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Research Article

The relationships between sensory and nutritional qualities are not consistent from one muscle to another in the same bovine carcass

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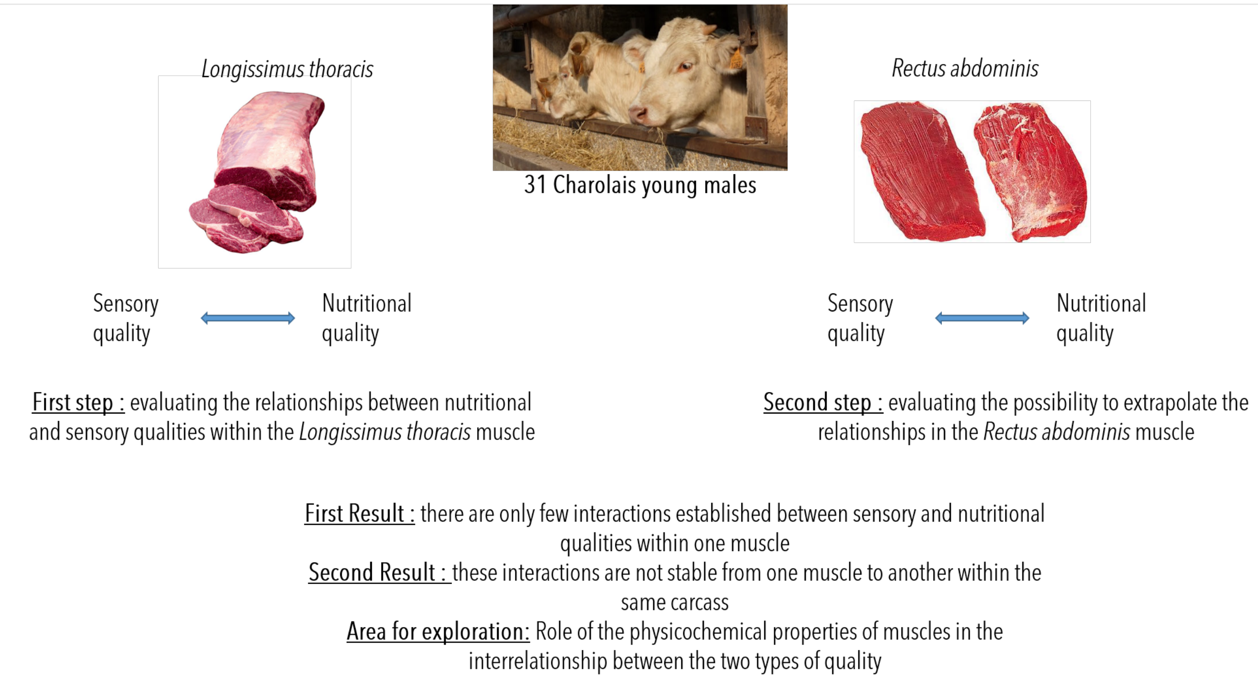
Graphical Abstract



Abstract

The sensory and nutritional qualities of meats are strong expectations for consumers. However, these two types of quality are sometimes difficult to achieve together and a trade-off is often necessary. Various studies try to establish this compromise on the Longissimus thoracis muscle, but it is not clear that the models established on this muscle can be extrapolated to other muscles.

Thus, the objective of our study was to evaluate the relationships between nutritional and sensory qualities within the Longissimus thoracis muscle and their extrapolation to the Rectus abdominis muscle on a population of 31 young Charolais cattle.

Various correlations were established between sensory and nutritional qualities in the Longissimus thoracis muscle, but there was practically no correlations between these two parameters in the Rectus abdominis muscle. The links between sensory quality and nutritional quality within a given muscle being quite tenuous, it seems impossible to extrapolate them to another muscle of the carcass. Moreover, when considering the integrative method of variable clustering, no cluster highlighted included both sensory descriptors and nutritional indicators. It is thus possible to conclude that 1) there was only few interactions established between sensory and nutritional qualities within one muscle, and 2) these interactions were not stable from one muscle to another within the same carcass.

Introduction

A large number of butcher muscles with various nutritional and sensory properties make up a cattle carcass. Depending on their muscular properties (and in particular their collagen content), these muscles can be intended for grilling, roasting, braising or even long cooking and are thus characterised by different sensory quality levels (Hocquette et al., 2014). If beef muscles have a relatively homogenous nutritional composition (at least for proteins and micronutrients), their content in lipids (ranging from 1-2% to around 15%) (Li, 2017; Normand et al., 2005) and in saturated fatty acids (someone being detrimental to human health) is variable (Bauchart and Gandemer, 2010; McAfee et al., 2010), and thus likely to contrary the consumer.

Indeed, if cconsumer's expectations are varied and growing (animal welfare, environment, agroecology, durability, ...) (Ellies-Oury et al., 2019; Hocquette et al., 2018; Verbeke et al., 2010a, 2010b), they also expect a certain homogeneity of meat sensory quality together with healthy meats of good nutritional quality (Ellies-Oury et al., 2019; Hocquette et al., 2018; Miller, 2020). However, it is well known that these two types of quality are not always easy to satisfy simultaneously (Conanec et al., 2019; Ellies-Oury et al., 2020) and that a trade-off has to be found to meet consumers' expectations.

Recent studies tried to evaluate the links between the nutritional and sensory qualities in order to establish this trade-off (Conanec et al., 2019; Ellies-Oury et al., 2016). But these models are generally carried out on the *Longissimus thoracis muscle* (LT), that is commonly considered as a reference. However, it is not certain that the relationships established on this muscle can be effectively extrapolated to the other muscles of the carcass. Indeed, in the light of various studies, it appears that the response laws and prediction models are not always extrapolable between experiments or between muscles within the same animal (Conanec et al., 2019, 2019; Ellies-Oury et al., 2020; Gagaoua et al., 2018; Hocquette et al., 2017; Soulat et al., 2016, 2018).

The purpose of this work was thus to determine whether the interactions established between sensory and nutritional qualities were stable from one muscle to another within the same carcass. If our hypothesis turns out to be true, it would then be possible to predict the properties of other muscles of the carcass by knowing the properties of one of them. To answer this hypothesis, two successive questions were proposed: 1) are there any links between sensory and nutritional qualities within a given muscle? 2) are these links transposable (at least in part) from one muscle to another within the same carcass?

To address this issue, the results of an experiment conducted at the INRAE and stored in the Unit's databases were used. It concerned 31 Charolais bulls for which the same properties were studied on both the *Longissimus thoracis* (LT) and the *Rectus abdominis* (RA) muscles.

Results and Discussion

Pearson correlations

According to the Table 2, numerous “significant” correlations (defined here as correlations with absolute values greater than 0.40) were established between the different sensory descriptors and the fatty acid composition of the LT muscle. According to Arshad et al., (2018), fat content was the major contributor to the flavor development in meat. The MQ score being obtained by linear correlation of different sensory descriptors, including flavor (which has a greater weight than the other descriptors in the MQ equation), it is therefore consistent that fat (which is highly correlated to flavor) was also a major contributor to MQ score. Fat content being positively linked to SFA proportions and negatively to PUFA ones, it appears logical that MQ and flavor scores were positively correlated with SFA proportions (including C16:0) and MUFA and negatively correlated with PUFA ones (including C18:3n-3).

In contrast, only few correlations were established between the different sensory descriptors and the fatty acid composition of the RA muscle. On the other hand, only few identical correlations between the two muscles were highlighted between the sensory descriptors and the nutritional quality variables:

- MQ was positively linked to % MUFA and negatively linked to % PUFA and % C18:3n-3

- Flavor was positively linked to % C16:0 and negatively linked to % C18:3n-3. The low part of the correlations established in the LD muscle also found in the RA muscle may be due to the metabolic specificities of the RA muscle. Indeed, it has previously been demonstrated in different studies (Oury et al., 2010) that the RA muscle has muscular physico-chemical properties very different from the other muscles of the carcass and in particular from the LT muscle. It is therefore conceivable that more of the relationships established in the LT muscle could be applicable in other muscles of the carcass (except for the RA muscle). Thus, it is now essential to evaluate in further analysis whether the relationships between the LT and other muscles of the carcasses are stable. In particular, this question could be addressed on the basis of the Semitendinosus, Semimembranosus or Triceps brachii muscles, which seem to have more homogeneous properties within animals. In the present work, the sensory evaluation scores were provided by a trained jury, which is commonly known to give repeatable results that do not necessarily reflect reality. On the contrary, consumer's evaluations are known to give less repeatable, but closer to the reality results. Thus, it may be interesting to verify the present conclusions in the future by integrating hedonic consumer evaluations and/or instrumental evaluations of the sensory quality of meat (shear force, juice losses, chromatography, etc.)

Table 1 | Properties of LT and RA muscles used to evaluate the relationships established between nutritional and sensory quality.

Variables evaluated to characterize the sensory quality of both muscles (psq=5)	Tenderness; Juiciness; Residue; Overall appreciation; Overall flavor; Meat Quality 4 (MQ)
Variables evaluated to characterize the nutritional quality of both muscle (pnq=28)	**Fatty acid composition expressed in content (g or mg / 100 g of muscle):** Total Fatty Acids (FA); Saturated FA (SFA) **Fatty acid composition expressed in proportions (% of total FA):** Saturated FA (SFA); Monounsaturated FA (MUFA); Polyunsaturated FA (PUFA); PUFA n-6; PUFA n-3; C16:0; C18:0; C18:1 n-9 cis; C18:1 n-9 trans; C18:1 n-11 cis ;C18:2 n-6 cis cis; C18:3 n-3; eicosapentaenoic acid (EPA); docosapentaenoic acid (DPA); conjugated Linoleic acid (CLA) **Ratios:** Unsaturated FA/SFA ; PUFA / SFA ; C16:0/C18:0 ; PUFA n-6 / PUFA n-3 ; C18:2 n-6 / C18:3 n-3

Table 2 | Significant correlations established between sensory and nutritional quality in both muscles.

	LT	RA
Tenderness	%C16:0 %C18:0	
MQ	Total Lipids, Total FA %SFA, %C16:0, **%MUFA**, %C18:1D9cis C16:0/C18:0 PUFA/SFA, C18:2n-6/C18:3n-3, %C18:0 **%PUFA**, %n-3PUFA, %n-6PUFA %C18:2 n-6 *cis cis*, **%C18:3n-3**, %EPA, %DPA	**%MUFA** **%PUFA**, **%C18:3n-3**
Juciness		%C18:3n-3
Flavor	Total FA %SFA, **%C16:0** %MUFA, %C18:2 n-9 *cis* C18:2n-6/C18:3n-3 %PUFA, %n-6PUFA, %n-3PUFA **%C18:3n-3**, % EPA, %DPA	**%C16:0** **%C18:3n-3**
Overall appreciation	%SFA, % C16:0, %MUFA, %C18:1 n-9 *cis* C18:2n-6/C18:3n-3 %n-6PUFA, %n-3PUFA %C18:3n-3, %DPA, %EPA, %C18:2 n-9 *cis cis*	

Only “significant” correlations, ie correlations with absolute values greater than 0.40, were reported. In green, the positive correlations; in blue, the negative ones; Underline and bold, the common correlations between muscles. The abbreviations used in this table have been explained in Table 1.

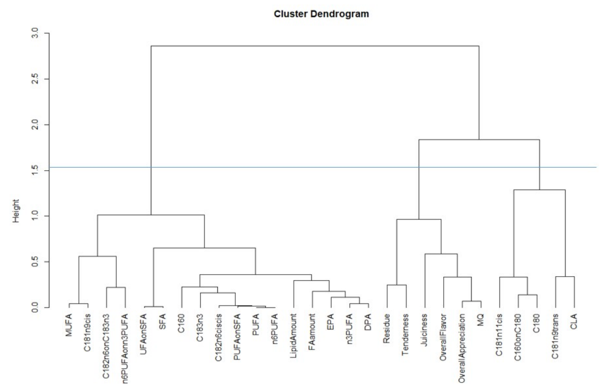
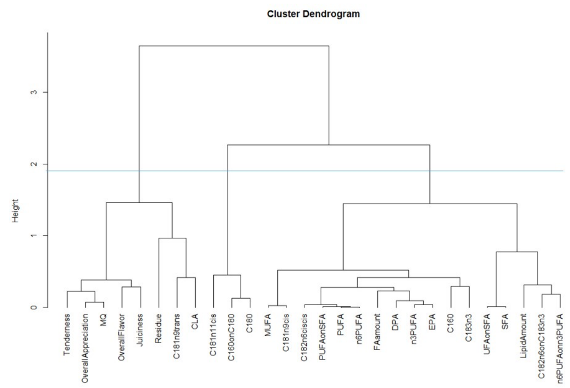
Clustering of Variables

The clustering of variables made it possible to group in 3 different clusters the nutritional and sensory variables of the LT (clusters LT1, LT2 and LT3) and, in the same way, the nutritional and sensory variables of the RA (clusters RA1, RA2 and RA3). A cluster of variables is defined as homogeneous when the variables in the cluster are strongly linked to a central quantitative synthetic variable also called the Synthetic Index. The increase of each of these Synthetic Index led to either an increase (for the variables indicated in green in the Table 3) or a decrease (for the variables indicated in red in the Table 3) of the variables that composed the cluster.

The clusters associated different variables that are commonly considered as linked together. This was the case for PUFA that are known to be negatively linked to lipid content and SFA proportions (Ellies-Oury et al., 2016; Wood et al., 2008), but also for sensory scores that are commonly positively related. Indeed, various authors indicated a strong association between tenderness, juiciness, flavor liking and overall liking from 0.63 to 0.99 when considering consumers evaluations (Pogorzelski et al., 2020; Polkinghorne et al., 2011; Thompson et al., 2008). O’Quinn et al., (2012) also showed that flavor liking was more strongly correlated with overall liking (r=0.88) than with tenderness (r=0.76) and juiciness (r=0.73). Another consistent conclusion by Hunt et al., (2014) illustrated that the overall liking was the most associated trait with flavor liking (r=0.85).

The three clusters established in the LT and in the RA muscles were practically the same, except for two variables (%CLA and %C18:1 n-9 trans) that changed cluster between one muscle and the other. However, in the RA muscle, these two variables were not really well represented in their cluster, as their square correlations were lower than 0.5. Thus, these variables were not used to interpret the RA1 cluster. For both muscles, the analysis showed that the two datasets (sensory quality / nutritional quality) were not associated with each other, and thus that sensory and nutritional qualities were not linked.

Table 3 | The three clusters of variables established in each muscle

Muscle LT	Muscle RA
	
Cluster LT1 **Residue** **MQ, Overall Appreciation, Tenderness, Overall Flavor, Juiciness**	Cluster RA1 **Residue** **MQ, Overall Appreciation, Tenderness, Overall Flavor, Juiciness**
Cluster LT2 **Lipid amount, FA amount,** **%SFA, % C16:0, %MUFA, %C18:1 n-9 cis** **PUFA/SFA, C18:2 n-6 / C18:3 n-3,** **UFA/SFA, n-6 PUFA / n-3 PUFA** **%PUFA, %n-6PUFA, %n-3PUFA** **%C18:2 n-6 cis cis, %C18 :3 n-3, %DPA, %EPA**	Cluster RA2 **Lipid amount, FA amount,** **%SFA, % C16:0, %MUFA, %C18:1 n-9 cis** **PUFA/SFA, C18:2 n-6 / C18:3 n-3,** **UFA/SFA, n-6 PUFA / n-3 PUFA** **%PUFA, %n-6PUFA, %n-3PUFA** **%C18:2 n-6 cis cis, %C18 :3 n-3, %DPA, %EPA**
Cluster LT3 **C16:0/C18:0, %C18:1 n-11 cis** **%C18:0**, %C18:1 n-9 trans, %CLA	Cluster RA3 **C16:0/C18:0, %C18:1 n-11 cis** **%C18:0**

In green, the positive correlations; in blue the negative ones; Underline and bold, the common correlations between muscles; Crossed out, the badly represented variables. The abbreviations used in this table have been explained in Table 1.

PERPECTIVES AND CONCLUSION

At the beginning of this work, we addressed two successive hypotheses: the first being that there are links between sensory quality and nutritional quality within a given muscle; and the second being that these links are transposable (at least in part) from one muscle to another within the same carcass. First, we were able to establish that there were many correlations between sensory and nutritional properties in the LT muscle, but only few in the RA one. When considering the integrative ClustOfVar method, it appears that none of established groups was constituted of variables from both quality types (neither in the LT muscle nor in the RA one). Therefore, the second hypothesis was, in fact, obsolete: the links within a muscle being non-existent, it is impossible to extrapolate them to another muscle of the carcass. The question that now arises is whether the muscular properties would be likely to induce nutritional / sensory gaps such that a model to weight the sensory and nutritional data according to the muscular properties could be built. Indeed, the muscular properties are known to be heterogonous among muscles as previously indicated by Listrat et al., (2020) and Oury et al., (2010). In the present experiment, for example, the LT muscles were characterized by significantly lower proportions of MyHC IIb (glycolytic myosin isoforms) and MyHC I (oxidative myosin isoforms) than in the RA muscle (4.1 vs. 23.9% and 24.9 vs. 30.4% respectively), compensated by higher proportions of MyHC IIa oxidoglycolytic fibers (62.0 vs. 45.7%) (Data not shown). In addition, LT muscle is characterized by lower levels of total collagen (3.9 vs. 6.2 µg OH-proline/mg dry mater) compared to RA muscle, while the solubility of the latter is equivalent between the two muscles (59.1%) (Data not shown). According to the literature, the role of total and insoluble collagen, cross-links, and type IIB + X and IIA muscle fibers is muscle dependent with respect to sensitivity (Listrat et al., 2020). Moreover, it has previously been indicated that the nutritional quality of striated muscle is depending of fiber type repartition. Thus, to test the hypothesis that the muscular properties would be likely to induce nutritional / sensory gaps, a consequent number of muscle data would be necessary, on a set of animals presenting muscles with heterogeneous properties in order to scan a large variability of situations.

Experimental Procedures

All the experimental procedures performed in this study were approved by the Animal Ethics Committee of INRA-CIRAD-IFREMER (APAFIS#1765-2015091516305 V3).

Animal's management and slaughtering

A total of 31 young Charolais bulls (313 ± 29.5 days old, mean live weight 482 ± 25.8 kg) were given individually for 6 months a basal diet consisting in 60% roughage (40% of corn silage and 20% of grass silage) and 40% of concentrate (Herbipole, INRAE, 2018). After 24 hours of food deprivation, animals were slaughtered in the experimental abattoir of the INRAE Research Centre, under standard conditions and in compliance with French welfare regulations. Animals were slaughtered at the same body weight (736 ± 39.5 kg). The carcasses were not electrically stimulated. They were chilled and stored at 4°C until 24 h post-mortem. Samples of the *Longissimus thoracis* (LT) and *Rectus abdominis* (RA) muscles were collected one day after the slaughter.

Sensory analysis

Samples of for sensory evaluation were cut into steaks, vacuum packed and kept at 4°C for ageing (14 days). Each sample was then frozen and stored at -20°C awaiting sensory evaluation.

Sensory analyses were done at INRAE "Le Magneraud" station. After 14 days of ageing, each sample was thawed at 4°C over 24 hours. The meat samples were cut into 1.5 thick steaks and grilled under domestic grills between 2 aluminum sheets, until the end-point temperature in the geometric center of the steak reached 55°C (typical in France). After grilling, each steak was cut into portions that were immediately presented to 12 panelists trained for beef meat sensory analysis. Each sample was rated between 0 to 10 on an unstructured scale for the following attributes: tenderness, juiciness, overall appreciation, overall flavor and residues. The score 0 represented a very low rating of the descriptor (extremely tough, very dry, ...) as opposed to the score 10 which corresponds to a very high rating (extremely tender, extremely juicy, ...).

At each sensory session, the 12 panelists evaluated 6 samples of the same muscle, randomly selected. The expert panelists were trained in accordance with the ISO standards ISO/TC as described by Gagaoua et al. (2016). The sessions were carried out in a sensory analysis room equipped with individual booths under artificial red light, to reduce the influence of the samples appearance. Each tasting booth was equipped with computer terminal linked to a fileserver running a sensory software (Fizz, version 2.20h; Biosystemes, Couternon, France) that facilitated the direct entry of assessor ratings. To complete the sensory evaluation, the Australian Meat Quality Score (MQ) created by combining tenderness, juiciness, flavor liking and overall liking scores was calculated according to the weightings for these four sensory traits previously about 0.3, 0.1, 0.3 and 0.3, respectively (Thompson et al., 2010). Indeed according to Miller (Miller et al., 2020), prior to the 1990s, tenderness was the most prevalent quality trait, which can be used as the main assessment criteria for both beef producers and consumers. In the last two decades, because of the improvement in tenderness and its reduction in variability, flavor liking has become the most important driving factor to beef overall liking. The variables composing sensory quality are reported in the Table 1.

Fatty acids composition

A part of the samples was cut into pieces (around 0.5 cm cross-section), ground into fine and homogeneous powder in liquid nitrogen with a mixer mill (Retch MM 301, Hann Germany) and stored at -80°C until analyses for intramuscular fat content and fatty acid composition. Samples for one analysis were always taken at the same anatomical position from on animal tothe other.

Total lipids of LT and RA muscles were extracted according to Folch et al. (1957) and quantified by gravimetry. LT and RA muscles were characterized by similar intramuscular lipid contents (2.7 ± 1.4 g / 100g of muscle). The FAs were extracted from total lipids and then converted into methyl esters by transmethylation using borontrifluoride-methanol (14% solution) according the method of Bauchart et al. (2005). Fatty acid methyl ester analysis was performed by GLC using a Peri 2100 chromatography system (Perichrom, Saulx-les-Chartreux, France) fitted with a CP-Sil 88 glass capillary column (Varian, Palo Alto, CA; length 100 m, dia. 0.25 mm) as previously described by Gruffat et al. (2020). The carrier gas was H2, and the oven and flame ionization detector temperatures were as follows: oven temperature was programmed for 70°C for 30 s, 70 to 175°C at a rate of 20°C/min, 175°C for 25 min, then 175 to 215°C at a rate of 10°C/min, and finally 215°C for 41 min; injector and detector temperatures were 235 and 250°C, respectively. Total FAs were quantified using 19:0 as an internal standard. Their identification and the calculation of the response coefficients were done using a C4-C24 quantitative mix (Supelco, Bellafonte, PA).

The variables composing nutritional quality are reported in the Table 1.

Statistical analysis

First of all, in order to identify the intra-muscle links between sensory descriptors and fatty acid composition, Pearson correlations between numerical variables within the same muscle (R software) were studied. Then, to determine whether the proximities observed between sensory and nutritional qualities within a muscle can be scaled up through muscles, we applied the *ClustOfVar* (clustering of variables) (Chavent et al., 2011; Ellies-Oury et al., 2016) approach to LT and RA muscles The number of clusters was determined by bootstrap and validated by the "stability" of the obtained partition. The results obtained for the LT muscle were compared to those obtained for the RA muscle to highlight comparable results between muscles within the same carcass.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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