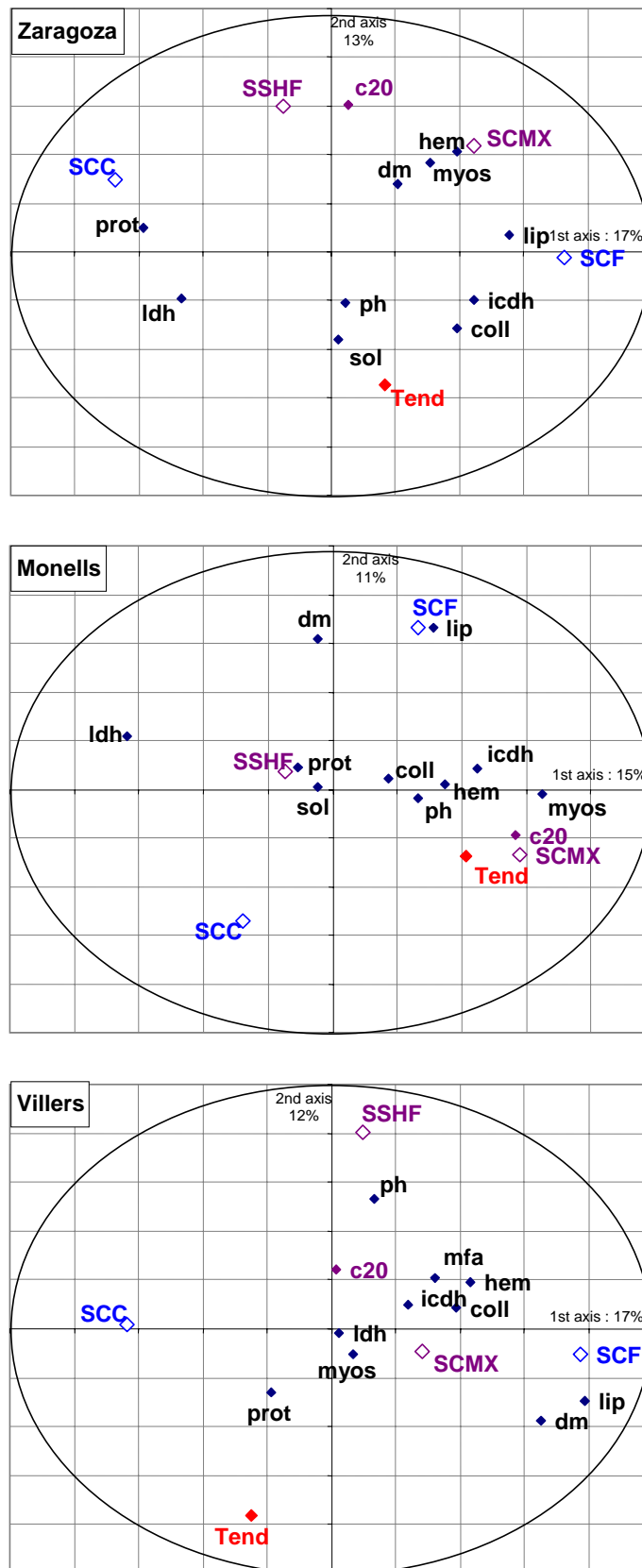


Figure 6. Relationships of carcass and meat instrumental traits with water loss and juiciness presented by laboratories (Zaragoza, Monells and Villers).

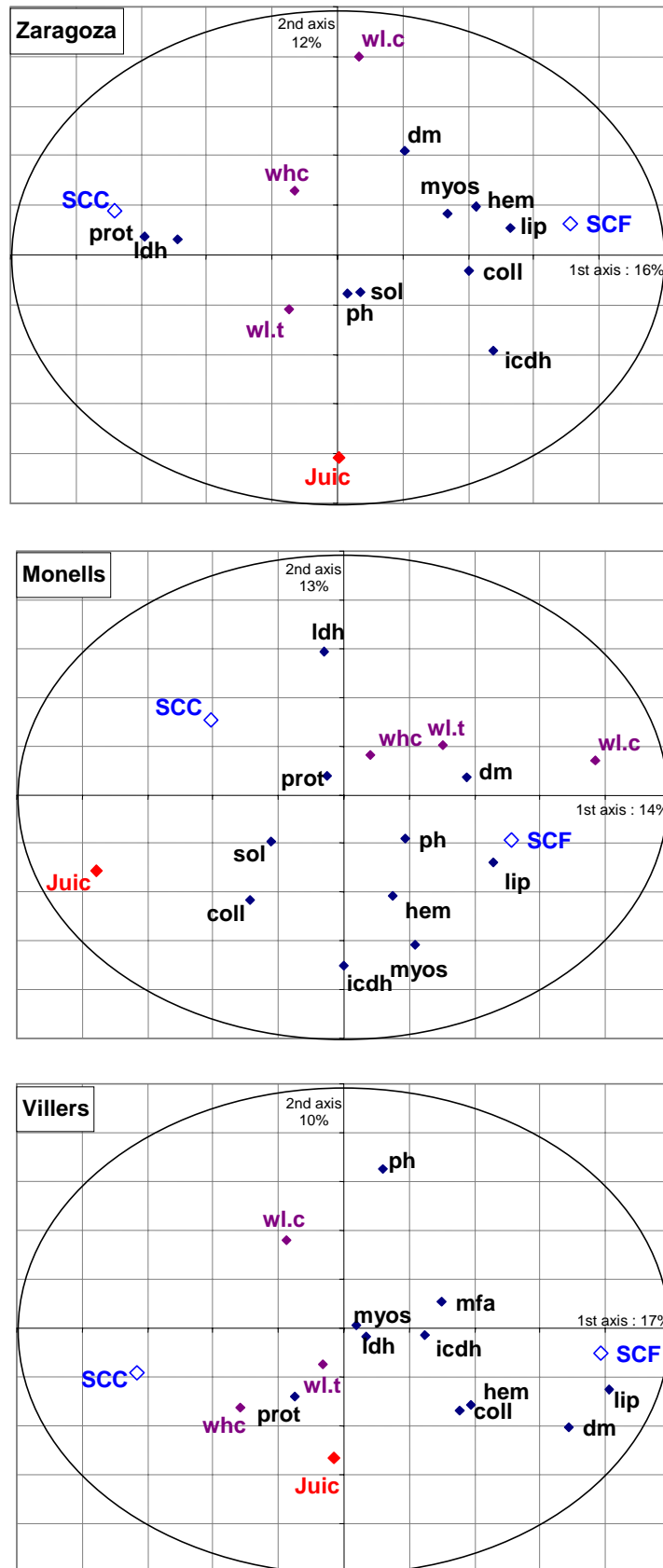


Figure 7. Relationships of carcass and meat instrumental traits with flavour and odour evaluations presented by laboratories (Zaragoza, Monells and Villers).

