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Meta-analysis of the relationships between beef tenderness and muscle characteristics

S. Chriki [a,b,e], G. Renand [c,d], B. Picard [a,b], D. Micol [a,b], L. Journaux [e], J.F. Hocquette [a,b,*]

[a] INRA, UMR1213, Recherches sur les Herbivores, F-63122 Saint Genès Champanelle, France
[b] VetAgro Sup, UMR1213, Recherches sur les Herbivores, F-63122 Saint Genès Champanelle, France
[c] INRA, UMR1313, Génétique Animale et Biologie Intégrative, F-78352 Jouy-en-Josas, France
[d] AgroParisTech, INRA UMR1313, Génétique Animale et Biologie Intégrative, F-78352 Jouy-en-Josas, France
[e] UNCEIA, 149 rue de Bercy, F-75595 Paris Cedex 12, France

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A B S T R A C T

Beef tenderness is characterised by a high and uncontrolled variability which depends, at least in part, on differences in muscle characteristics. The aim of this work was to identify general relationships between beef tenderness and muscle characteristics across experiments, using a large set of data available in the BIF-Beef (Integrated and Functional Biology of Beef) database. Tenderness was evaluated by sensory methods with trained panellists and by shear force measurements. Total and insoluble collagen contents, intramuscular fat content (IMF), mean cross sectional fibre area, isocitrate dehydrogenase (ICDH) and lactate dehydrogenase (LDH) activities and the proportion of slow oxidative (SO), fast oxido-glycolytic (FOG) and fast glycolytic (FG) muscle fibres were measured in both *Longissimus thoracis* (LT) and *Semitendinosus* (ST) muscles. Total collagen content, IMF content, mean muscle fibre area, LDH and ICDH activities explained respectively, 2%, 0.3%, 1.8%, 1.6% and 1.7% maximum of the variability (r^2) in the sensory tenderness score. The total and insoluble collagen contents, the LDH activity and the FG proportion explained, respectively, 6%, 6%, 4% and 5% of the variability in the shear force, essentially in the ST muscle but not in LT muscle. The relationships between different muscle characteristics were confirmed. It was demonstrated that the determinism of tenderness was complex and mainly muscle dependant. The large data set used allowed the statement of general laws and contributed to explain the divergent results in the literature from smaller sets of data originating from specific experiments.

1. Introduction

In beef meat, tenderness has long been recognised as the key determinant of eating quality, with evidence demonstrating that consumers accept to pay more for guaranteed tenderness (Boleman et al., 1997). Beef tenderness exhibits a high and uncontrolled variability (Morgan et al., 1991) which is one reason for consumer dissatisfaction and may explain the decline of beef meat consumption during the last decades (Hocquette and Chatellier, 2011). However, reliable eating-quality guarantee systems are lacking at least in Europe. The development of a beef quality grading and guarantee system through muscle profiling research can help to meet this demand (Verbeke et al., 2010). The variability of beef tenderness depends, at least partly, on differences in muscle characteristics (Guillemin et al., 2009). However, the association between eating quality traits (*i.e.* tenderness) and muscle characteristics varies according to the breed (Brouard et al., 2001). Nevertheless, Renand et al. (2001) demonstrated that some biochemical muscle traits explained in Charolais young bulls 33% only of tenderness variability in with beef samples. These differences between and also within animals are attributed to factors such as age, gender, feeding

* Corresponding author at: INRA, UMR1213, Recherches sur les Herbivores, F-63122 Saint Genès Champanelle, France. Tel.: +33 473624253.
E-mail address: jfhocquette@clermont.inra.fr (J.F. Hocquette).

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management, breed and muscle type. Muscle characteristics such as contractile fibre cross-sectional area, metabolic enzyme activity, collagen content and solubility, along with the lipid content contribute to explain more or less variability in beef quality and are regulated by the age of cattle (Maltin et al., 1998; Jurie et al., 2005). They differ between muscle types (Maltin et al., 2003; Picard et al., 2007) and depend also on feeding (Cassar-Malek et al., 2004; Jurie et al., 2006), exercise (Jurie et al., 2006), breed (Picard et al., 2007; Christensen et al., 2011), gender and post slaughter factors, as cooling rate and so on… (Picard et al., 2007).

Based on these observations, a collaborative group consisting of French researches, French professional partners and European partners of the ProSafeBeef European programme (www.prosafebeef.eu/) (2007–2012) compiled all data accumulated over the last 20 years from a total of 43 experiments. This data warehouse, called BIF-Beef (Integrated and Functional Biology of Beef), provides a new tool to explore phenotypic associations between growing performances, carcass composition, muscle tissue characteristics and beef quality attributes representative of the French beef production (Hocquette et al., 2011; Chriki et al., 2012). One of the goals of ProSafeBeef programme was to establish an European prediction model for beef quality from muscle characteristics.

Consequently, the present meta-analysis, based on the large number of the available data from the BIF-Beef database, aimed to identify general laws between beef tenderness and muscle characteristics in order to progress beyond the controversial results available in the literature.

2. Materials and methods

The BIF-Beef database contains about 332,000 measurements (including more than 15,700 measurements related to animal performances) on 621 variables assessed in 9 muscles on 5,197 animals from 1 to 120 months of age, belonging to 20 different breeds, and from 43 different experiments. BIF-Beef has already been described in details in previous papers (Chriki et al., 2012), new data being continuously added.

In this study, data on young bulls and cows (Table 1), mainly from the three main French beef breeds: Limousin (35%), Charolais (30%), Blond d'Aquitaine (20%) were analysed along with data from other breeds (15%). The age of animals is indicated in Table 1.

2.1. Tenderness evaluation

Tenderness was evaluated by two methods:

(i) Trained panellists who rated beef samples on non-structured line scales marked at the extremities 'low' and 'high' and subsequently scored as the distance in units of 1, from 1 to 10. Sensory analysis is generally considered as the reference method to evaluate eating quality. In the experiments considered in this study, 14-day aged samples at 4 °C, were grilled at 55–60 °C and then tasted (Oury et al., 2009; Allais et al., 2011).

(ii) Warner–Bratzler shear force (WB) on raw samples with an ageing time of 14 days *post-mortem*, using an Instron Universal Testing Machine (Lepetit et al., 1986; Kamoun and Culioli, 1988; Wheeler et al., 1997; Oury et al., 2009).

2.2. Biochemical and mechanical muscle traits

Different traits were measured on both *Longissimus thoracis* (LT) and *Semitendinosus* (ST) muscles. These two muscles were chosen because they present different proportions of the three major muscle fibre types (slow

Table 1
Adjusted means with appropriate standard errors (LSMeans ± SE) of muscle characteristics measured in *Longissimus thoracis* [LT] and *Semitendinosus* [ST] muscles from young bulls and cows.

	LT muscle				ST muscle			
	Young bulls		Cows		Young bulls		Cows	
	N	LSMean ± SE	*N*	LSMean ± SE	*N*	LSMean ± SE	*N*	LSMean ± SE
Age (months)	5006	$15^b \pm 0.06$	226	$56^a \pm 0.26$	5006	$15^b \pm 0.06$	226	$56^a \pm 0.26$
Sensory tenderness (scale: 1–10)	3547	$5.3^b \pm 0.02$	104	$5.9^a \pm 0.10$	138	$5.4^b \pm 0.10$	96	$4.9^c \pm 0.10$
WB shear force (N/cm^2)	82	$57^c \pm 3.5$	87	$44^d \pm 3.4$	83	$124^a \pm 3.4$	87	$105^b \pm 3.4$
Total collagen content (mg/g dry matter)	487	$3.3^c \pm 0.04$	94	$2.8^d \pm 0.10$	270	$5.4^a \pm 0.05$	92	$4.4^b \pm 0.10$
Insoluble collagen content (mg/g dry matter)	440	$2.9^c \pm 0.03$	91	$2.3^c \pm 0.10$	223	$4.1^a \pm 0.05$	93	$3.6^b \pm 0.10$
IMF content (mg/g)	3841	$23^b \pm 0.1$	90	$31^a \pm 0.8$	153	$10^d \pm 0.6$	90	$17^c \pm 0.8$
Mean cross-sectional fibre area (μm²)	4019	$2991^d \pm 13$	142	$3169^c \pm 70$	594	$3609^b \pm 34$	145	$4402^a \pm 69$
LDH (μmole/min/g)	1225	$1027^b \pm 5$	126	$962^c \pm 15$	630	$1041^a \pm 6$	119	$1052^a \pm 15$
ICDH (μmole/min/g)	1236	$1.6^a \pm 0.01$	168	$1.5^a \pm 0.04$	710	$1.2^b \pm 0.02$	162	$1.0^c \pm 0.04$
SO (%)	317	$31^a \pm 0.4$	142	$30^b \pm 0.6$	462	$12^d \pm 0.3$	145	$10^c \pm 0.6$
FOG (%)	316	$18^c \pm 0.5$	142	$16^c \pm 0.8$	461	$25^b \pm 0.4$	145	$25^a \pm 0.8$
FG (%)	317	$53^b \pm 0.4$	142	$55^c \pm 0.6$	463	$63^a \pm 0.3$	145	$65^a \pm 0.6$

N: number of data
IMF: intramuscular fat content; LDH: Lactate dehydrogenase activity; ICDH: Isocitrate dehydrogenase activity; SO: proportion of slow oxidative muscle fibres; FOG: proportion of fast oxido-glycolytic muscle fibres; FG: proportion of fast glycolytic muscle fibres.
a, b, c, d: $p < 0.05$.