



Title	Essential and toxic trace element concentrations in different commercial veal cuts in Spain
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Publication date	2016-11
Publication information	López-Alonso, Marta, Marta Miranda, José Luis Benedito, Victor Pereira, and Marco García-Vaquero. "Essential and Toxic Trace Element Concentrations in Different Commercial Veal Cuts in Spain." Elsevier, November 2016. https://doi.org/10.1016/j.meatsci.2016.05.013 .
Publisher	Elsevier
Item record/more information	http://hdl.handle.net/10197/8232
Publisher's statement	This is the author's version of a work that was accepted for publication in Meat Science. Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in Meat Science (VOL 121, ISSUE 2016, (2016)) DOI: 10.1016/j.meatsci.2016.05.013.
Publisher's version (DOI)	10.1016/j.meatsci.2016.05.013

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1 **Essential and toxic trace element concentrations in different commercial veal cuts in**
 2 **Spain**

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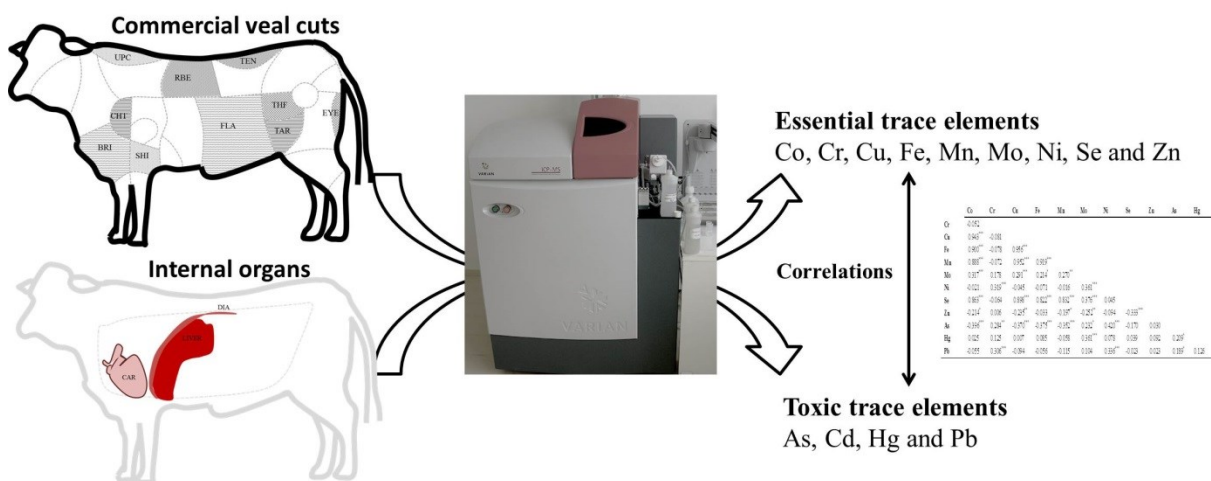
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14 **Keywords:** meat and muscle, cattle and beef, Galician Supreme Veal, essential and toxic
 15 metals.

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20 **Abstract**

21 The aim of this study was to evaluate essential and toxic element concentration of ten
22 commercially available veal cuts, together with diaphragm, cardiac muscle and liver tissue
23 from 10 animals of “Galician Supreme Veal”. Essential trace elements (Co, Cr, Cu, Fe, Mn,
24 Mo, Ni, Se and Zn) and toxic elements (As, Cd, Hg and Pb) were determined by ICP-MS.
25 Essential trace element concentrations ranged from 0.002-55.64 mg/kg between muscles.
26 Toxic element concentrations were very low, and high numbers of samples showed
27 unquantifiable residues of Cd and Pb. Veal cuts including muscles with a high proportion of
28 oxidative slow-twitch fibers (diaphragm and cardiac muscle) showed significantly higher
29 essential trace element concentrations, the lower concentrations being found in veal cuts
30 including glycolytic fast-twitch fibers (eye round). Our results suggest that essential and toxic
31 trace element concentration could be used as a new meat quality parameter, or to add further
32 value to certain products (i.e. livestock reared on extensive systems with high physical
33 activity).

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45 **1. Introduction**

46 Meat is an important component of dietary consumption patterns in today's society, with beef
47 and cattle products accounting for a significant portion of the global food market.
48 Consumption rates in Europe were estimated to be over 10.5 kg of beef and cattle meat per
49 capita in 2014 (<https://data.oecd.org/agroutput/meat-consumption.htm>). Meat and meat
50 products for human consumption have been traditionally evaluated in terms of their
51 proximate macronutrient composition (i.e. moisture, protein and fat contents). Recently, other
52 characteristics such as the fatty acid profiling of meat from different animal species (Enser et
53 al., 1998; Morán et al., 2013; Waszkiewicz-Robak et al., 2015), vitamin composition (i.e.
54 B12) (Szterk, Roszko, Małek, Czerwonka, & Waszkiewicz-Robak, 2012) as well as essential
55 and toxic trace element concentration have gained increased attention due to variation related
56 to factors such as breed, the age of the animal, feeding practices and geographical conditions
57 amongst others (Czerwonka & Szterk, 2015). The accumulation of trace elements is
58 important from a toxicological point of view and lead the European Union to set up
59 maximum limits for certain toxic elements in foodstuff for human consumption (Commission
60 Regulation (EC), No 1881/2006).

61 To date, studies investigating essential and toxic element concentrations in different animal
62 species have primarily analyzed samples from the liver and kidney, focusing on the
63 relationship between concentrations found in these organs and the health and mineral status
64 of the animals under different production systems (Tomović et al., 2011) or experimental
65 conditions (García-Vaquero, Miranda, Benedito, Blanco-Penedo, & López-Alonso, 2011).
66 The accumulation patterns of trace elements were also described within these organs,
67 analyzing differences in metal accumulation between the medulla and cortex in the kidney
68 (Olsson & Oskarsson, 2001), different accumulation in the lobules in the liver (Miranda et al.,

69 2010) and histological differences due to variation at hepatic cellular and sub-cellular levels
70 (Garcia-Vaquero, Benedito, Lopez-Alonso, & Miranda, 2012).

71 There is a notable absence of research investigating essential and toxic trace element
72 accumulation in muscle tissue, the current research is limited to a range of commercial cuts
73 (Czerwonka & Szterk, 2015; Dermauw et al., 2014; García-Vaquero, Miranda, Benedito, et
74 al., 2011; McGilchrist, Greenwood, Pethick, & Gardner, 2016) and non-specified muscular
75 tissue in other instances (Abou-Arab, 2001; Sedki, Lekouch, Gamon, & Pineau, 2003).
76 Recent studies report metal accumulation in treated meat, such as smoked meat (Mitić,
77 Stojković, Pavlović, Tošić, & Mitić, 2012) and other meat products such as sausages and
78 hamburgers (Abedi, Ferdousi, Eskandari, Seyyedahmadian, & Khaksar, 2011; González-
79 Weller et al., 2006).

80 This study seeks to investigate essential and toxic trace element concentrations in order to
81 develop a complete trace element distribution profile of different commercial cuts of veal,
82 representative of the beef carcass and patterns of human consumption in Spain and many
83 other countries.

84 **2. Material and methods**

85 **2.1. Experimental design and sample collection**

86 For this study veal samples from ten male Galician blond calves from Lugo (Galicia, Spain)
87 were selected. Animals were raised under the regulations of the protected geographical
88 indication (PGI) of “Galician Veal” and its meat was certified and labelled as “Supreme
89 Galician Veal” category. “Galician veal” was selected for being one of the main meat
90 production systems in our region and due to its high presence in the national market, with
91 more than 50% of the PGI meat commercialized in Spain certified as “Galician Veal” in the
92 year 2014 (http://www.terneragallega.com/pdf/informe_castellano.pdf). Basically, in this

93 production system calves are suckled on their mothers until slaughter and the diet of the
94 mother is based on local pasture that could be supplemented with fresh forage and grain-
95 based authorized concentrate (Council Regulation (EC), No 510/2006 ; Commission
96 Regulation (EC), No. 2400/1996; Regulation, (EU) 2015/1393).

97 Samples were collected at slaughter when calves were approximately 9 months old and
98 242±7 kg carcass weight. Ten muscle cuts were taken from each animal, being representative
99 of the different commercial categories (extra, first A, first B, second and third categories) in
100 Spain (Sañudo & Campo, 1998) (see Fig. 1). The commercial veal cuts selected for this study
101 (rib boneless entrecote (RBE), tenderloin (TEN), eye round (EYE), thick flank (THF), tail of
102 rump (TAR), chuck tender (CHT), shin (SHI), upper chunk (UPC), flank (FLA) and brisket
103 (BRI) are represented in Fig. 1. The muscular fibres constituting the different commercial
104 veal cuts selected are summarized in table 1. In addition, based on previous trace element
105 accumulation studies in calves (Gutiérrez, 2009), samples of diaphragm (DIA) and cardiac
106 muscles (CAR), as well as liver - one of the main target organs of trace element accumulation
107 and mineral status of the animals (Nwude, Okoye, & Babayemi, 2011) - were collected.

108 All samples of approximately 100 g were collected immediately after slaughter, packed
109 individually and refrigerated at 4-6°C for 2 hours until further processing in the laboratory
110 and then stored at - 18°C for further analysis.

111 **2.2. Chemicals**

112 The following chemicals were purchased for trace element determination of the muscular
113 samples: concentrated nitric acid (65%, Suprapur grade, Merck), hydrogen peroxide (30 %
114 p/v, Sigma-Aldrich) and certified reference material (Standard Reference Material® 1577c
115 Bovine Liver, National Institute of Standards & Technology, USA). Ultra-pure water of
116 resistivity 18 MΩ cm was obtained from a Milli-Q® Plus model (Millipore Co.).

117 **2.3. Sample analysis**

118 Tissue samples of approximately 1 g were digested with nitric acid and hydrogen peroxide in
119 a microwave digestion system (Milestone Ethos Plus) and diluted to 15 mL with ultrapure
120 water following the protocol previously described by García-Vaquero, Miranda, López-
121 Alonso, Castillo, and Benedito (2011). The concentrations of essential (cobalt (Co),
122 chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni),
123 selenium (Se) and zinc (Zn)) and toxic (arsenic (As), cadmium (Cd), lead (Pb) and mercury
124 (Hg)) trace elements were determined by inductively coupled plasma mass spectrometry
125 (ICP-MS; VGElemental PlasmaQuad SOption) under the following previously established
126 operational conditions (Gutiérrez, 2009). Briefly, the main analytical parameters consisted on
127 RF power 1.35 kW, plasma flow rate of 14 mL/min, auxiliary gas flow rate 1 mL/min,
128 nebulizer gas flow 0.8 mL/min and 3 readings/replicates.

129 **2.4. Analytical quality control**

130 An analytical quality control was applied throughout the study. Blanks and certified reference
131 material were run alongside samples. Blank values were subtracted from all sample readings
132 and the limits of detection were calculated as three times the standard deviation of the reagent
133 blanks and were based on the mean sample weight analyzed. Non-detectable (ND)
134 concentrations were assigned a value of half the quantification limit. Analytical recoveries
135 were determined from certified reference material (Standard Reference Material® 1577c
136 Bovine Liver, National Institute of Standards & Technology, USA). There was a good
137 agreement between the measured and the certified values (table 2).

138 **2.5. Statistical analysis**

139 All statistical analyses were done in SPSS (v. 20). Normality and equality of variances of the
140 data were analyzed using Kolmogorov-Smirnov and Levene tests respectively and data was
141 logarithmically transformed. One way Anova tests were used to check for differences in
142 essential and toxic trace element concentrations amongst the different muscle samples

143 analysed and post-hoc DHS Tukey tests when needed. Associations between pairs of
144 essential and toxic trace element concentrations in the different muscle samples were
145 evaluated by Spearman correlation analysis. Statistical treatments were not performed in the
146 case of Cd and Pb due to the high number of muscle samples with residues under the
147 detection limit of the method.

148 **3. Results and discussion**

149 Essential trace element concentration (expressed as average \pm standard deviation of the mean
150 on a wet weight basis (wt.w.)) in the liver (as the main indicator of trace mineral status) of
151 calves in this study (see table 3) were within the adequate ranges Puls (1994). Toxic metal
152 accumulation in the liver (As: 2.71 ± 0.27 $\mu\text{g/Kg}$; Cd: 7.88 ± 0.80 $\mu\text{g/Kg}$; Hg: 1.53 ± 0.05 $\mu\text{g/Kg}$
153 and Pb: 6.45 ± 1.14 $\mu\text{g/Kg}$) was low, similar to that found in other non-polluted agricultural
154 areas worldwide (García-Vaquero, López-Alonso, et al., 2011; Nriagu et al., 2009; Yabe et
155 al., 2012). Thus, it is unlikely that trace element deficiencies and/or metal interactions, as
156 well as toxic effects resulting from excessive toxic and trace element accumulation are
157 affecting animals of this study.

158 Essential trace element concentrations in the different veal cuts, diaphragm and cardiac
159 muscles analysed in our study are presented in table 3. Little information exists in the
160 literature on trace element concentration for specific veal cuts (García-Vaquero, Miranda,
161 Benedito, et al., 2011; McGilchrist et al., 2016; Tomović et al., 2011). Overall, trace element
162 concentrations in veal in our study are within the adequate range of muscle in cattle (in
163 parenthesis adequate ranges (expressed as wt.w.) according to Puls (1994) for Fe (9-21
164 mg/kg), Se (0.07-0.15 mg/kg) and Zn (20-70 mg/kg); however, no information is given in
165 Puls (1994) for Co and Mo concentrations in muscle, and for Cr (100-200 $\mu\text{g/kg}$), Cu (1.2-1.5
166 mg/kg), Mn (0.5-0.9 mg/kg) and Ni (350-400 $\mu\text{g/kg}$) concentrations measured in our study
167 are below the adequate ranges. Nevertheless, it should be noted that no information is given

168 on how these ranges were determined and only in the case of Zn levels of 20-30 and 70
169 mg/kg wet weight, were these explicated for light and dark fibre muscles respectively. The
170 trace elements from the adequate ranges in this study, noted above, were those that
171 demonstrated the largest ranges (Cu and Mn) and those lacking empirical explanation within
172 the current literature (Cr and Ni). Overall, the mean trace element concentrations in the
173 muscles investigated for this study were similar to those previously reported (Abou-Arab,
174 2001; Gawdaman, Sudha, & Pal; McGilchrist et al., 2016; Nwude, Okoye, & Babayemi,
175 2010; Tomović et al., 2011), although a comprehensive comparison cannot be made for most
176 veal cuts due to disparities related to muscle cuts, age, sex and production systems of the
177 animals in different studies. When compared with the data cumulated in the course of this
178 project, from samples obtained in our region, the trace element concentration observed was
179 consistent with the analysis of muscle pieces in other instances (García-Vaquero, Miranda,
180 Benedito, et al., 2011; Gutiérrez, 2009).

181 When evaluating trace element concentrations in detail, across the array of veal cuts assessed
182 in our study, statistically significant differences between types of muscles were observed for
183 Co, Cu, Fe, Mn, Se and Zn; elements that play a vital role in muscular metabolism (table 3).
184 No relationship could be established between trace element concentrations and commercial
185 categories. However, with the exception of Zn, certain accumulation patterns were
186 appreciated: the highest trace element concentrations were found in the cardiac muscle
187 (CAR) —up to ca. 3-fold most other veal cuts ($p < 0.001$)—followed by diaphragm muscle
188 (DIA)—that also showed statistically significantly higher levels of Cu, Fe and Mn than the
189 rest of the muscle sample—whereas the lowest concentrations were found in the eye round
190 (EYE) (except for Se). This trace element distribution pattern across the carcass seems to be
191 related to the predominant metabolic and contractile activities of the muscles (Talmant,
192 Monin, Briand, Dadet, & Briand, 1986). Trace element concentrations are higher in muscles

193 with a predominance of oxidative slow-twitch fibers or red fibers (Czerwonka & Szterk,
194 2015), cardiac muscle, masseter and diaphragm represent the best examples in the bovine
195 carcass (Talmant et al., 1986). Slow-twitch muscular fibers contain higher levels of
196 mitochondrial enzymes, myoglobin and iron-containing cytochrome to support an enhanced
197 aerobic metabolic capacity (Choi & Kim, 2009). In contrast to this, trace element
198 concentrations are low in muscles with a high proportion of glycolytic fast-twitch fibers,
199 *Semitendinosus* included in the eye round (EYE) are characteristic of this in the bovine
200 carcass (Talmant et al., 1986). Other veal cuts including predominantly glycolytic muscles
201 according to Talmant et al. (1986) that show low trace element concentrations in our study
202 are tenderloin (*Psoas mayor*), flank (*Rectus abdominalis*), tail of rump (*Tensior fasciae latae*)
203 and brisket (*Pectoralis profundus*).

204 Meat quality was traditionally defined by its compositional quality (mainly fat and protein)
205 and palatability factors (i.e. visual appearance, smell, firmness, juiciness, tenderness, and
206 flavor) (FAO, 2014). Branding, differentiation by healthiness and by process characteristics
207 (organic production and animal welfare), are contemplated as new possibilities for the
208 development of competitive meat products (Grunert, Bredahl, & Brunsø, 2004). The results
209 of essential trace elements of the present study could be used to add further value to non-
210 competitive meat cuts (i.e. diaphragm and cardiac muscle could be marketed as a source of
211 essential trace elements to population segments suffering trace elements deficiencies) or
212 production systems (i.e. certain livestock breeds reared on extensive systems with high
213 degree of physical activity could show differences in essential trace element profile in the
214 carcass).

215 Toxic element residues in veal cuts in our study are presented in table 4. Overall metal
216 concentrations were very low and a high proportion of samples had unquantifiable residues
217 (especially of Cd and Pb, 92 and 73% respectively), while the remainder had concentrations

218 very close to the detection limit. These results were similar to or lower than to previous
219 studies on trace element accumulation in meat, both in- and out-side our region (Falandysz,
220 1993; García-Vaquero, Miranda, Benedito, et al., 2011; Gawdaman et al.; González-Weller et
221 al., 2006; Tomović et al., 2011) and none of the muscle samples exceeded the maximum
222 admissible levels established by the European Commission for meat products (0.05 mg Cd/kg
223 and 0.1 mg Pb/kg wt.w.; (Commission Regulation (EC), No 1881/2006; Commission
224 Regulation (EU), No 488/2014). In the case of As, the European Union has no legal limits in
225 meat products, although recently the European Food Safety Authority (EFSA) was asked to
226 prepare a scientific briefing on human health risks related to the presence of As in foodstuffs
227 (Commission Recommendation (EU), 2015/1381). When analysing toxic element
228 accumulation within the different veal cuts, it was observed that, unlike essential trace
229 element concentrations, the lowest As residues ($p < 0.01$) were found in the cardiac muscle
230 whereas the highest residues were measured in veal cuts including muscles with a high
231 proportion of glycolytic fast-twitch fibers. These results are consistent with previous findings
232 (García-Vaquero, Miranda, Benedito, et al., 2011) and could suggest that muscles with higher
233 metabolic activity could have a greater capacity for toxic metal detoxification.

234 When evaluating the associations between trace elements in the different veal cuts in our
235 study (table 5) strong relationships ($r_s > 0.5$, $p < 0.001$ in all cases) were found between the
236 essential elements that showed a common intermuscular distribution pattern (such as Cu, Fe,
237 Mn and Zn). I.e. a strong association between Cu and Fe concentrations in the different
238 samples analysed in this study is shown in Fig. 2. These results could reinforce the hypothesis
239 that under conditions of adequate mineral status as in this study, trace element concentrations
240 in the muscular tissue are dependent on its own internal metabolism. To maintain the mineral
241 homeostasis, in the muscle as well as in other tissues, the organism developed different
242 mechanisms as metallothioneins, chaperones and other metal transporters (Andrews, 2002);

243 special relevance has acquired the divalent metal transporter 1 (DMT1), involved in the
244 traffic into the cells of divalent metals such as Fe, Zn, Cd, Cu, Co, Ni and Pb (Gunshin et al.,
245 1997; Mackenzie, Takanaga, Hubert, Rolfs, & Hediger, 2007) and ubiquitously expressed in
246 all tissues. The fact that some of the essential metals (Cr, Mo and Zn) do not follow the same
247 intermuscular distribution pattern could be related to metal interactions or antagonisms to
248 maintain a correct mineral balance.

249 **4. Conclusions**

250 Under the conditions of this study, including animals with adequate mineral status, there were
251 significant differences on essential and toxic trace element concentrations across the carcass.
252 Veal cuts including muscles with a high proportion of oxidative slow-twitch fibers (i.e.
253 diaphragm and cardiac muscle) showed higher essential trace element concentrations, the
254 lower concentrations being found in veal cuts including glycolytic fast-twitch fibers (i.e. eye
255 round). Since the proportion of slow and fast twitch fibers in the muscle can be modulated by
256 genetic selection and physical activity, our results suggest that essential and toxic element
257 concentration could be used as a new meat quality parameter or to add further value to certain
258 products (i.e. certain livestock breeds reared on extensive systems with high degree of
259 physical activity). More studies are needed in muscular tissue to further understand and
260 evaluate the importance of trace element accumulation in different veal cuts.

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268 **Acknowledgements**

269 This work was supported by the Xunta de Galicia (Spain) through contract
270 07MRU030261PR. Marco García-Vaquero was in receipt of a post-doctoral fellowship
271 granted by The Barrié Foundation (Galicia, Spain) for the period 2014-2016. The authors
272 thank Lucia Casanova Iglesias for her technical assistance and Beatriz Morán Neira, José M.
273 Cruz López, Julio García Varela and Esperanza Rial for their help during the collection of the
274 samples.

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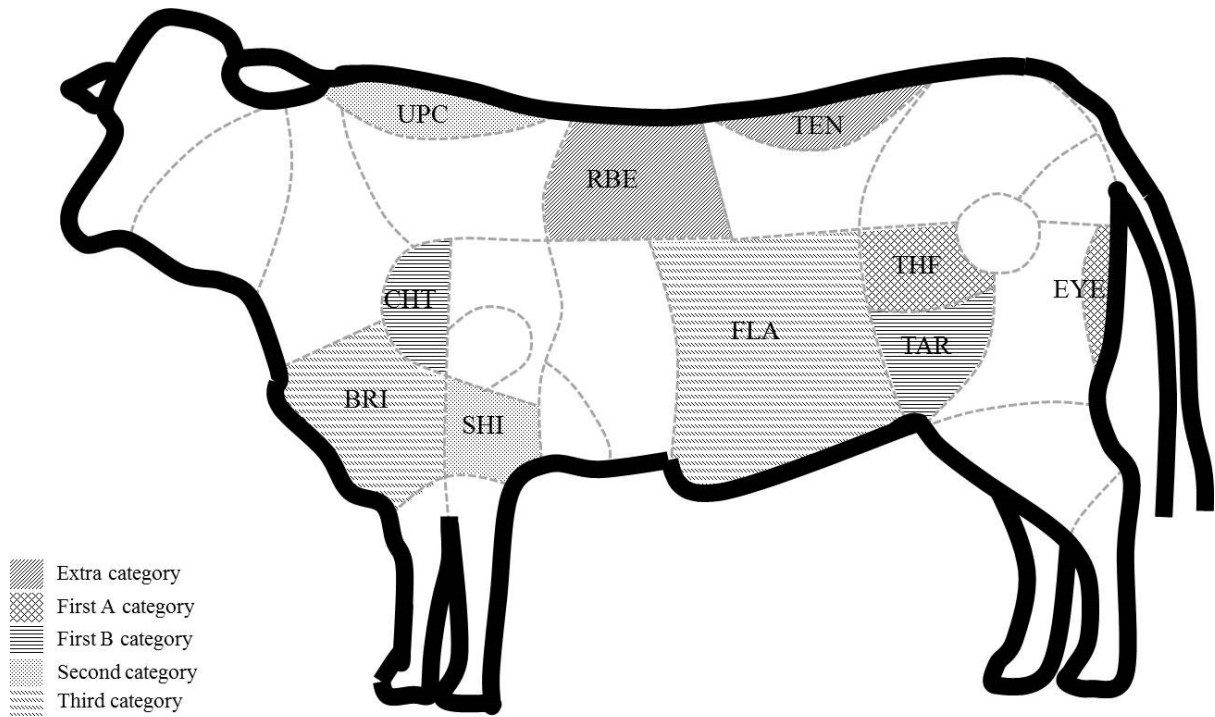
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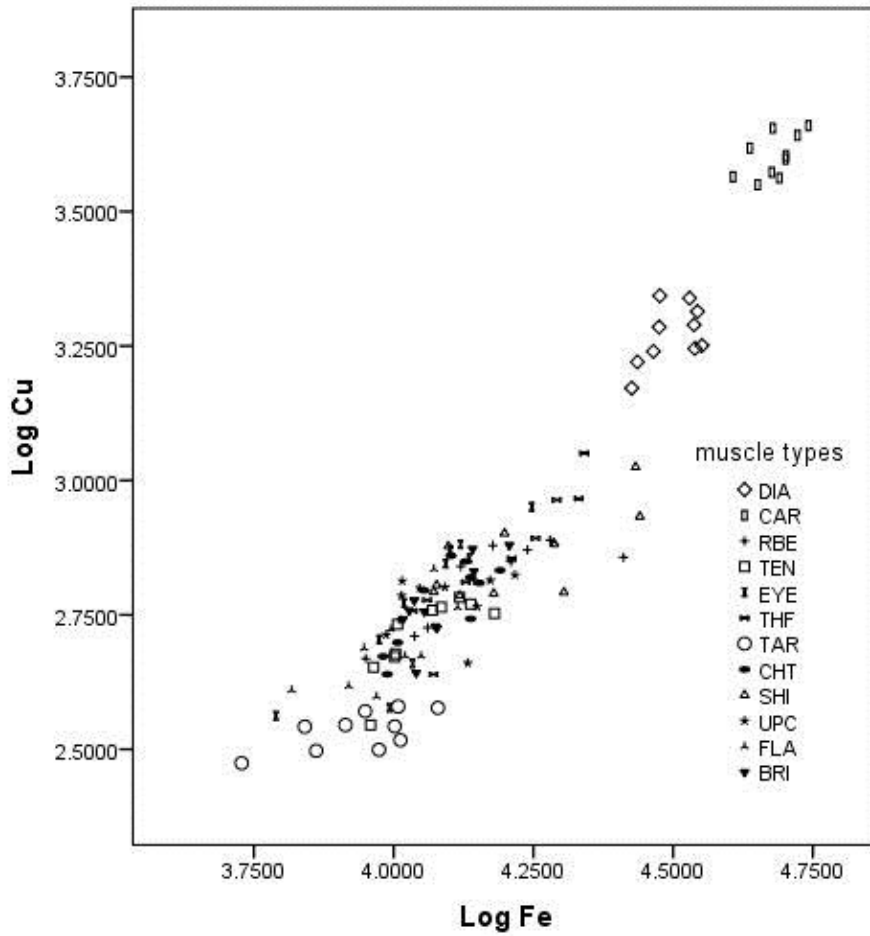
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414 **Fig. 1.** Carcass showing the commercial muscle cuts selected. Muscle abbreviations are as
415 follows RBE (rib boneless entrecote), TEN (tenderloin), EYE (eye round), THF (thick flank),
416 TAR (tail of rump), CHT (chuck tender), SHI (shin), UPC (upper chuck), FLA (flank) and
417 BRI (brisket). Commercial categories of veal cuts according to the Spanish regulations are
418 represented in the figure by different filling patterns.



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429 **Fig. 2.** Scatterplot showing correlation between Cu and Fe concentrations ($r_s= 0.829$,
 430 $P<0.001$, $n=120$) in the different muscle samples. Abbreviations of muscles were as follows:
 431 RBE (rib boneless entrecote), TEN (tenderloin), EYE (eye round), THF (thick flank), TAR
 432 (tail of rump), CHT (chuck tender), SHI (shin), UPC (upper chuck), FLA (flank), BRI
 433 (brisket), DIA (diaphragm) and CAR (cardiac muscle).



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443 **Table 1.** Commercial veal cuts and muscles integrating each selected cut.

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Commercial veal cuts	Muscles involved
Rib boneless entrecote (RBE)	<i>Longissimus thoracis</i> and <i>L. costarum</i> , <i>Spinalis dorsi</i> , <i>Multifidi dorsi</i> , <i>Complexus</i> and <i>internal/external intercostal</i>
Tenderloin (TEN)	<i>Psoas major</i> , <i>P. minor</i> and <i>Iliacus</i>
Eye round (EYE)	<i>Semitendinous</i> muscle
Thick flank (THF)	<i>Quadriceps femoralis</i>
Tail of rump (TAR)	<i>Tensor fasciae latae</i>
Chuck tender (CHT)	<i>Supraspinatus</i> muscle
Shin (SHI)	<i>Brachialis</i> , <i>Biceps</i> , <i>Coracobrachialis</i> and <i>Extensor carpo radialis</i>
Upper chunk (UPC)	<i>Rhomboideus</i>
Flank (FLA)	<i>Rectus abdominalis</i>
Brisket (BRI)	<i>Pectoralis profundus</i>

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464 **Table 2.** Analytical quality program expressed as mean \pm standard deviation used in the
 465 determination of essential and toxic trace elements.

	Detection limit (mg/Kg)	SRM 1577c	
		Certified levels (mg/Kg)	Analysed levels (mg/Kg)
As	0.0002	0.0196 \pm 0.0014	0.0119 \pm 0.0008
Cd	0.0002	0.0970 \pm 0.0014	0.1034 \pm 0.0052
Co	0.0002	0.300 \pm 0.018	0.320 \pm 0.006
Cr	0.0009	0.053 \pm 0.014	0.080 \pm 0.029
Cu	0.0276	275.2 \pm 4.6	291.1 \pm 10.6
Fe	0.3568	197.94 \pm 0.65	196.63 \pm 6.04
Hg	0.0006	-	0.147 \pm 0.020
Mn	0.0180	10.46 \pm 0.47	10.42 \pm 0.23
Mo	0.0057	3.30 \pm 0.13	3.35 \pm 0.35
Ni	0.0085	0.0445 \pm 0.0092	0.0724 \pm 0.0033
Pb	0.0017	0.0628 \pm 0.0001	0.0583 \pm 0.0054
Se	0.0273	2.031 \pm 0.045	1.849 \pm 0.052
Zn	0.2259	181.1 \pm 1.0	179.6 \pm 1.9

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482 **Table 3.** Essential trace element (Co, Cr, Cu, Fe, Mn, Mo, Ni, Se and Zn) concentrations in muscles and liver tissue expressed as mean ±
 483 standard error of the mean. Essential trace element concentration means from muscular samples with a common letter following them do not
 484 differ significantly (p < 0.05).

Essential trace elements	Co (µg/kg wt.w.)	Cr (µg/kg wt.w.)	Cu (mg/kg wt.w.)	Fe (mg/kg wt.w.)	Mn (mg/kg wt.w.)	Mo (µg/kg wt.w.)	Ni (µg/kg wt.w.)	Se (mg/kg wt.w.)	Zn (mg/kg wt.w.)	
Commercial Veal cuts	RBE	2.48±0.19 c	26.42±4.13 a	0.66±0.03 c	15.18±1.53 cde	0.85±0.01 cde	16.35±4.63 a	29.37±13.76 a	0.10±0.003 bc	48.35±4.96 ab
	TEN	1.92±0.14 c	46.77±12.54 a	0.52±0.03 cd	11.45±0.65 de	0.09±0.01 cd	42.99±13.32 a	28.75±9.24 a	0.11±0.005 bc	27.19±3.17 ef
	EYE	2.28±0.21 c	31.36±4.32 a	0.61±0.06 d	11.61±0.97 e	0.10±0.01 d	25.28±9.31 a	23.02±9.59 a	0.1±0.004 bc	36.99±3.02 def
	THF	2.52±0.30 c	26.16±4.23 a	0.75±0.07 c	16.07±1.38 cd	0.10±0.01 cd	16.42±4.97 a	10.04±1.20 a	0.09±0.004 c	41.86±2.76 abcd
	TAR	3.59±1.84 c	28.45±5.83 a	0.34±0.01 c	8.86±0.62 de	0.05±0.01 cd	20.31±8.30 a	15.95±4.54 a	0.10±0.004 bc	30.22±1.51 bcde
	CHT	2.12±0.11 c	40.86±10.70 a	0.60±0.03 c	12.41±0.66 cde	0.10±0.01 c	20.74±7.56 a	21.42±6.00 a	0.10±0.005 bc	42.69±1.78 abcd
	SHI	2.96±0.38 bc	44.45±12.82 a	0.73±0.05 c	17.45±1.88 c	0.12±0.01 c	18.69±5.53 a	11.79±0.10 a	0.10±0.004 bc	55.64±6.65 a
	UPC	2.16±0.28 c	45.86±10.50 a	0.59±0.02 cd	12.32±0.74 cde	0.10±0.01 cd	21.40±7.11 a	69.06±54.77 a	0.10±0.005 bc	44.34±1.88 abcd
	FLA	2.22±0.18 c	24.41±5.06 a	0.52±0.04 cd	10.88±1.10 de	0.07±0.01 cd	33.31±21.96 a	14.22±7.27 a	0.10±0.003 c	34.21±4.27 cdef
	BRI	2.41±0.16 c	43.62±10.45 a	0.60±0.03 c	12.19±0.59 cde	0.10±0.01 cde	21.67±7.54 a	19.26±2.50 a	0.11±0.004 bc	30.33±1.94 def
Internal muscles	DIA	3.99±0.11 b	41.88±8.52 a	1.87±0.07 b	31.63±1.08 b	0.23±0.01 b	36.13±14.94 a	18.45±2.45 a	0.12±0.01 b	47±1.34 abc
	CAR	10.77±0.48 a	25.50±6.95 a	4.02±0.12 a	48.14±1.39 a	0.41±0.02 a	48.302±5.44 a	13.56±3.98 a	0.22±0.01 a	19.97±0.55 f
Liver	70.04±6.20	18.04±4.54	124.86±17.76	36.67±3.92	3.04±0.21	1243.36±42.85	16.63±5.33	0.53±0.08	41.04±1.24	

485 RBE (rib boneless entrecote), TEN (tenderloin), EYE (eye round), THF (thick flank), TAR (tail of rump), CHT (chuck tender), SHI (shin), UPC (upper chuck), FLA (flank),
 486 BRI (brisket), DIA (diaphragm) and CAR (cardiac muscle).

487 **Table 4.** Toxic trace element (As, Cd, Hg and Pb) concentrations in different muscle types
 488 and liver tissue. Toxic trace element concentration means from muscular samples with a
 489 common letter following them do not differ significantly ($p < 0.05$).

	As		Cd		Hg		Pb	
	median	range	median	range	median	range	median	range
Commercial veal cuts								
RBE	1.61 ab	0.58-2.71	ND	ND-ND	0.866	ND-1.39	1.71	ND-5.12
TEN	1.76 b	1.36-3.37	ND	ND-1.23	0.766	ND-1.27	ND	ND-4.88
EYE	1.60 ab	0.93-3.13	ND	ND-0.169	0.491	ND-1.15	ND	ND-2.35
THF	1.54ab	1.02-2.37	ND	ND-0.810	0.557	0.415-1.04	ND	ND-2.21
TAR	1.53 ab	1.08-2.55	ND	ND-ND	0.863	ND-1.04	ND	ND-3.00
CHT	1.58 ab	0.96-3.39	ND	ND-0.465	0.572	0.409-1.11	ND	ND-5.44
SHI	1.49 ab	1.01-3.08	ND	ND-ND	0.791	ND-1.47	ND	ND-2.86
UPC	1.61 ab	1.35-3.14	ND	ND-0.779	0.671	ND-1.30	ND	ND-3.55
FLA	1.46 ab	0.88-2.30	ND	ND-7.64	0.359	ND-1.26	ND	ND-2.82
BRI	1.92 b	1.31-2.75	ND	ND-0.141	0.664	ND-1.27	1.78	ND-6.46
Internal muscles								
DIA	1.35 ab	0.83-2.60	ND	ND-ND	0.883	0.522-1.71	ND	ND-5.33
CAR	0.93 a	0.63-1.34	ND	ND-0.305	0.505	0.405-0.990	ND	ND-1.88
Liver	2.72	1.94-3.59	8.48	4.72-9			6.35	3.48-9.57

490 ND (Non-detectable concentrations) indicate residues below the limit of detection of the method.

491 RBE (rib boneless entrecote), TEN (tenderloin), EYE (eye round), THF (thick flank), TAR (tail of rump), CHT
 492 (chuck tender), SHI (shin), UPC (upper chuck), FLA (flank), BRI (brisket), DIA (diaphragm) and CAR (cardiac
 493 muscle).

494 Maximum admissible levels for meat products established by the European Commission are 0.05 mg Cd/kg
 495 wt.w. and 0.1 mg Pb/kg wt.w. (Commission Regulation (EC), No 1881/2006; Commission Regulation (EU), No
 496 488/2014). No legal limits have been set for As and Hg in meat products.

497 **Table 5.** Spearman rank correlation coefficients and probability between pairs of essential and toxic trace element concentrations in all muscle
 498 samples analyzed in our study (n=120). Statistical significance of the correlations was indicated by * p<0.05, ** p<0.01 and *** p<0.001.
 499 Correlations were not calculated for Cd, Hg and Pb due to the high number of samples under the quantification limits of the method.

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	Co	Cr	Cu	Fe	Mn	Mo	Ni	Se	Zn
Cr	0.11								
Cu	0.506***	0.006							
Fe	0.485***	0.01	0.851***						
Mn	0.254*	0.004	0.596***	0.640***					
Mo	0.311**	0.167	0.139	0.074	0.059				
Ni	0.132	0.381***	-0.058	-0.044	0.147	0.354***			
Se	-0.206*	0.133	-0.079	-0.166	-0.194	0.165	0.179		
Zn	0.291**	0.012	0.678***	0.704***	0.394***	0.004	-0.092	-0.043	
As	-0.131	0.254*	-0.014	-0.024	-0.03	0.156	0.314**	0.502***	-0.031

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