Using recursive mixed models to evaluate the relationships between meat quality traits of M. *flexor digitorum and* M. *psoas major*

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Introduction

The perception of the quality is an important factor, related to an increase in the value of beef cuts (Hildrum et al., 2009). Tenderness, flavor and juiciness were ranked as the three most important meat quality traits by consumers (Huffman, 1996). However, the assessment of meat quality by sensory evaluations on a large scale is expensive and there is a potential measurement error (Gill et al., 2010). For that reason, some studies have investigated the relationships between sensory and instrumental traits. Warner-Bratzler shear force (WBS) has been reported to be negatively correlated with tenderness (Caine et al., 2003; Destefanis et al., 2008), differing the magnitude of the correlation regarding the muscles investigated. Collagen content has also been related to meat tenderness. Lepetit (2008) reviewed the collagen contribution to meat toughness, indicating that the number of cross-linked chains per volume of meat explains a large amount of the tenderness variation, depending on muscle type, animal age and sex. Undesirable water holding capacity (WHC) of meat, defined as the ability to hold all or part of its own and/or added water (te Pas et al., 2004), produces negative consequences to the quality of the meat, such as a decrease in juiciness, an increase in drip losses and microbial effects (Huff-Lonergan and Lonergan, 2005). This ability depends on many factors, as physical or biochemical factors, including genetic or steric effects, and the postmortem proteolysis, which is affected by the calpain system, the calpastatin and the protein oxidation (see Huff-Lonergan and Lonergan, 2005 for more details). The rate and extent of pH decline has been reported as a key factor, together with the structure of the muscle and the muscle cell itself (Huff-Lonergan and Lonergan, 2007).

Some previous studies have investigated the relationships between meat quality traits through correlations, but to our knowledge, none has applied recursive models (Gianola and Sorensen, 2004; Wright, 1921), more appropriate to analyze the cause-effect relationship between those traits. The aim of this study was to investigate and quantify the relationships between some meat quality traits associated to the tenderness and juiciness and muscle characteristics of M. *flexor digitorum* (FD) and M. *psoas major* (PM); two muscles with largely different functions, compositions, which support two cuts of different monetary value, in bovine.

Material and methods

Data

Samples of FD and PM muscles were taken from 712 male calves of Avileña Negra- Ibérica, a Spanish local breed linked to the EU quality label 'Carne de Ávila'. Calves were reared under local and extensive production systems, and started to be fattened at 5-8 months of age in 17 fattening places, with common feeding regimes controlled by the quality assurance

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scheme ”Consejo Regulador de Carne de Ávila”. After the fattening period, calves were transported to commercial EU-licensed abattoirs, slaughtered and dressed according to commercial practices. After the carcasses were chilled for 24 hr, samples of FD and PM muscles were taken in 400 out of the 712 animals, whereas in the remaining 312 only FD was sampled. Muscles were vacuum-packed and aged 7 days at 4ºC. Samples were stored at -20ºC± 2ºC until further analyses were performed. In this study, relationships among pH, thawing losses (TL), cooking losses (CL), collagen (COL), Warner-Bratzler shear force (WBS) and intramuscular fat (IMF) were analyzed. The pH was measured at 7 d postmortem using a pH meter Crison/MicropH 2002. In order to obtain a representative pH measurement, three readings were taken at different positions within each sample, and then the average was computed. TL were calculated as the difference (%) between initial and thawed weights, and cooking losses CL were determined following the method described by Honikel (1998). CL were expressed as the percentages of loss related to the initial weight. IMF and COL contents were estimated with an Infratec 1265 Meat Analyser. Thirty transmittance measurements were taken from 200 g of homogenized sample, placed on a tray, and then, the average was computed for each measurement (Josemaría-Bastida et al., 1999).WBS, measured as the maximum force (kg), was evaluated in 3 manually prepared strips of cooked meat of a 1 cm^2 cross section and 3 to 4 cm in length, with fibres perpendicular to the direction of the blade attached to an Aname TA-XT2 texturometer (Honikel, 1998).

Statistical models

To account for the residual heterogeneity of COL, CL, TL, WBS and IMF phenotypes regarding the muscle and to simplify the computations (unpublished results), the phenotypes of those traits were standardized by the residual variance regarding the muscle. Based on the relationships between ‘standardized’ traits (see Figure 1), different relationships between the meat quality traits depending on the muscle were allowed in each model. Two bivariate recursive mixed models were considered to study the relationships between pH and TL/CL in each muscle. It was hypothesized that the pH affects linearly to the losses within each muscle. The mathematical expression of those models is:

$$\begin{cases} \mathbf{y}_{pH} = \mathbf{X}\mathbf{b}_{pH} + \mathbf{Z}_p\mathbf{p}_{pH} + \mathbf{Z}_u\mathbf{u}_{pH} + \mathbf{e}_{pH} \\ \mathbf{y}_{TL/CL} = I(m=FD)\lambda_{TL/CL\leftarrow pH(FD)}\mathbf{y}_{pH(FD)} + I(m=PM)\lambda_{TL/CL\leftarrow pH(PM)}\mathbf{y}_{pH(PM)} \\ \qquad + \mathbf{X}\mathbf{b}_{TL/CL} + \mathbf{Z}_p\mathbf{p}_{TL/CL} + \mathbf{Z}_u\mathbf{u}_{TL/CL} + \mathbf{e}_{TL/CL} \end{cases}$$

The relationships between collagen/IMF and WBS were modeled with a trivariate recursive mixed model, assuming that both collagen and IMF linearly affect WBS within muscle, as follows:

$$\begin{cases} \mathbf{y}_{collagen} = \mathbf{X}\mathbf{b}_{collagen} + \mathbf{Z}_p\mathbf{p}_{collagen} + \mathbf{Z}_u\mathbf{u}_{collagen} + \mathbf{e}_{collagen} \\ \mathbf{y}_{IMF} = \mathbf{X}\mathbf{b}_{IMF} + \mathbf{Z}_p\mathbf{p}_{IMF} + \mathbf{Z}_u\mathbf{u}_{IMF} + \mathbf{e}_{IMF} \\ \quad \mathbf{y}_{WBS} = I(m=FD)\lambda_{WBS\leftarrow collagen(FD)}\mathbf{y}_{collagen(FD)} + I(m=PM)\lambda_{WBS\leftarrow collagen(PM)}\mathbf{y}_{collagen(PM)} \\ + I(m=FD)\lambda_{WBS\leftarrow IMF(FD)}\mathbf{y}_{IMF(FD)} + I(m=PM)\lambda_{WBS\leftarrow IMF(PM)}\mathbf{y}_{IMF(PM)} + \mathbf{X}\mathbf{b}_{WBS} + \mathbf{Z}_p\mathbf{p}_{WBS} + \mathbf{Z}_u\mathbf{u}_{WBS} + \mathbf{e}_{WBS} \end{cases}$$

Above, $\mathbf{y}_i$ (i=pH, CL, TL, collagen, WBS and IMF) corresponds to the vector of phenotypes; $\mathbf{b}_i$, $\mathbf{p}_i$, $\mathbf{u}_i$ and $\mathbf{e}_i$ are the vectors of systematic, permanent environmental, genetic, and residual effects; $\lambda_{j\leftarrow i(m)}$ corresponds to the structural coefficient relating trait i to the trait j in the muscle m; and $I(m)$ is an indicator variable, taking the value of 1 if the muscle is equal to *FD* or *PM*, and 0 otherwise. The same, although with different number of levels, systematic (combination between year and fattening place, length of fattening period, slaughter age, muscle, slaughter season and slaughterhouse), genetic and permanent environmental effects were considered for all traits. Bayesian methodology *via* McMC methods was implemented in this study to obtain the posterior distributions of the parameters of interest. Improper priors were assumed for the dispersion parameters and systematic effects. Genetic, permanent and residual effects were assumed to be distributed as follows ($\mathbf{u}_i|\mathbf{G} \sim MVN(\mathbf{0}, \mathbf{G} \otimes \mathbf{A})$, $\mathbf{p}_i|\mathbf{P} \sim MVN(\mathbf{0}, \mathbf{P} \otimes \mathbf{I})$ and $\mathbf{e}_i|\mathbf{R} \sim MVN(\mathbf{0}, \mathbf{R} \otimes \mathbf{I})$). To avoid identification problems, $\mathbf{R}$ was assumed to be diagonal, and $\sigma^2_{e_i}$ was assumed to follow a χ^{-2} distribution. Fully conditional distributions for location effects were multivariate normal, and inverted Wishart and χ^{-2} distributions for dispersion parameters.

Results and discussion

Table 1 shows the posterior means (standard deviations) of the structural coefficients. The pH affected negatively TL (*i. e.*, the effect was positive in terms of meat quality) in both muscles, as reported by Huff-Lonergan and Lonergan (2005), although in a different magnitude (with a probability of 95%). Thus, an increment of pH reduced the TL 2.75% in PM whereas in FD the reduction was smaller (1.76%). Differences between WHC among muscles have been related to differences in postmortem degradation of intermediate filament proteins like desmin and rate of activation/autolysis of μ-calpain, which may be affected by pH decline (Kristensen and Purslow, 2001; Melody et al., 2004). However, no effect was found between pH and CL in any of the two muscles. A possible reason could be that most of the water was lost during the thawing process. WBS was affected by IMF and/or COL depending on the muscle. COL had a positive effect on WBS in FD but did not have any effect in PM. On the contrary, IMF affected negatively the WBS in PM and did not have any effect on WBS of FD. The different effect of COL and IMF on WBS depending on the muscle can be explained by the difference in COL and IMF contents existing among them. A previous study (non published results) showed that FD had a 2.10% more COL than PM and the latter had a 1.62% higher IMF content than FD.

Posterior distributions of genetic correlations were wide and almost comprising the whole parametric space, except those between IMF and collagen content in both muscles with a posterior mean of -0.72, and high probability of being negative, (Pr<0)>0.95. The lack of studies investigating the genetic relationships between meat quality traits makes difficult to compare this result.

Conclusions

This study shows that the cause-effect relationships between meat quality indicator traits and muscle characteristics differ between them. This reflects the problem of using a muscle type as reference in evaluating the quality of whole carcass and the complexity of mechanisms responsible of specific muscle quality attributes.

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Figure 1. Scatter plots of the relationships between pH and thawing/cooking losses, and collagen and intramuscular fat percentages and the Warner-Bratzler shear force, all of them corrected by residual heterogeneity regarding the muscle.

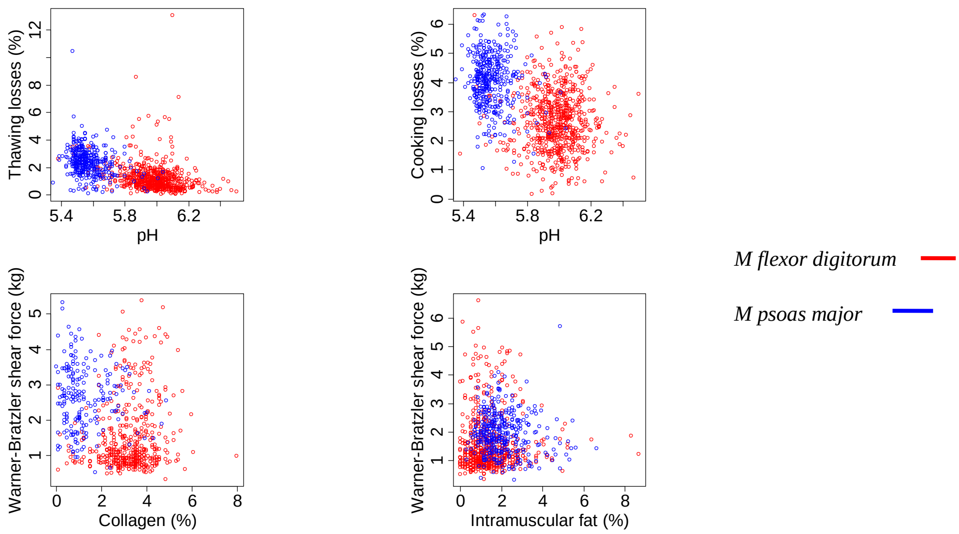

Table 1. Posterior means (standard deviations) of the structural coefficients

	$\lambda_{TL\leftarrow pH}$	$\lambda_{CL\leftarrow pH}$	$\lambda_{WBS\leftarrow collagen}$	$\lambda_{WBS\leftarrow IMF}$
M flexor digitorum	-1.76 (0.44)***	-0.17 (0.43)	0.11 (0.06)**	-0.00 (0.08)
M psoas major	-2.75 (0.56)***	-0.65 (0.59)	-0.02 (0.08)	-0.15 (0.06)***

***: (*Pr*>0)>0.99; **: 0.95< (*Pr* >0) <0.99