Cluster analysis application in research of muscle biochemical determinants for beef tenderness

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Abstract— **The BIF-Beef (Integrated and functional biology of beef) data warehouse contains animal, carcass, muscle and meat measurements derived from numerous experiments mainly with *longissimus thoracis* muscle from young bulls. The aim of this study was to explain variability in tenderness from muscle biochemical traits. To achieve this goal, we created three tenderness clusters (high, medium, low) from trained-taste-panel tenderness scores of all meat samples consumed (4366 observations from 40 different experiments). Each cluster was then tested for its association with muscle mechanical and biochemical traits which may be related to tenderness. As expected, lower shear force values were associated with more tender meat. In addition, muscles in the highest tenderness cluster had the highest enzyme mitochondrial activities (isocitrate dehydrogenase, cytochrome-*c* oxidase), the highest proportion of slow oxidative muscle fibres, the lowest phosphofructokinase activity and the lowest proportion of fast-glycolytic muscle fibres. Furthermore, muscles in the lowest tenderness group had the highest average muscle fibre cross-sectional area.**

Keywords— **tenderness, beef, meta-analysis**

I. INTRODUCTION

Variability in beef tenderness depends at least in part on differences in muscle characteristics [7]. These differences both between and within animals are attributed to factors such as genetics, muscle type, breed, and sex, etc. Research so far has identified that muscle characteristics such as contractile fibre cross-sectional area, metabolic enzyme activity, collagen content and solubility, as well as lipid content change as cattle mature, and also differ between muscle types, breeds and sexes [5]. Taking these observations into account, a collaborative group consisting of French scientists, French professionals and European partners of the ProSafeBeef (*www.prosafebeef.eu/*) programme have compiled all the data they have accumulated in the last 20 years from different experiments. This data warehouse, called BIF-Beef (Integrated and functional biology of beef), represents a new tool to explore phenotypic associations between animal growth, carcass composition, muscle tissue characteristics and beef quality attributes within animals that are representative of French beef production.

The aim of this study was hence to explain, at least in part, variability in beef tenderness from muscle biochemical traits available in the BIF-Beef database. Our hypothesis is that muscular fibres and connective tissue characteristics do influence beef tenderness.

II. METHODS

Currently, the database BIF-Beef contains about 331,745 measurements (including more than 15,764 measurements related to animal growth) of 621 variables observed within 6 muscles from 5197 animals (1-120 months of age) belonging to 20 different breeds, and from 43 different experiments [6]. This data-set was clustered into 3 tenderness groups (high, medium, low) on the basis of trained-taste-panel tenderness scores of all meat samples consumed (4366 observations from 40 different experiments). In all experiments, grilled (55 or 75°C) samples were chewed and rated by trained panellists on non-structured line scales marked at the extremities ‘low’ and ‘high’ and subsequently scored as the distance in units of 1, from 0 to 10 [3]. These muscle samples came from the *Semitendinosus*, *Semimembranus*, *Rectus abdominis*, *Triceps brachii* and principally *Longissimus thoracis*.

Different mechanical and biochemical traits were studied in this paper: Shear force (SF) on cut beef values at 14 days post-mortem [N/cm²], muscle activities of Lactate dehydrogenase (LDH), phosphofructokinase (PFK), Isocitrate dehydrogenase (ICDH), Citrate synthase (CS) and cytochrome-*c* oxidase (COX) [µmole/min per g muscle], which are all metabolic enzymes, proportions of fast-glycolytic (FG) and slow-oxidative fibres (SO), cross-sectional area (CSA) of fibres and finally muscle contents of total and insoluble collagen [mg/g dry matter].

To analyse results and create classes of tenderness, a cluster analysis was performed with SAS (Statistical Analysis System) using taste-panel tenderness scores. Then, each cluster (corresponding to high, medium or low scores) was tested for its association with muscle mechanical and biochemical traits which may be related to tenderness. Clusters were then used as a fixed effect to study variability in other traits which may be related to tenderness.

III. RESULTS AND DISCUSSION

As expected, lower shear force values were associated with more tender beef (Table 1), aligning well previous work [2]. This is likely to be linked to the lower insoluble and total collagen content demonstrated within the high tenderness group, this result being supported by numerous other studies [7] but not all [4]. Muscles in the highest tenderness group or class also had the highest mitochondrial enzyme activities (isocitrate dehydrogenase, cytochrome-*c* oxidase), the highest proportion of slow oxidative muscle fibres, the lowest phosphofructokinase activity and the lowest proportion of fast-glycolytic muscle fibres. These results indicate that slow-oxidative muscle types will favour beef tenderness as observed by Dransfield et al. [3]. The relationship between muscle fibre type and beef tenderness has been a subject of debate due to contradictory results generated within numerous experiments carried out in different countries with different animal types or different cuts [5].

Lastly, muscles in the lowest tenderness class had the highest average muscle fibre cross-sectional area, and muscles in the highest tenderness class had the lowest average muscle fibre cross-sectional area. This observation fits well with the results of Berry et al. [1].

Table 1 Means (M), Standard Deviation (SD) and Number of 3 Tenderness group and different mechanical and biochemical traits of bovine muscles

	Low	**Medium**	**High**
Tenderness (0-10 Scale)			
M ± SD	4.60 ^{C} ± 0.55	5.93 ^{b} ± 0.35	7.13 ^{a} ± 0.50
Number	1019	1269	2078
Shear Force (N/cm²)			
M ± SD	46.04 ^{b} ± 11.29	40.11 ^{a} ± 8.42	35.93 ^{c} ± 6.72
Number	619	1645	1054
Total collagen [mg/g dry matter]			
M ± SD	28.97 ^{a} ± 7.27	27.58 ^{b} ± 7.9	27.71 ^{b} ± 10.06
Number	335	296	134
Insoluble collagen [mg/g dry matter]			
M ± SD	22.58 ^{a} ± 6.08	22.51 ^{a} ± 6.09	20.71 ^{b} ± 5.53
Number	335	296	134
FG (%)			
M ± SD	54 ^{a} ± 11.2	53 ^{ab} ± 11.7	52 ^{b} ± 9.6
Number	261	267	132
SO (%)			
M ± SD	22.6 ^{b} ± 11.8	25 ^{a} ± 11.9	25 ^{a} ± 12.1
Number	261	267	132
ICDH [µmole/min per g muscle]			
M ± SD	1.4 ^{b} ± 0.60	1.56 ^{a} ± 0.61	1.63 ^{a} ± 0.60
Number	180	382	372
LDH [µmole/min per g muscle]			
M ± SD	938 ^{a} ± 163	941 ^{a} ± 206	941 ^{a} ± 219
Number	180	382	372
PFK [µmole/min per g muscle]			
M ± SD	23.31 ^{a} ± 7.38	19.08 ^{b} ± 9.23	15.80 ^{b} ± 7.31
Number	33	51	31
CS [µmole/min per g muscle]			
M ± SD	4.57 ^{b} ± 1.22	4.59 ^{b} ± 1.12	4.72 ^{a} ± 1.05
Number	108	78	34
COX [µmole/min per g muscle]			
M ± SD	11.64 ^{c} ± 4.64	13.44 ^{b} ± 4.62	15.19 ^{a} ± 3.81
Number	91	74	34
CSA (µm²)			
M ± SD	3336 ^{a} ± 1053	2903 ^{c} ± 802	3057 ^{b} ± 836
Number	903	1912	1186

IV. CONCLUSIONS

In conclusion, many muscle characteristics appear to influence beef tenderness which confirms the complexity of this quality criteria. The large data set of this meta-analysis enables confirmation of well known negative relationships between tenderness and mechanical properties on one hand, and between tenderness and collagen characteristics on the other hand. Furthermore, the strength of this meta-analysis with different muscle types is to dispel some controversy by showing that oxidative muscle fibre types and a low average muscle fibre cross-sectional area are associated with improved tenderness.

The classes of tenderness studied in this work had different muscles sampled from animals of different breeds with different sexes and ages which induces a high number of variability factors in this group of data. So, in fact, the meta-analysis of this study emphasises that a large quantity of data are needed to draw robust conclusions regarding differences between muscle types according to breed and sex. Indeed, the volume of data not only brings statistical strength but also a better understanding of the variability according to various criteria (breed, age, sex, etc). Further work will include more data in the BIF-Beef database in order to identify more variables which may influence meat quality.

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