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Muscle and meat characteristics from the main beef breeds of the Massif Central

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1 – INTRODUCTION

Although beef consumption in France has recovered to the level before the 2 BSE crises, consumers remain unsatisfied with organoleptic quality, in particular with the large variability in the tenderness and flavour. This presents a major problem to the beef industry faced with competition from white meats offering a better retail quality/price ratio. Research in the last few years has shown that the variability is a consequence of animal factors (breed, sex, age), the production conditions (Hocquette et al., 2005), and of the slaughtering and maturing conditions (Culioli, 1999). The organoleptic qualities depend on the composition and structural properties of the muscle, particularly the two main components: the connective tissue and myofibres. The connective tissue is composed essentially of collagen, and its content, nature and heat solubility in water determine meat tenderness (Lepetit, 2004). These criteria are the basis for the three cooking classes of beef: stew, braise and roast/grill. The muscle fibres, that form most (≈85%) of the muscle volume, are classified on the basis of their contractile (fast or slow contracting) and metabolic properties (glycolytic that uses mainly carbohydrates as the source of energy and oxidative using mainly fatty acids). In adult cattle three types of fibres are present: SO (slow oxidative), FOG (fast oxido-glycolytic) and FG (fast glycolytic) (Picard et al., 2003). These types are present in different proportions in different muscles. Meat tenderness depends not only on the muscle properties but also on the phase of maturation. Maturation is a complex multifactorial process that affects mainly the myofibrillar structure and depends on several ante- and post-mortem factors. It is essentially an enzymatic process (Ouali, 1992) in which endogenous proteases act on the contractile proteins and on the components of the cytoskeleton (Huff-LonerGAN and Lonergan, 1999). The proteolytic systems comprise the metallopeptidases (Matrix Metallopeptidases or MMPs), the calpains, the cathepsins, the proteasome and the serine peptidases (Goll et al.,

1. Unité de Recherches sur les Herbivores.
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1999; BALCERZAK et al., 2001). Two of them, the calpains and cathepsins, have been studied extensively (OUALI, 1992) and a significant contribution of the 20S proteasome has been shown recently (DUTAUD et al., 2006). Results also indicate that the level of specific inhibitors of those enzymes offer a better indicator of the tenderisation process than the level of the enzymes themselves (OUALI and TALMANT, 1990). The maturation phase depends on the physicochemical factors such as the concentration of calcium ions in the muscle, the osmotic pressure, the processes of peroxidation that are linked to the contractile and metabolic properties of the muscle fibres. It has also been shown that the maturation process is faster in rapid glycolytic fibres than in oxidative fibres (OUALI, 1992).

So, because of its multifactorial origin that has not been totally established, it is difficult to control meat tenderness. It was within this context that a 5-year trial was set-up in 1996 and was financed by the Commissariat au Développement Economique and in the Aménagement du Massif Central as part of the XIe Contrat de Plan État-Région. The main aim was to establish the contribution of each muscle component in determining the tenderness of beef. The trial was carried out on young bulls and cull cows from the 4 main breeds of suckler breeds in the Massif Central, namely Aubrac, Charolaise, Limousine and Salers, and provides information on the effects of age, sex and breed on the muscle properties and on the organoleptic quality of the meat.

2 – MATERIALS AND METHODS

A total of 168 animals were analysed. The bulls (T) (n=84) from the 4 breeds were bought at 9 months of age and raised, to 3 different ages, 15, 19 or 24 months (n=7, bulls from each of the 4 breeds), and fed ad libitum on a ration typical of the Limagne auvergnate region. That ration was formed from pressed sugar beet pulp silage (85%), and made up with corn, soya-bean cake and urea. The cull cows (V) (n=84) from the 4 breeds were bought during the year of their slaughter and raised on the same ration until slaughter at the same level of fatness (average score, 3.5). So their length of fattening (from 7 days to 4 months) varied as a function of their fatness at the beginning of the study. The animals were grouped into 3 age groups: 4-5 years, 6-7 years and 8-9 years. Seven cull cows per age group and breed were analysed.

The animals (T and V) were slaughtered at the experimental abattoir at the Centre INRA of Clermont-Theix. From all carcasses, 3 roasting muscles with different muscle characteristics: the Longissimus thoracis (LT, faux-filet), the Semi-tendinosus (ST, silverside) and the Triceps brachii (TB, shoulder) were analysed. The structural and biochemical characteristics of the muscles (collagen, muscle fibres, lipids, proteases, and connective tissue) were determined just after slaughter. The change in these characteristics followed during storage and the tenderness of these muscles, at 2 times of storage were analysed by mechanical methods and by a panel of experienced judges (DRANSFIELD et al., 2002).
3 – RESULTS AND DISCUSSION

3.1 Effect of breed

The final live-weight of the animals, their empty body-weight and the composition of the carcasses varied significantly among the breeds for the two types of production. These differences were more marked for the cull cows than for the young bulls. Overall the final live-weight and the empty body-weight were significantly higher for the Charolais than for the other three breeds. The carcass weights for both the cull cows and the bulls did not differ significantly among the four breeds. However, the muscles were heavier for the two beef breeds (Charolais and Limousin) and most so for the Limousin breed. Independent of the type of animal, the Limousins had a muscle weight significantly greater than the other breeds and had less fat, while the Salers gave the lightest muscles and were the fattest (PICARD et al., 2002 and JURIE et al., 2005).

Over all the characteristics measured and all the muscles, the most marked differences were in the metabolic properties between the types of production (oxidative activity ICDH: T: P < 0.05; V: P < 0.001 – glycolytic activity LDH: T: P < 0.01; V: P<0.001) and the thermal stability of the collagen (amount of insoluble collagen T: P < 0.05; V: P < 0.05) (PICARD et al., 2002). The Limousins differed most from the other breeds in having the most glycolytic and least oxidative muscles, the difference most marked in the cull cows than in the bulls. Also their content of insoluble collagen was lower. The total lipid (P < 0.05) and triglyceride (P < 0.05) contents differed among the breeds only in the cull cows and they were lowest in the Limousins and highest in the Aubracs (BAUCHART et al., 2002b). The content of calpain I, measured only in the LT muscle, was significantly higher in the Limousins (T: P < 0.10; V: P < 0.5). The level of calpain II was also higher in that breed but the difference was only significant in the bulls (P < 0.01). The ratio of calpain/calpastatin, which is linked to the rate of maturation, was lowest in Charolais and Limousin and highest in Charolais (P < 0.05). Concerning the level of 20S proteasome in LT muscle, there were no significant differences among the different breed studied. The shear force (on raw meat aged 14 days) was lowest in Limousin bulls (P < 0.10). Interestingly the compression force on raw muscle differed among the breeds at 24 hours (T: P < 0.001; V: P < 0.10) but not after 14 days after slaughter (T: P < 0.10; V: P = 0.23), which shows different rates of maturation but a similar degree of maturation after storage.

Despite some differences in muscle characteristics among the breeds, the quality (sensory tenderness, juiciness and flavour) was not significantly different among the four breeds for the two types of production and muscle (DRANSFIELD et al., 2002).

These results show that animals from different breeds raised or fattened under identical conditions produce different weights, carcass compositions and muscle yields. However, the muscle characteristics of the animals showed only few marked differences. The main differences were in the muscle metabolic characteristics which were more glycolytic in the beef breeds and more oxidative in the rustic breeds. These results are consistent with a selection based on muscle growth potential that induces an increase in the number of rapid glycolytic muscle fibres (HOCQUETTE et al., 2005). However, it is interesting to note that the difference in mechani-
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Cal strength observed at, or after 24 hours after slaughter, disappeared after 14 days storage. Also the Limousin animals, whose muscle characteristics favour a higher rate of maturation, had, after 14 days maturation, a similar sensory quality to that of the other breeds.

4 – EFFECT OF MUSCLE TYPE

4.1 Young bulls

All the muscle characteristics studied were significantly different among the muscles. In particular, the average muscle fibre cross-sectional area was the smallest (3420 µm²) in the LT, largest (5534 µm²) in ST and intermediate (4174 µm²) in the TB muscle. The same order (LT < TB < ST) was also found for the the average surface area for each type (SO, FOG et FG) of muscle fibre.

The three muscles, ST, LT, TB differed also in their proportions of SO fibres (38.6; 12.7; 28.5% respectively), FOG (13.5; 22.0; 24.4% respectively) and FG fibre-type, which was higher in the ST (65.4 %) than in the LT and TB muscles which were similar (47.9 and 47.2% respectively). In agreement with the higher proportion of FG fibres, the ST muscle had a higher LDH activity (1062.2 µmole/min.g of muscle) than the LT and TB which were similar to each other (897.6 and 927.8 respectively). On the contrary, the ICDH activity was lower in the ST (0.97 µmole/min.g of muscle) than in the TB (1.77) which was close to, but significantly different from that in the LT (1.92) (JURIE et al., 2005).

Despite the large differences in metabolism, the muscles had similar pHs measured at 1 hour post-mortem. However, the rate of pH decline was higher in the ST (the more glycolytic muscle) as the pH at 3 hours pm was lower than in the other muscle. However, these differences in pH among the muscles were not detected at 24 hours after slaughter.

Concerning the collagen characteristics, the LT muscle had, as expected, a lower content of total and insoluble collagen than the other two muscles, ST and TB. Although the content of total collagen was the same in the ST and TB muscles, the content of insoluble collagen was higher in the ST than the TB which means a higher cross-linking in the collagen from ST than from TB.

These three muscles also had very different intramuscular lipid contents (P < 0.001): LT > TB > ST. The same order was found for their triglyceride contents, expressed in mg/g of wet or dry muscle (P < 0.001). Concerning the content of phospholipids, the TB had the highest values and the LT the lowest values (P < 0.001) (BAUCHART et al., 2002b).

So, in bulls the 3 muscles had very different biochemical characteristics. Usually the LT and ST had the extreme characteristics with the TB intermediate. The LT had the highest proportion of slow oxidative fibres and the most oxidative and least glycolytic metabolism. It contained the highest proportion of total and triglyceride lipids and the least phospholipids. Its fibres were the thinnest and it had the less collagen which was the more soluble than that in the other two muscles. All these variations in characteristics are coherent.
4.2 Cull cows

Most of the biochemical differences found in the bulls were also found in the cull cows. However, several differences were noted:

- the cross-sectional area of SO and FOG fibres did not differ significantly among the cull cow muscles whereas there were marked differences among the bulls.

- the proportion of FG fibres (fast glycolytic) in TB was similar to that in LT in bulls but, in cull cows, it was ranked TB < LT < ST.

- the order of ICDH (oxydative) activity was also reversed for the LT and TB. The TB > LT > ST was observed in cull cows but was LT > TB > ST in bulls.

- The spread of pH among muscles, seen in bull muscles only at 3 hours pm, was still detectable at 24 hours in the cull cow muscles.

The differences in the biochemical properties observed among muscles will affect the mechanical measurements taken. In particular the muscle effect has a very marked impact on the shear force. For both the cull cows and the bulls, the order of shear force was: LT < TB < ST, which reflects the order of increasing collagen content. The same order is found for the mechanical resistance of heated meat but the differences are smaller. Concerning the index of maturation of the muscles, the LT appears more matured than the other two muscles both at 1 and 14 days of storage.

So the LT muscle is characterised as more matured and with a lower shear force associated with lower collagen content than the other muscles.

Concerning the sensory analyses, we showed that the steaks of LT were of good quality with average scores for tenderness, juiciness and flavour between 5.1 and 6.6 on a 10-point scale. The ST had scores from 4.8 to 6.6 and the TB from 5.0 to 6.5. Across all breeds, it appears that the same differences are found in bulls and cull cows. The ST is, on average, the least tender and with less flavour than the other two muscles. The LT is the most tender but less juicy. The TB has an intermediate tenderness, appears more juicy but has the least flavour, particularly for the cull cow muscles (DRANSFIELD et al., 2003).

5 – EFFECT OF AGE

5.1 Young bulls

Significant differences were observed among the three age groups for all the biochemical characteristics. In particular, the average cross-sectional area (overall and by type) increased significantly with age (P < 0.001) (JURIE et al., 2005). The increase in area of the SO and FOG fibres was greater than that in the FG fibres. These changes were smallest in the LT and greatest in the TB. For all three muscles, there was little change in the proportions of the different fibre types between 15 and 19 months. However, between 19 and 24 months,
the proportion of SO fibres increased and that of the FOG decreased. These changes in the size and type of fibres induce a growth in the percentage of area occupied by the SO fibres and a decrease in that occupied by the FG fibre between 19 and 24 months. In concert with the changes in contractile properties, the metabolic properties in the three muscles did not change between 15 and 19 months and between 19 and 24 months the oxidative activity increased whilst the glycolytic activity decreased (JURIE et al., 2005).

The age of the animal had no effect on the pH at 1 and 3 hours in the 3 muscles or on the pH of the LT measured at 24 hour pm.

The content of total collagen increased significantly between 19 and 24 months and the collagen solubility changed with age in all three muscles. It increased between 15 and 19 months and decreased between 19 and 24 months down to values similar to those in bulls at 15 months (JURIE et al., 2005).

Overall the total lipid content increased significantly with age (P < 0.01) for all muscles. In the ST muscle the increase was due to an increase in phospholipids content while, in the other two muscles, it was linked to an increase in triglyceride content (BAUCHART et al., 2002b). Differences were observed among the four breeds. Total lipid increased with age, particularly between 19 and 24 months, only in the Charolais. The triglyceride content also increased between 19 and 24 months in LT and TB, again only in Charolais. The phospholipids content increased significantly with age in the ST muscle from Aubrac, Charolais and Limousin but did not change in the Salers. In the three breeds, it decreased between 15 and 19 months and then increased between 19 and 24 months.

Measured only in the LT, the level of calpain I decreased significantly between 15 and 19 months (P < 0.001). The level of calpain II was also high at 15 and 19 months but non-significantly. Similarly, the level of calpain inhibitor, calpastatin, did not change significantly with age. The level of 20S proteasome decreased significantly between 19 and 24 months.

The index of maturation measured on raw muscle at 1 day, decreased with age in the three muscles. After 14 days, the differences persisted only in the LT muscle. The compression and shear forces on cooked meat were not significantly different among the three ages.

Similarly, the sensory analyses on cooked meat did not show significant differences among the 3 ages.

So, the changes in muscle properties observed between 15 and 24 months did not induce notable changes in the sensory qualities of the meat. These results agree with the literature data suggesting that the tenderness of meat changes little before 2 years of age (TOURAILLE et al., 1982).

5.2 Cull cows

Overall, including all breeds, age had little influence on the muscle characteristics studied. Only the average area fibres in ST muscle and the collagen properties changed with age. The area of each type of fibres increased significantly from 4-5 to 6-7 years in ST and explains the increase in average size in ST muscle. The content of total collagen and of insoluble collagen decreased from 4-5 to 6-7 years and then remained stable (JURIE et al., 2006).
In TB and ST there was a significant interaction between age and breed for the total lipid and triglyceride contents. In the TB from Salers cows, the total lipid content decreased between 6-7 and 8-9 years. On the other hand, in the ST from Aubrac, it increased in this age range. The triglyceride content increased in Aubrac in the 3 muscles but it decreased with age in the ST and TB from Salers and in the LT from Charolais (BAUCHART et al., 2002a).

Although the level of calpain and calpastatin did not differ among the 3 age groups, the level of 20S proteasome was significantly lower in the oldest cows (P < 0.05).

The indices of maturation determined at 1 and 7 days were not influenced by age of the cows. However, at 14 days, they were significantly higher in the 8-9 year-old cows, indicating that the meat from these cows had matured less quickly (P < 0.001). The observation could be linked to the fact that the level of proteasome was significantly lower in the 8-9 year-old cows. However, the shear force measurements on raw meat and the compression on cooked meat, measured at 14 days, did not show differences among the 3 age groups.

The sensory results show that for the Salers and Aubrac there was a tendency that the oldest animals (8-9 years) were less tender (average score 5.9) than the two other age groups (average score 6.6). This effect was not found in the Charolais and Limousin in which the tenderness of animals aged 4-5 years (average score 6.2) was similar to that from animals aged 8-9 years (average score 6.5). The change in flavour with age was also influenced by the breed. For the Aubrac, Charolais and Limousin, the flavour appeared weakest in the 6-7 year group (P < 0.05, 6.11 vs 5.77 vs 6.11). However, for the Salers, the 4-5 year-old group had a stronger flavour (6.8) than the oldest animals (average score 5.6). The juiciness was not different among the 3 age groups in the 4 breeds (DRANSFIELD et al., 2002).

For the ST muscle, the age effect was marked for all the sensory profile attributes. The group of 8-9 year-olds (tenderness 5.3) tended to be less tender than the other 2 age groups (5.4). The 4-5 year old group tended to be more juicy (5.6 vs 5.3) and the 6-7 year-old group had slightly less flavour (5.3 vs 5.8).

Concerning the TB, tenderness varied with age depending on the breed. The average scores showed that tenderness tended to be higher in 8-9 years (initial tenderness 5.9 vs 5.4), except for the Salers in which the 4-6 year-old group was the most tender. Concerning flavour, for the Limousin and Salers, the 6-7 year-old group tended to have lower scores than the other age groups (5.7 vs 6.2), while for the Aubrac and Charolais, no difference was observed between the age groups.

It is important to note that the biochemical characteristics of the 3 muscles changed very little from 4 to 9 years in the cull cows. In the LT, no change was observed which agrees with the fact the tenderness remains stable in this muscle as shown by BASTIEN et al. (2002) in LT muscle of Limousin and Normandy cows aged from 3.5 to 5 years and from 9 to 11 years old. However, in comparing the muscles from cows aged 5 to 11 years, DUMONT et al. (1991) showed that tenderness was lower in cuts from 11 year-old cows suggesting a decreased rate of maturation with increasing age. This agrees with the decrease in level of proteasome that we observed in the oldest cows.
6 - RELATIONSHIPS BETWEEN SENSORY QUALITY AND MUSCLE COMPOSITION

To determine the relationships between the sensory quality and the characteristics of the muscles, a principal component analysis was conducted on all the measures of quality (the 5 sensory attributes from the 3 muscles from all the animals). The coordinates on the 2 principal axes were grouped into 3 quality classes: class 1 (lowest quality), group 2 (intermediate quality) and 3 (highest quality) containing respectively 102 (21%), 167 (33%) and 228 (46%) of the meats DRANSFIELD et al., 2003). The average note for the best quality was about 2 points higher than that of the lowest quality.

The distribution of muscle types was significantly different across the classes. The highest quality contained the largest proportion (44%) of LT and the smallest proportion (21%) of ST muscles, opposite to that found in the lowest quality class (only 13% LT and 32% ST muscles). The TB muscle was distributed equally among the 3 classes. The distribution of sexes/system of production and breed did not vary significantly across the quality classes. The contribution of the Limousine breed in the highest quality class seemed higher but the effect was not statistically significant. The effect of age was sometimes significant and the lowest quality class tended to contain more of the animals of intermediate age (bulls aged 19 months, cows aged 5-6 years) and the highest quality class rather the younger animals (47% of bulls aged 15 months and 37% of cull cows aged 4-5 years).

In the bull beef, the variation in tenderness was correlated positively by the total lipid and triglyceride contents and correlated negatively with the average fibre area, the pH at 24 hours and the amount of total and insoluble collagen (table 1A). For the cull cows, these correlations were higher. In addition, tenderness was correlated positively with the proportion of SO (slow oxidative) fibres and correlated negatively with the percentage of FOG (fast oxido-glycolytic). In beef from the cull cows, the pH at 3 hours pm had the highest correlation coefficient (positive) with tenderness (table 1A).

In bulls, the maximum force was correlated significantly with the average cross-sectional area of the fibres and also with the amount of insoluble collagen (table 1B). As with overall tenderness, there were more significant correlations with the cull cow beef and included the properties of the muscle fibres: the % of fast (FG and FOG) fibres which were correlated positively with the maximum force, and the % of SO fibres which was correlated negatively consistent with the negative correlation between the ICDH activity and the maximum force. A positive correlation was observed between the amount of total collagen and the maximum force while the pHs at 1, 3 and 24 hours had negative correlations (table 1B).

However, the percentage explained was higher for the cows than for the bulls: with bulls, all the characteristics explained 11% of the variability in tenderness and 16% of the variability in maximum stress while, for the cows the figures were 32% and 22.5% respectively.
Table 1
Correlation coefficients between the muscle characteristics and sensory tenderness rating (A) and the maximum force (B) of cooked meat after 14 days maturation.

<table>
<thead>
<tr>
<th>A</th>
<th>Lipids</th>
<th>Fibres</th>
<th>pH</th>
<th>Collagen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulls</td>
<td>lipid tot. + 0.13*</td>
<td>surf. ave. – 0.17**</td>
<td>pH 24h – 0.17*</td>
<td>coll. tot. – 0.13*</td>
</tr>
<tr>
<td>LT + ST + TB</td>
<td>TG + 0.17**</td>
<td>surf. FOG – 0.15*</td>
<td>coll. insol. – 0.13*</td>
<td></td>
</tr>
<tr>
<td>Cull cows</td>
<td>lipids tot. + 0.23***</td>
<td>surf. ave. – 0.19**</td>
<td>pH 3h + 0.28***</td>
<td>coll. tot. – 0.23***</td>
</tr>
<tr>
<td>LT + ST + TB</td>
<td>TG + 0.29***</td>
<td>surf. FOG – 0.19**</td>
<td>pH 1h + 0.14*</td>
<td>coll. insol. – 0.30***</td>
</tr>
<tr>
<td></td>
<td>PL – 0.18**</td>
<td>% SO – 0.28***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bull-LT</td>
<td></td>
<td></td>
<td>pH 24h – 0.23*</td>
<td></td>
</tr>
<tr>
<td>Bull-ST</td>
<td></td>
<td></td>
<td>pH 24h – 0.23*</td>
<td></td>
</tr>
<tr>
<td>Bull-TB</td>
<td></td>
<td>surf. FG – 0.23*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cull cow-LT</td>
<td>% SO + 0.23*</td>
<td>coll. tot. – 0.27*</td>
<td>coll. insol. – 0.26*</td>
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<tr>
<td>Cull cow-ST</td>
<td></td>
<td>LDH + 0.23*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cull cow-TB</td>
<td>TG + 0.30**</td>
<td>pH 1h + 0.22*</td>
<td></td>
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<table>
<thead>
<tr>
<th>B</th>
<th>Lipids</th>
<th>Fibres</th>
<th>pH and EA</th>
<th>Collagen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulls</td>
<td>surf. ave. + 0.21***</td>
<td>surf. SO + 0.16*</td>
<td>pH 1h + 0.22***</td>
<td>coll. insol. + 0.19***</td>
</tr>
<tr>
<td>LT + ST + TB</td>
<td>surf. FOG + 0.12*</td>
<td>surf. FG + 0.22***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cull cows</td>
<td>lipids tot. – 0.45***</td>
<td>surf. ave. + 0.28***</td>
<td>pH 3h – 0.36***</td>
<td>coll. tot. + 0.31***</td>
</tr>
<tr>
<td>LT + ST + TB</td>
<td>TG – 0.47***</td>
<td>surf. FOG + 0.25***</td>
<td>pH 1h – 0.25***</td>
<td>coll. insol. + 0.29***</td>
</tr>
<tr>
<td></td>
<td>% SO – 0.40***</td>
<td>% FG + 0.25***</td>
<td>pH 24h – 0.14*</td>
<td>coll. tot. + 0.31***</td>
</tr>
<tr>
<td></td>
<td>% FOG + 0.16**</td>
<td></td>
<td>ICDH – 0.37***</td>
<td>coll. insol. + 0.29***</td>
</tr>
<tr>
<td>Bull-LT</td>
<td></td>
<td></td>
<td>pH 1h + 0.37**</td>
<td>coll. tot. + 0.23*</td>
</tr>
<tr>
<td>Bull-ST</td>
<td></td>
<td></td>
<td>pH 3h + 0.23*</td>
<td>coll. tot. + 0.23*</td>
</tr>
<tr>
<td>Bull-TB</td>
<td></td>
<td></td>
<td></td>
<td>coll. tot. + 0.23*</td>
</tr>
<tr>
<td>Cull cow-LT</td>
<td>lipids tot. – 0.49***</td>
<td>TG – 0.48***</td>
<td>ICDH – 0.24*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PL + 0.34**</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Cull cow-ST</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Cull cow-TB</td>
<td>TG – 0.25*</td>
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</table>

lipids tot. = total lipids; TG = triglycerides; PL = phospholipides (mg/g of dry tissue); surf. ave. = average surface (µm²); SO = slow oxidative fibre; FOG = oxydo-glycolytic fibres, FG = glycolytic fibres; EA = enzymatic activity: LDH = lactate dehydrogenase; ICDH = isocitrate dehydrogenase (µmole/min/g muscle); Coll. tot. = total collagen, coll. insol. = insoluble collagen (µg OH-proline / mg of dry matter).
So, the whole data show that meat tenderness, defined by the sensory analysis or by mechanical measurement, is explained in part by the size of the cross-sectional area of the muscle fibres and the amount of insoluble collagen in both production systems, young bulls and cull cows. An effect of fibre diameter on the toughness of meat had been found in other studies, in particular that of Renand et al., (2001) in the LT muscle from 106 bulls aged from 14 to 21 months but this relationship has not been found by others. The pH value pm, in particular the pH at 3 hours pm, appears to be well correlated with tenderness, above all for the cows (Dransfield et al., 2003). It has been proposed by Marsh et al., (1988) that the pH at 3 hours pm could be an indicator of tenderness and that a value of about 6.1 would give rise to the most tender meat. However, according to one study on 444 cattle (Shakelford et al., 1994), the pH measured very early after slaughter was not well correlated with tenderness. The results obtained here show that the most tender muscles (mainly LT) had a slow decline in pH (Dransfield et al., 2003) which confirms the importance of this factor.

The decline in pH post-mortem depends on the contractile and metabolic properties of the muscle. In agreement with this, these properties appear correlated with sensory tenderness and mechanical toughness, only in the cull cows. Even more, the content of total and triglyceride lipids and of collagen was correlated more highly to tenderness in the cow beef. The absence of such relationships in young bull beef may be explained by its low level of fat which may be insufficient to affect the mechanical measurements.

When considering each type of muscle and animal, the relationships between the biochemical characteristics are rarely significantly correlated with tenderness (table 1 A and B). This is probably due to the lower number of samples analysed. However, the highest correlations were found in cull cow beef. The LT muscle from cows appears to be the most tender when it contains the highest total and triglyceride lipid content, most slow and oxidative fibres and the smallest amounts of total and insoluble collagen. It is surprising that there was only a strong link the amount of collagen and sensory tenderness in the LT which is the muscle that has the least amount of collagen. In the opposite way to that in LT, the most tender ST muscles were those that had the highest glycolytic (LDH) activity. This was the only property that was significantly correlated to tenderness in this muscle. This demonstrates that, dependent on the type of muscle, the tenderness of the meat could be explained by different characteristics, which may be at the origin of the numerous contradictions found in the literature concerning the relationship between the biochemical characteristics and the sensory quality of the meat, which, according to the authors, had been carried out on different types of muscle and animals. There was only this property that gave significant correlation with muscle tenderness. This shows that no one muscle can be a predictor of the sensory quality of the other muscles in the carcass. The levels of calpains I and II, measured only in the LT muscle, was positively correlated with the maximum force in meat from the young bulls (table 1B). This surprising result should be tested in other types of muscle.

Flavour had a tendency to be stronger in those muscles containing the higher lipid content and fewer FG fibres. These results show that, the higher the percentage of FG fibres, the lower the amount of lipid ($r = -0.57$) which could be at the origin of the observed decrease in flavour with an increase in proportion of FG fibres (Dransfield et al., 2003).
Juiciness was highest in the most oxidative muscles and which contained the highest lipid content. These relationships were stronger in meat from the cows than from bulls. For the two types of production, a negative correlation between the amount of calpastatin (inhibitor of calcium-dependent proteases) and juiciness indicates that the muscles which mature less well has a lower juiciness.

It is clear from these results that the variability in tenderness is little explained by the composition and the physico-chemical characteristics of the muscles. It was in meat from female animals that we observed the largest number of muscle characteristics linked to tenderness or to toughness. In addition, it appears that from one muscle to another, the sensory qualities are explained by different biochemical characteristics. This explains the numerous contradictions found in the literature on the relationships between the properties of the muscle and the sensory quality.

7 - CONCLUSION

These results show that, although the characteristics of the bull muscles change significantly between 15 and 24 months, the tenderness is not changed. This is consistent with the fact that, in bulls, the muscle characteristics (phospholipid, percentage of FG fibres) explain only 7 to 13% of the variation in tenderness depending on the muscle (ST or TB respectively). This study also clearly shows that the muscle characteristics are little or not affected by age of the cull cows between 4 and 9 years old. For the first time, this study shows that for the 2 rustic breeds, the tenderness of ST and TB decrease between 4 and 9 years while that from the meat breeds was not altered. The tenderness of the LT muscle was not changed between these ages in any breed.

The variables explaining tenderness are not the same for the two types of production. The muscle characteristics explained more of the variation in tenderness in muscles from the cull cows than from the bulls. In particular, the contractile and metabolic properties explained tenderness only for the cull cows. Furthermore the correlations of the muscle characteristics and tenderness depended on the muscle type. For example, in the LT, tenderness was correlated positively with the slow oxidative state while for the ST it was correlated positively with the glycolytic properties. This illustrates the complexity and the difficulty in controlling the tenderness of different muscle in the carcass. It was also shown that the tenderness rated by a panel was not explained by the same variables as the toughness determined mechanically. It is clear that the characteristics of muscle composition cannot be used as the only predictors of meat tenderness. As a consequence, it does not seem possible, at least from these muscle characteristics from these types of animals, to define a generalised model to predict tenderness. From these results, it appears that any model will be specific to the type of animal (bull or cull cow) and to the type of muscle.

These results show the complexity in controlling the sensory quality and the tenderness in particular. It is clear that the known characteristics explain only a
small part of the variation in tenderness which suggests that tenderness depends on other characteristics of muscle composition and structure that were not measured in these trials. A functional genomic approach, by analysing the transcriptome and/or the proteome that allows the simultaneous study of certain genes or proteins, should help in the identification of new and unknown characteristics related to tenderness.

8 – ACKNOWLEDGEMENTS

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REFERENCES


