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PAPER

A data warehouse of muscle characteristics and beef quality in France and a demonstration of potential applications

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Abstract

The BIF-Beef (Beef Integrated and Functional Biology) database contains animal, carcass, muscle and meat data (331,745 entries) collected from 43 experiments over the last 20 years and a great number of variables (621) characterising muscles (fat and collagen contents, cross-section and types of fibres, metabolic activity), making it a relevant tool to relate muscle characteristics to beef quality. Wide variation was observed in all described traits according to muscle type, sex and breed. The BIF-Beef database was mainly composed of data from young bulls of late-maturing beef breeds, which is why live weight and carcass weights of the animals were greater, and beef was leaner and lighter than results from other existing databases. Average cross-sectional area of fibres was greater in *Semitendinosus* than in *Longissimus thoracis* muscle and, for *Longissimus*, greater in steers than in young bulls. Intramuscular fat content was in descending order: Charolais > Limousin > Blond d'Aquitaine and females > steers > young bulls. *Semitendinosus* muscle was less oxidative and contained more collagen than *Longissimus* muscle. Collagen content in *Longissimus* was higher in Charolais than in Blond d'Aquitaine and Limousin young bulls. Within the Charolais breed, collagen content in *Longissimus* was higher in young bulls and steers than in females. *Longissimus* samples from young bulls were less tender than from females. Based on the above results, this database is a prerequisite for meta-analysis of relationships between muscle characteristics and beef quality in the European context.

Introduction

Beef is a major type of meat in the human diet of many countries mainly Europe, Australia and America. Indeed, beef is one of the most nutrient-rich foods, an excellent natural source of protein (17 to 22% fresh tissue), rich in essential amino acids and containing the full range of essential amino acids required for an adult's or child's diet (Rémond *et al.*, 2010). Beef is also an excellent source of haeminic iron (3 to 4 times greater than that in pork or chicken) (Geay *et al.*, 2001), zinc, vitamin B3, selenium, and also other B-vitamins (Bauchart and Gandemer, 2010). Generally, beef contributes to a healthy, varied and well-balanced diet (Wyness, 2011).

Quality has been defined as: product performance that results in consumer satisfaction and freedom from deficiencies, and which avoids consumer dissatisfaction. Other definitions state that quality refers to characteristics of products, *e.g.* that bear on themselves ability to satisfy given needs (Luning *et al.*, 2002). Whatever the definition, most of the experts have also made a distinction between intrinsic qualities (such as texture, flavour, shelf life, chemical and nutritional attributes, reliability and convenience) and extrinsic quality attributes (production system characteristics including animal welfare and environmental aspects, marketing variables including price, brand name, distribution, origin, packaging, labelling, and traceability) (Grunert *et al.*, 2004; Luning *et al.*, 2002). Consumer studies have shown that beef meets many of these criteria since consumer rating of beef is high especially for palatability, health and nutrient content (Pethick *et al.*, 2009). In addition, beef products from pasture-raised cattle were evaluated very positively (Grunert *et al.*, 2011) reflecting the good image of herbivores in grass-fed systems perceived as natural farming systems which respect environmental and welfare issues. However, the prediction of intrinsic qualities of beef, especially tenderness, still remains imprecise since, at least in Europe, reliable eating-quality guarantee systems are lacking (Verbeke *et al.*, 2010). Several groups in different countries have started beef quality modelling studies using very large databases, with different strategies according to the country. The Meat Standards Australia (MSA) system uses a total quality management approach to predict beef palatability combining animal traits and technological factors with extensive consumer sensory testing (Thompson and Polkinghorne, 2008). In Florida, a strategy known as muscle profiling (Von Seggern *et al.*, 2005) relies on a profile of the most noteworthy characteristics of muscles from the bovine carcass based on the fact that the differences in muscle characteristics among cuts explain most of the variability in beef quality. Recently, a survey was carried out

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among beef consumers in France, Spain, the United Kingdom and Germany by partners of the European ProSafeBeef programme (*www.prosafebeef. eu/*) to assess opinions on beef muscle profiling and interest in a beef eating-quality guarantee such as the MSA system. It is clear that both concepts would be well accepted by European beef consumers despite some minor questions and limitations (Verbeke *et al.*, 2010). Generally, beef quality score depends partially on differences in muscle characteristics of live animals at the time of slaughtering (Renand *et al.*, 2001). Variations in beef quality between and within animals are partly attributed to genetic factors, muscle type, breed, and sex. Research so far has identified that muscle characteristics such as muscle fibre cross-sectional area, metabolic enzyme activity, collagen content and solubility, and lipid content change as cattle mature (Jurie *et al.*, 1995a; Wegner *et al.*, 2000), and also differ between muscle types (Jurie *et al.*, 1995b; Von Seggern *et al.*, 2005), breeds (Christensen *et al.*, 2011) and sexes (Picard *et al.*, 1995a).

Given this, French scientists, French professionals and European partners of the ProSafeBeef programme have taken the initiative to bring together all the data they had accumulated over many years. The BIF-Beef (Beef Integrated and Functional Biology) data warehouse, which gathers all these data, is thus a new tool to analyse the available phenotypes of animal growth, carcass composition, muscle tissue characteristics and beef quality scores specific for European and, more precisely, French characteristics of beef production. This BIF-Beef data warehouse is a large-volume database in terms of characteristics of recorded data and animals in different experiments over years. Other publications with specific targeted aims have previously used this database for specific purposes (Chriki *et al.*, 2012a; Chriki *et al.*, 2012b; Hocquette *et al.*, 2011; Schreurs *et al.*, 2008). Besides providing a detailed description of the BIF-Beef database, another aim of our study is to illustrate by a few examples its usefulness by describing breed, sex and muscle effects on the variability of some animal, carcass and muscle traits (live and carcass weights, fatness score, average area of muscular fibres, muscular fibre metabolism, lipid content, total collagen content, and shear force).

Materials and methods

Database description

The data come from the BIF-Beef database (Chriki *et al.*, 2012a, 2012b; Hocquette *et al.*, 2011) combining data from different projects including three major sources: the INRA database named FiLiCol, the European GEMQUAL programme and the French QUALVIGENE project database. The BIF-Beef data warehouse was initiated by the creation of an internal database, named FiLiCol (for Fibres, Lipids and Collagen), containing data from numerous experiments where animal, carcass, muscle and meat quality measurements were collected (Schreurs *et al.*, 2008). Then, data from several research programmes including QUALVIGENE (Allais *et al.*, 2010; Allais *et al.*, 2011) and GEMQUAL (Christensen *et al.*, 2011) were added. FiLiCol contains some 50,000 measurements obtained on 9 muscles from 394 animals (young bulls, heifers, adult cows and steers) belonging to 7 different breeds (Schreurs *et al.*, 2008). GEMQUAL is based on 435 young bulls from 15 different bovine breeds (Alberti *et al.*, 2008) and was initially developed to study polymorphisms in genes in relation to beef quality. All the phenotype data (about 56,000 measurements) recorded for the *Longissimus thoracis* muscle were entered in the BIF-Beef data warehouse. QUALVIGENE addresses genes which, due to their polymorphisms, are liable to have an impact on beef quality in the Blonde d'Aquitaine, Charolais and Limousin beef breeds (Allais *et al.*, 2010). The phenotype data concerning *Longissimus thoracis* muscle from 3350 young bulls were included in the database (some 160,000 measurements).

Currently, the BIF-Beef database contains 331,153 measurements (including more than 15,764 measurements related to animal growth) from 43 different experiments and related to 621 variables obtained on nine muscles from 5197 animals (1-120 months of age). New data are continuously being added. The BIF-Beef database contains information on animals from 20 genetic types, the majority of which is represented by 3 French beef breeds: Charolais (34%), Limousin (32%) and Blonde d'Aquitaine (19%). Other breeds (which represent 15% of the data) include Montbéliard, Salers, Aubrac, Jersey, Aberdeen Angus, Highland, South Devon, Red Cattle, Simmental, Asturiana de los Valles, Casina, Avilena, Pirenaica, Marchigiana, Holstein crossed Charolais × Salers and Piemontese.

The BIF-Beef database contains data from 9 muscles. Both *Longissimus thoracis* (LT) and *Semitendinosus* (ST) with 128,654 and 21,341 measurements respectively (equivalent to 39% and 6% of the total number of measurements) are the most represented muscles. Other muscle types (representing 59% of the data) include *Triceps brachii*, *Rectus abdominis*, *Semimembranosus*, *Serratus ventralis thoracis*, *Tensor fascia latae*, *Biceps femoris*, *Cutaneus trunci*.

Experiments represented in the BIF-Beef database

As indicated earlier, data present in the BIF-beef database originate from 43 different experiments which have been previously published. Table 1 indicates the initial objectives of the experiments and the corresponding publications.

Table 1. Main bibliographic references of the different experiments reported in the BIF-Beef data warehouse.

Experiments	Bibliographic references
Nutritional value of beef: effects of n-6 or n-3 PUFA enriched diets thanks to supplementation with sunflower oil, linseed seed or linseed oil	Bauchart *et al.*, 2001, 2008, 2010a, 2010b; Bauchart and Gandemer, 2010; Bouhraoua *et al.*, 2001; Durand *et al.*, 2001.
Effect of the type of diet on muscle characteristics and meat quality	Bauchart *et al.*, 2001; Dozias and Picard, 1997; Faulconnier *et al.*, 2007; Hoch *et al.*, 2005; Jurie *et al.*, 1995a, 2006; Listrat *et al.*, 1999, 2001.
Effect of livestock practices (castration, age, housing methods and compensatory growth) on muscle characteristics and meat quality	Brandstetter *et al.*, 1998a, 1998b; Cassar-Malek *et al.*, 2004; Hocquette *et al.*, 1997, 2001; Jurie *et al.*, 1995a, 1998; 2007b; Picard *et al.*, 1995a, 1995b.
Genetic selection of cattle in France and genomic markers of beef quality	Allais *et al.*, 2010, 2011; Bernard *et al.*, 2007, 2009; Hocquette *et al.*, 2007, 2009; Renand *et al.*, 2001.
Effect of breed on muscle and meat characteristics from the main European breeds and from local French breeds	Alberti *et al.*, 2008; Bauchart *et al.*, 2002; Christensen *et al.*, 2011; Dransfield *et al.*, 2003; Jurie *et al.*, 2006; Picard *et al.*, 2007, 2010; Serrano *et al.*, 2007.

Methods used for the different measurements in the BIF-Beef data warehouse

Methods for live weight and body size measurements were reported by Alberti *et al.* (2008). Carcass conformation score was graded according to the EUROP classification (European Commission, 1991), with a scale range from 1 (very poor conformation) to 18 (very good conformation). Fatness score was measured by EU classification, with a 15-point scale (1, very low fat to 15, very high fat).

Morphological measures were determined according to the methodology described by De Boer *et al.* (1974). Carcass composition was estimated by the method described by Robelin and Geay (1975) combining the weight of internal fat with the results of the 6th rib dissection. Objective colour (CIE L^*, a^* and b^* [L^*: light-dark; a^*: red-green; b^*: yellow-blue]) of the external surface of muscles was measured with the method described by Torrescano *et al.* (2003). Determination of total, insoluble and soluble collagen contents was determined using the method of Listrat *et al.* (1999) slightly modified by Listrat and Hocquette (2004).

Intramuscular fat was extracted by the method of Folch (1957) with occasional modifications (Scollan *et al.*, 2001). Identification, proportion and cross-sectional area of the different muscle fibre types were determined by histochemical (Picard *et al.*, 1998) and electrophoretic methods (Picard *et al.*, 1999). Aerobic oxidative metabolism was assessed by cytochrome-*c* oxidase (COX) activity as described by Piot *et al.* (1998) and Jurie *et al.* (2006). The mechanical properties (shear force and compression of meat) were measured instrumentally (Boccard, 1981; Chrystall *et al.*, 1994; Kamoun and Culioli, 1988; Lepetit *et al.*, 1986). To assess sensory quality (sensory tenderness, flavour and juiciness), meat samples were presented to trained taste panellists (0-10 scale) as described by Nute (2002), Dransfield *et al.* (2003) and Allais *et al.* (2010).

Statistical analysis

Data were analysed with Statistical Analysis Systems (SAS, 1987). Analysis of variance was carried out using the GLM procedure of SAS, including the effects of sex and muscle plus the sex × muscle interaction. A second analysis including the effects of breed was also performed when possible. It was not possible to test the effects of breed and sex in the same analysis because each sex was not present in all studied breeds. Therefore, breed and sex were analysed separately with different sets of data. To compare breeds, we used only data from young bulls (valid for all tables, except Table 4) and to compare sexes, we used only data from the Charolais breed. Differences between means were compared in the ANOVA model using the PDIFF option of SAS. More details on each analysis are indicated in the relevant Tables.

Results and discussion

Considering the high amount of data in the BIF-Beef data warehouse, only results about the three main French beef breeds: Charolais (Ch), Limousin (Li) and Blonde d'Aquitaine (BA) will be described here as examples. Indeed, data for these breeds are the most abundant (85%) in the BIF-Beef database.

Live weight and carcass characteristics

Animals were weighed prior to slaughter. Mean weight (kg) and standard deviation for Li, Ch and BA breeds were 636±65, 712±58 and 621±54, respectively. Ch young bulls were heavier than Li ones, which in turn were heavier than the BA young bulls (Table 2). Mean

Table 2. Results of one way ANOVA carried out on slaughter weight (kg) of different breeds (young bulls only) and of different sexes (Charolais breed only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	1369	636±65[b]	16
Charolais	1447	712±58[a]	17
Blonde d'Aquitaine	1000	621±54[c]	14
Sex			
Young bulls	1447	712±58[b]	17
Females	36	719±98[b]	59
Steers	289	689±75[a]	28

°Only mean values are reported. [a,b,c]Mean differences at P<0.05 between means across breeds or across sexes.

Table 3. Results of one way ANOVA carried out on carcass weight (kg) of animals of different breeds (young bulls only) and of different sexes (Charolais breed only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	1509	400±42[c]	16
Charolais	1473	423±36[a]	16
Blonde d'Aquitaine	993	412±38[b]	14
Sex			
Young bulls	1473	423±36[a]	16
Steers	289	414±48[b]	29

°Only mean values are reported. [a,b,c]Mean differences at P<0.05 between means across breeds or across sexes.

Table 4. Results of one way ANOVA carried out on fatness score (from 1 to 15) of animals of different breeds (females only) and of different sexes (Charolais breed only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	119	8.4±1.5[a]	76
Charolais	166	8.7±1.0[a]	56
Sex			
Females	166	8.7±1.0[a]	56
Steers	133	8.1±1.5[b]	24

°Only mean values are reported. [a,b]Mean differences at P<0.05 between means across breeds or across sexes.

weight (kg) and standard deviation for young bulls, steers and females of the Ch breed were 712±58, 689±75 and 719±98, respectively (Table 2). Females and young bulls were significantly (P<0.05) heavier animals (Table 2, P<0.05). In the Charolais breed, the average carcass weights of young bulls were significantly (P<0.05) greater than average carcass weights of steers (Table 3).

Due to this difference between young bulls and steers, the comparison between breeds in Table 3 was done for young bulls only. Ch young bulls had a significantly (P<0.05) heavier carcass weight and Li the lowest carcass weight. Since fat score depends markedly on both sex and breed, a comparison was made between Li and Ch females and between steers and females in the Ch breed, taking into account available and comparable data present in the data warehouse. Mean fatness scores in females did not significantly differ between the two studied breeds. As expected, there was a significant difference (P<0.05) between females and steers in Ch animals, with greater (P<0.05) fatness scores in females (Table 4). Body weight of animals varies to a great extent among age, breed and sex. The fact that animals of the BA breed were young compared to those from other breeds explains why BA animals in our database were the lightest (Table 2), in agreement with many studies which classify BA as a late-maturing breed. The fact that Ch young bulls were heavier than Li young bulls (Table 2) is in concordance with the work of Alberti *et al*. (2008) with 15 European breeds (Ch: 634 and Li: 565 kg), with young bulls of the same age (15 months)

Generally speaking, differences in animal characteristics such as sex, age and breed influence carcass characteristics (Choat *et al.*, 2006; Crouse *et al.*, 1985; Field, 1971; Garcia-Launay and Micol, 2010; Marchello *et al.*, 1970; Seideman *et al.*, 1982; Zhang *et al.*, 2010). Carcass weights were on average much greater in our data warehouse (about 400-425 kg which corresponds to animals with live weight of 620-720 kg) compared to the animals described by Von Seggern *et al.* (2005) for which carcass weights varied between 250 and 431 kg. This is clearly explained by different factors which correspond to the specificities of the French and the American beef production systems respectively. In France, farmers rear mainly late-maturing beef breeds (Li, Ch and BA) (Micol *et al.*, 1993) with heavier and leaner carcasses compared to early-maturing beef breeds in the United States (Alberti *et al.*, 2008). Furthermore, we have mainly young bulls in our database which produce leaner and heavier carcasses in contrast to steers described by Von Seggern *et al.* (2005). Indeed, some studies have reported that bulls showed greater muscle development, less fat deposition and were more efficient in producing leaner carcasses than steers (Crouse *et al.*, 1985; Field, 1971; Seideman *et al.*, 1982). It may be mainly attributed to the effects of male hormones (testosterone) on muscle protein anabolism (Morgan *et al.*, 1993).

Conformation and fatness scores constitute the main criteria of qualitative carcass levels (Garcia-Launay and Micol, 2010). The fatness score of Li and Ch breeds was in agreement with results of Alberti *et al.* (2008) for animals at the same age. The latter reported wide variations across 15 different European breeds. However, animals in BIF-Beef were older (24-76 months of age, Table 4) compared to those of Alberti *et al.* (2008, 15 months of age). Micol *et al.* (1993) found that cows were more early-maturing than steers and bulls. Consequently, at the same young age, heifers had a greater fatness score than steers and bulls. Indeed, in this study, steers (24 months of age) had a lower fatness score than cows (56 months of age, Table 4). Moreover, Choat *et al.* (2006) reported, that carcass fatness measured at the 12th rib was similar between steers and heifers. In addition, these authors reported that heifers produced carcasses with better quality grades than steers, contradicting the findings of Marchello *et al.* (1970) and Zinn *et al.* (1970).

Muscle characteristics

Average cross-sectional area of muscle fibres

The mean cross-sectional area of fibres varied greatly, between the different muscles, sexes and breeds (Table 5). For LT muscle in young bulls, there was a significant difference between the three studied breeds with Ch and Li having the largest (P<0.05) fibre cross-sectional area and BA the lowest (Table 5). For LT muscle, in the Ch breed, there was a significant difference (P<0.05) in cross-sectional area between sexes, with a higher fibre size in steers than in young bulls (Table 5). When we compared muscle types for Ch young bulls of the same age (Table 5), we observed that fibre cross-sectional area was significantly (P<0.05) greater in ST muscle than in LT muscle.

The muscular fibre area depends on carcass weight, sex, breed, feed, age and level of physical activity of the individual (Totland and Kryvi, 1991). Moreover, the average cross-sectional area and composition of muscle fibre types varied considerably according to the studied muscles (Totland and Kryvi, 1991) and the variations influence beef quality (Dransfield *et al.*, 2003). A significant effect of breed was observed in average cross-sectional area, for LT (Table 5). Seideman and Crouse (1986), also observed differences on LT muscle in average cross-sectional area between breeds. In addition, a significant difference in average cross-sectional area between sexes was observed in this study (Table 5). We observed that young bulls had smaller mean fibre muscle size than steers in LT muscle as a consequence of the different age of young bulls and steers: younger animals have smaller cross-section area of fibres in agreement with numerous studies *e.g.,* that of Seideman and Crouse (1986) working on LT. However, in our study, ST muscle in young bulls had larger mean fibre muscle size than steers (data not shown) as observed by Seideman and Crouse (1986).

Average cross-sectional area of ST was greater than LT which is in concordance with results from Totland and Kryvi (1991). Indeed, they found that fast glycolytic fibres had the largest average fibre area in all muscles studied. Therefore, the fast glycolytic fibres of the ST and *Rectus abdominis* (RA) muscles (hindpart muscles) were on average 10% larger than of LT (forepart muscles) (Totland and Kryvi, 1991). This is in agreement with Oury *et al.* (2010), who found that average cross-sectional area of RA was greater than of LT, and with Jurie *et al.* (2005) who found that for all fibre types, cross-sectional areas were larger in ST than in LT.

Furthermore, across all breeds and sexes, a high variability of average cross-sectional area was observed in the ST muscles (22 to 53%, data not shown). This result is in agreement with the conclusions of Totland and Kryvi (1991) who found that hindpart muscles (*e.g.* ST) showed even larger inter- and intramuscular size variations (between superficial and deep layers of muscle). The great variability in average cross-sectional area of muscular fibres may explain the ambiguous results often obtained in comparative studies attempting to correlate muscle fibre characteristics to functional, biochemical or technological (*e.g*. meat quality) properties. In some studies, a greater mean fibre area could be unfavourable to meat quality traits. Indeed, some studies indicated a negative correlation between tenderness and mean fibre area (Renand *et al.*, 2001), which was recently confirmed by meta-analysis (Chriki *et al*., 2012a).

Fat content

There was a significant difference (P<0.05) between breeds with a greater intra-muscular fat (IMF) level in Ch than in Li young bulls. In addition, IMF level was greater in Ch and Li breeds than in BA breed (Table 6). In the Ch breed, there was a significant difference ($P<0.05$) between sexes with a greater IMF level in females (24±9 mg/g of wet tissue) than in steers (20±8 mg/g) with an IMF level which, in turn, was greater than in young bulls (16±9 mg/g). In Ch young bulls, there was a significant difference ($P<0.05$) between muscles with a greater IMF level in ST, TB and RA muscles (18 to 21 mg/g of wet tissue) from 19-month-old young bulls than in LT (16±9 mg/g) muscle which was sampled from slightly younger animals.

The chemical composition of muscles is relatively constant (about 75% water, 19-25% proteins, and 1-2% minerals and glycogen). However, lipid levels are highly variable, both between species, between individuals in a given species and between muscles and cuts (Hocquette *et al.*, 2010). As expected, in this study, a significant difference in IMF level was observed in LT between breeds (Ch>Li>BA) and sexes, females being fatter. Von Seggern *et al.* (2005) indicated that IMF level, for American beef, was 77 and 57 mg/g of wet tissue, respectively, for LT and TB muscles. However, in our study we had IMF level lower than or equal to 21 mg/g, for LT, RA, ST and TB muscles in Ch young bulls, confirming that French beef is much leaner than beef from North America. Furthermore, Chambaz *et al.* (2003) reported a greater fat content in LT of Ch and Li than that from BIF-Beef data. These major differences are likely to be explained by the fact that, in our database, we have mainly young bulls which are leaner than steers used in other studies. However, flavour in meat increases with more fat content (Dransfield *et al.*, 2003; Hocquette *et al.*, 2011). Indeed, not only lipids contribute to meat flavour but also *e.g.* heterocyclic, phenolic and S-containing compounds are important flavour-producing end products (Gandemer, 1999).

Muscle metabolism

In this study, we have detailed the variability of COX activity (mole/mm per g) for the assessment of oxidative metabolism of muscles (Piot *et al.*, 1998).The mean COX activity of the muscles varied between the different muscles, the ST muscle being the least oxidative (Table 7). For LT muscle of young bulls, we did not observe any significant difference between breeds (Li and CH). Due to the low amount of data, we could not test the difference between sexes. The absence of difference in COX activity between Li and Ch young bulls

Table 5. Results of one way ANOVA carried out on average cross-sectional area (m^2) of muscular fibres of different breeds (*Longissimus thoracis* muscle from young bulls only), of different sexes (*Longissimus thoracis* muscle from Charolais animals only) and of different muscles (Charolais young bulls only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	1319	3022±708[a]	16
Charolais	1537	2986±788[a]	17
Blonde d'Aquitaine	982	2863±593[b]	14
Sex			
Young bulls	1537	2986±788[b]	17
Steers	63	3568±939[a]	28
Muscle			
Longissimus thoracis	1537	2986±788[b]	17
Semitendinosus	104	4481±1562[a]	17

°Only mean values are reported. [a,b]Mean differences at $P<0.05$ between means across breeds or across sexes.

Table 6. Results of one-way ANOVA carried out on Intra-Muscular Fat (IMF) content (mg/g of wet tissue) of samples of different breeds (*Longissimus thoracis* muscle from young bulls only), of different sexes (Longissimus thoracis muscle from Charolais animals only) and of different muscles (Charolais young bulls only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	1316	12±5[b]	16
Charolais	1248	16±9[a]	17
Blonde d'Aquitaine	1010	6±4[c]	14
Sex			
Young bulls	1248	16±9[c]	17
Females	65	24±9[a]	80
Steers	186	20±8[b]	27
Muscle			
Longissimus thoracis	1248	16±9[b]	17
Rectus abdominis	111	18±6[a]	19
Semitendinosus	131	21±8[a]	19
Triceps brachii	49	21±8[a]	19

°Only mean values are reported. [a,b,c]Mean differences at $P<0.05$ between means across breeds or across sexes.

Table 7. Results of ANOVA carried out on cytochrome-c oxydase (COX) activity (mole / min per g) of samples of different breeds (*Longissimus thoracis* muscle from young bulls only), and of different muscles (Charolais steers only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	31	12±3[a]	14
Charolais	95	13±4[a]	17
Muscle			
Longissimus thoracis	44	13±5[a]	31
Rectus abdominis	135	12±6[a]	28
Semitendinosus	160	9±5[b]	29

°Only mean values are reported. [a,b]Mean differences at $P<0.05$ between means across breeds or across muscles.

in LT muscle is in disagreement with Jurie *et al.* (2005), who found that isocitrate dehyrogenase activity [ICDH] (another enzyme representative of oxidative metabolism) was lower in muscles from Li than Ch bulls. A recent study (Hocquette *et al.*, 2012) showed that these two metabolic enzymes (COX and ICDH) are differentially regulated depending on breeding factors.

Oxidative metabolism could be in favour of meat tenderness. Indeed, in LT and RA muscles, tenderness scores increased and shear force decreased with muscle oxidative metabolism. The more oxidative muscles were shown to be of better quality, particularly in terms of tenderness (Renand *et al.*, 2001). However, Strydom *et al.* (2000) observed a negative correlation between oxidative metabolism and meat tenderness. More recently, Chriki *et al.* (2012a), who studied the relationship between muscle metabolism and tenderness, showed that muscle type played a considerable role in these controversies. ST muscle had the lowest oxidative activity compared to LT and RA, in agreement with studies describing ST as a glycolytic muscle (Dransfield *et al.*, 2003; Jurie *et al.*, 2007a; Jurie *et al.*, 2007b; Schreurs *et al.*, 2008). Nevertheless, this is not true for all breeds and all sexes. In fact, this result was inversed in dairy breeds such as Holstein and Montbéliard, and steers (Chriki *et al.*, 2012b). Besides, ST had a high variability compared to other muscles which confirms the results from Brandstetter *et al.* (1998b) demonstrating heterogeneity within the ST muscle.

Total collagen content

In the BIF-Beef data warehouse, collagen was expressed as mg hydroxyproline/g (or µg/mg) of dry matter. In order to express results in international units and to compare data with other results from other publications, collagen content was converted into mg collagen per g of tissue. According to Etherington and Sims (1981), we use the coefficient 7.14 to convert hydroxyproline to collagen content (mg/g). Total collagen content varied between the different muscles and breeds, total collagen content being 52% higher in ST muscle than in LT muscle for Ch young bulls (Table 8). In LT muscle of young bulls, there was a significant difference ($P<0.05$) between breeds in total collagen content with a greater total collagen content in Ch (25±7 mg/g dry matter) than in Li and BA breeds (21 to 23 mg/g). In LT muscle of the Ch breed, total collagen content means were significantly greater in steers and young bulls (25 to 29 mg/g dry matter) than in females (19±3 mg/g). Collagen is the major component of muscle connective tissue, and its association with meat tenderness has been the target of numerous studies (Lepetit, 2004, 2007). LT muscle had lower total collagen content than ST muscle, in agreement with Jurie *et al.* (2005). Furthermore, LT is described as being more tender than ST. In addition, some authors (Oury *et al.*, 2010; Rhee *et al.*, 2004) observed a negative correlation between tenderness and collagen content underlying that collagen content plays a major role in meat tenderness. As Jurie *et al.* (2005), we observed that Ch had a greater total collagen content than Li young bulls. However, in disagreement with Prost *et al.* (1975) who failed to find any significant difference in collagen content between the sexes of animals, we observed that for LT muscle from Ch animals, young bulls and steers had a higher total collagen content compared to females.

Tenderness evaluation by Warner-Bratzler shear

Warner-Bratzler shear force (WBSF) was measured on cooked (55-60°C) meat after 14 days of ageing *post-mortem*. Shear force measurements (Warner-Bratzler) varied greatly, between the different muscles and sexes (Table 9). Samples from Ch young bulls were significantly ($P<0.05$) less tender (higher WBSF: 68±19 N/cm²) than females (lower WBSF: 49±18 N/cm²). In addition, samples from LT were significantly ($P<0.05$) more tender (lower WBSF: 68±19 N/cm²) than samples from ST and TB muscles (WBSF: 119 to 127 N/cm²).

Destefanis *et al.* (2008) used a sensory panel of 220 people to evaluate 60 samples of LT. The aim of their study was to investigate the consumer's ability to discern different levels of tenderness indirectly established by WBSF. They concluded that beef with WB values greater than 53 N/cm², and lower than 43 N/cm², was perceived by most consumers as tough or tender, respectively.

Table 8. Results of ANOVA carried out on total collagen content (mg/g dry matter) of samples of different breeds (*Longissimus thoracis* muscle from young bulls only), of different sexes (*Longissimus thoracis* muscle from Charolais animals only) and of different muscles (Charolais young bulls only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Breed			
Limousin	19	21±6[b]	19
Charolais	370	25±7[a]	17
Blonde d'Aquitaine	11	23±3[b]	15
Sex			
Young bulls	370	25±7[a]	17
Females	22	19±3[b]	80
Steers	52	29±9[a]	31
Muscle			
Longissimus thoracis	370	25±7[b]	17
Semitendinosus	49	38±7[a]	18

°Only mean values are reported. [a,b]Mean differences at $P<0.05$ between means across breeds, across sexes or across muscles.

Table 9. Results of ANOVA carried out on of shear force (Warner Bratzler at 14 days *post-mortem* in N/cm²) of samples of different sexes (*Longissimus thoracis* muscle from Charolais animals only), and of different muscles (Charolais young bulls only) with data from the BIF-Beef data warehouse. The average age at slaughter (months) for animals analysed in each sub-dataset is also reported.

	Animal, no.	Mean±SD	Age at slaughter°
Sex			
Young bulls	21	68±19[a]	19
Females	22	49±18[b]	80
Muscle			
Longissimus thoracis	21	68±19[b]	19
Semitendinosus	21	127±37[a]	19
Triceps brachii	19	119±44[a]	19

°Only mean values are reported. [a,b]Mean differences at $P<0.05$ between means across sexes or across muscles.

Across all studied muscles, in Ch breed (Table 9), samples from young bulls were less tender than from females (P<0.05), in agreement with Hanzelková *et al.* (2011) who found that meat from young bulls was significantly less tender than that of heifers. Conversely, Wulf *et al.* (1996) reported that steaks from heifer carcasses had greater shear force values than steaks from steer carcasses. However, in this study, a large amount of androgens was administrated to heifers, which could have influenced the meat texture (Wulf *et al.*, 1996). Choat *et al.* (2006) concluded that there is a difference in meat palatability between heifers and steers, whereas, some studies (Gracia *et al.*, 1970; Prost *et al.*, 1975; Zinn *et al.*, 1970) have reported no difference in tenderness between cooked steaks from steers and heifers. Hedrick *et al.* (1969) also found no significant differences in WBSF values between sex groups. Across studied breed and sexes, LT was more tender than TB and ST muscles (Table 9), in agreement with Voges *et al.* (2007) who found that, for retail meat cuts, the three cuts from the round (as ST) had the highest WBSF values compared to cuts from the chuck (as LT and TB).

Conclusions

After this general presentation and description of the BIF-Beef data warehouse, we observed a major variation in all studied traits (animal and carcass measurements, average area of different muscular fibres, lipid content, COX activity and muscular fibre metabolism, total collagen content and shear force values). This variability was observed across breeds, sexes and in the same animal between different muscles.

In fact, we can conclude that a large quantity of data is needed to draw robust conclusions regarding differences between muscle traits according to breed and sex and other factors. Indeed, the amount of data not only brings statistical strength but also a better understanding of the variability according to various criteria (such as breed, age and sex). Therefore, it is important to include more data in the BIF-Beef database in order to understand how the different studied variables may influence meat quality.

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