

1 Has breed any effect on beef sensory quality?

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19 Highlights

- 20
- The 15 studied beef breeds can be categorized in five groups of sensory quality.
- 21
- After ten days of ageing, beef from rustic breeds is slightly less tender than those from the
- 22
- other breeds.
- 23
- Fat breeds like Aberdeen Angus, Highland and Jersey produce meat with the highest beef
- 24
- flavor intensity.

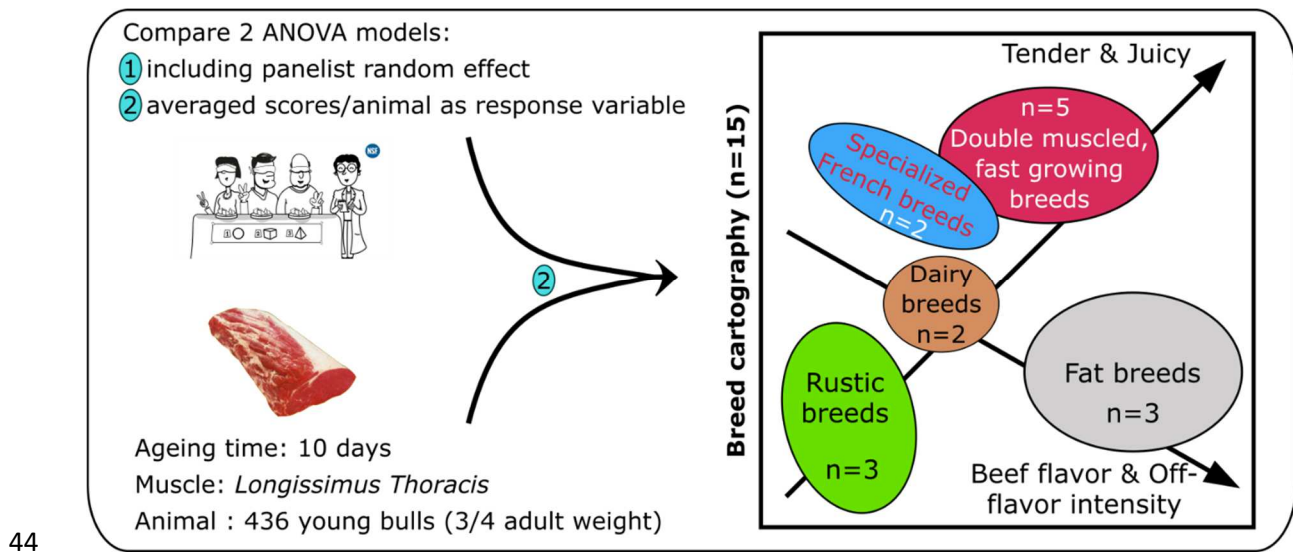
- 25 • Mixed effect models including “panelist” as a random effect provide similar results as ANOVA
26 based on average scores per animal.

27 Abstract

28 A total of 436 young cattle from 15 cattle breeds **were** reared in as similar conditions as possible to
29 evaluate the impact of breed on sensory quality of beef from *longissimus* muscle determined by
30 sensory analysis. Two statistical methods for processing the sensory data were compared. The
31 analysis of variance with or without the panelist effect gave similar conclusions indicating that the
32 robustness of the results was not dependent on the method chosen. The 4 meat descriptors
33 (tenderness, juiciness, beef flavor and off-flavor) placed breeds into 5 groups using an unsupervised
34 classification (hierarchical ascending classification). Aberdeen Angus, Highland and Jersey, that have
35 a high lipid content in the muscle studied, differed from the other breeds **in that they had a higher**
36 **beef flavour**. The dual-purpose and rustic breeds, Simmental, Casina and Marchigiana, produced
37 significantly less juicy and less tender **meat** than that from breeds selected for meat production.
38 Overall, **despite significant differences previously identified for animal, carcass, muscle and beef**
39 **traits for the same animals**, differences in sensory scores between most of the breeds **were** small,
40 with only significant differences between the few breeds that had extreme sensory profiles (such as
41 Simmental and Pirenaica).

42

43 Graphical abstract



45 Keywords

46 beef; breed; sensory analysis; mixed effect models; fixed effect models

47 Abbreviations

- 48 • ME: Mixed Effect
- 49 • FE: Fixed Effect

50 1. Introduction

51 Given the significant heterogeneity between regions and territories and the selection of cattle breeds
52 either for milk or meat production, there is a significant phenotypic and genetic diversity among
53 cattle breeds in Europe. The meat production characteristics of these breeds is quite heterogeneous:
54 conformation and fat cover of carcasses and meat yield vary greatly from one breed to another. The
55 variation among breeds in size and carcass characteristics is well known (Albertí et al. 2008),
56 however, the impact of the breed on the sensory quality of meat is still subject of debate, and
57 therefore of interest.

58 Breed is a factor commonly taken into account when characterizing and studying sensory quality of
59 meat. Significant differences in tenderness, juiciness and beef flavor intensities have been reported
60 between Aberdeen Angus and Gasconne, Holstein and Simmental breeds (Bures et al. 2018). The
61 tenderness of the Gasconne breed has been shown to be superior to that of the Holstein and
62 Simmental breeds while the Angus breed has superior tenderness and juiciness compared to the Red
63 Nordic (Huuskonen et al. 2016), although these breeds were not found to differ in beef flavor. The
64 meat from the Charolais breed has been reported be more tender and have a higher and beef flavor
65 than that from the Simmental and Eastern Anatolian Red, but not to have higher juiciness (Ozluturk
66 et al. 2004). Avileña -Negra Ibérica breed is reported to have higher tenderness and beef flavor
67 intensity than Bruna dels Pirineus and Morucha (Serra et al. 2008). Other studies, however, have
68 reported no significant difference in beef characteristics between breeds e.g. Limousine vs Aberdeen
69 Angus, (Pesonen et al. 2012) or Holstein vs Jersey (Nian et al. 2017). This raises the question as to
70 whether the differences observed are variations among the breeds or a result of differences in
71 management and feeding practices. Increasing ageing time of beef also seems to decrease
72 differences in sensory quality between breeds. Better tenderness scores were obtained after ageing
73 for one week for fast-growing breeds (Pirenaica and Rubia Gallega) compared with a double muscle
74 Spanish breed (Asturiana de los Valles), a dual-purpose breed (Brown Swiss) and rustic breeds
75 (Avileña-Negra Ibérica Morucha and Retinta), but the differences were no longer significant after 21
76 days ageing (Campo et al. 1999).

77 Studies that have compared f beef eating quality between breeds have generally been limited in size,
78 and in the number of breeds compared. While comparisons among studies is impaired by the
79 different experimental protocols used. Work carried out so far has rarely studied more than 7 breeds
80 under similar experimental conditions (Judge et al. 2021) and in larger studies comparisons could not
81 be made, as rearing conditions were country specific (Panea et al. 2018). The differences observed
82 between breeds are generally small and not always consistent between studies, which is most likely
83 due to the different animal management and meat sensory protocols used. The European

84 consortium **GemQual (GEnetics of Meat Quality)** addressed these issues by studying the influence of
85 breed on meat quality with all animals managed under similar husbandry conditions and as close as
86 possible the same rearing conditions. The sensory quality of meat from young bulls from 15 European
87 breeds was compared by testing in the same laboratories or by the same taste panels. **Data related**
88 **to growth, carcass properties, muscle biochemical contents and physical measurements from these**
89 **animals have been published (Alberti et al. 2008; Christensen et al. 2011) and these data are used**
90 **here to test the grouping of breed by sensory parameters.**

91 The statistical treatment of the sensory data differs among studies, majority of which average scores
92 provided by the panelists per animal before using them in statistical models (Pesonen et al. 2012 and
93 Ozluturk et al. 2004 for example). Models used may include one or more fixed factors such as breed,
94 diet, sex, etc., to assess their potential impact on meat quality. However, in other studies, sensory
95 analysis is conducted using a statistical model that also include random effects, particularly to take
96 into account variations in ratings between panelists. This approach is commonly used for food
97 products, e.g. yoghurts (Saint-eve et al. 2006), cheese (Gierczynski et al. 2007) and wine (Vidal et al.
98 2003), and has been used to study meat quality (Bures et al. 2018, Blanco et al. 2020). However, this
99 is not the general case (Pesonen et al. 2012 and Ozluturk et al. 2004, Nian et al. 2017, Huuskonen et
100 al. 2016).

101 The objective of this study was to evaluate the effect of breed on sensory quality of meat using the
102 most appropriate statistical treatment. Two statistical treatments were tested, one of which included
103 the effect of the panelist to assess if this would reduce the residual variability.

104 2. Materials & Methods

105 2.1. Experimental design

106 The study involved 436 **young bulls**, from 15 European breeds, reared under as similar conditions as
107 possible (Albertí et al. 2008) in five European experimental stations: in France **(for the Limousin and**

108 Charolais breeds), the United Kingdom (for the Jersey, South Devon, Hereford, Aberdeen Angus and
109 Galloway breeds), Spain (for the Casina, Avileña -Negra Ibérica, Pirenaica and Asturiana de los Valles
110 breeds), Italy (for the Piemontese and Marchigiana breeds) and Denmark (for the Holstein, Danish
111 Red and Simmental breeds). Animals with no direct relationship for two generations were selected to
112 represent the genetic diversity of each breed. All management procedures were approved by the
113 respective ethics committees of each research centre in accordance with the European Directive
114 (U.S., 2010). The animals were slaughtered when they reached 75% of the average mature weight for
115 their breed (15 ± 1.3 months of age, with a range from 398 and 511 days, Alberti et al., 2008). They
116 were slaughtered by captive bolt pistol and exsanguination in commercial or experimental
117 slaughterhouses depending on the infrastructure available in the different countries. Carcass
118 dressing followed a standardized project protocol, without use of electrical stimulation, and with the
119 removal of the remaining subcutaneous fat cover and testicles. Carcasses were split into two sides
120 with tail on the right side of the carcass and chilled at 4 ± 1 °C for 24 h. Temperature in the center of
121 *M. longissimus thoracis*, at the 10th thoracic rib, was not allowed to fall below 10 °C within the first 10
122 h. The *Longissimus thoracis* muscle was cut at 24h *post-mortem* between the 6th and 13th left ribs and
123 vacuum-packed for maturation at $2^{\circ}\text{C} \pm 1^{\circ}\text{C}$ for 10 days *post-mortem* and then frozen at -18°C for
124 preservation until analysis (Christensen et al. 2011).

125 2.2. Sensory analysis and texture measurements

126 Sensory assessment was as described by MacKintosh et al. (2017). In brief, after overnight thawing at
127 1°C , 2 cm steaks were cooked under a conventional grill temperature turning every 2min until the
128 internal temperature of the muscle reached 74°C as measured by a thermocouple probe (Testo
129 Limited, Alton, UK). After cooking, cubes (2 x 2 x 1.9 cm) were then cut from the centre of the steak
130 (avoiding incursions of connective tissue where present), one per panelist, wrapped in aluminum foil,
131 coded with three-digit numbers, and kept warm for less than 10 min at 55°C before tasting took
132 place. Samples were served hot to a 10-person trained professional taste panel, using the same
133 people for the duration of each experiment.

134 Two panels composed of 10 trained panelists, one in the United Kingdom and the other in Spain,
135 assessed the meat quality using 4 sensory descriptors: tenderness, juiciness, beef flavour and off-
136 flavour, on an 8-point scale with 1 meaning less intense descriptor to 8 meaning most intense
137 descriptor, as described by Wood et al. (1995). Each beef sample from between 29 and 31 animals
138 per breed was assessed by 10 trained panelists, in sessions with 12 samples each in plates of 4
139 samples, with random order between panelists to avoid first-order and carry-over effects.
140 Assessments took place in a purpose-built panel room illuminated by red-light. Each booth contained
141 a computer screen and optical mouse as part of the computerised sensory system, (Fizz, Version 2.20
142 h, Biosystemes, Couternon, France), for direct entry of sensory responses. Assessors tasted the
143 samples in an order based on the designs outlined by MacFie et al. (1989) for balancing carryover
144 effects between samples.

145 A common set of samples were used for training and calibrating the panels. One extra sample was
146 taken from 40 animals from 7 breeds that was tasted by both panels. This extra sample was used to
147 compare the Spanish panel vs the UK panel to set the calibration values for each sensory attribute. A
148 strong relationship was found between the scores although absolute values differed. Results for
149 animals tested in common by both panels were used to derive a correction factor between both
150 panels. Training consisted of 5 sessions of 8 samples each with discussion, reaching common
151 agreement between panelists.

152 Values for Warner–Bratzler shear force and compressive force measured on raw and cooked meat
153 obtained for samples from the same animals (Christensen et al. 2011) were used in the statistical
154 analyses. For these measurements, frozen samples were thawed overnight and equilibrated to room
155 temperature (25 °C) prior to texture analysis. For Warner–Bratzler shear force, slices were cooked in
156 a water bath at 80 °C until the internal temperature reached 75 °C. The sample was then cooled for
157 45 min in running tap water and stored at 4 °C until analysed. Shear force measurements for raw and
158 cooked samples were performed on 10 blocks (2 cm in length and 1 cm by 1 cm of cross section) cut

159 perpendicular to the fiber direction. For the compression test, samples (1 cm² in cross section), were
160 cut with muscle fibers, parallel to the longitudinal axis, and were analyzed using a modified
161 compression device that avoids transversal elongation of the sample. Shear force and compression
162 data are described in Christensen et al. (2011).

163 2.3. Statistical treatment

164 The statistical processing of sensory data compared a model that included a random effect to take
165 into account the differences in scoring between panelists with a classical analysis of variance using
166 the average scores for each sample.

167 The score $y_{ijkl}^{(d)}$ of the descriptor d (tenderness, juiciness, beef flavor and off- flavor) for breed i given
168 by the panelist j for the sample from animal k analyzed by the panel l can be decomposed by the
169 following model:

$$170 \quad (1) \quad y_{ijkl}^{(d)} = \mu^{(d)} + \alpha_i^{(d)} + \beta_j^{(d)} + \gamma_{k(i)}^{(d)} + \lambda age_k + \delta_l^{(d)} + \varepsilon_{ijkl}^{(d)}$$

171 Where, for a given d descriptor, $\mu^{(d)}$ is the average score of all animals, $\alpha_i^{(d)}$ is the effect of breed i ,
172 $\beta_j^{(d)}$ is the effect of panelist j , $\gamma_{k(i)}^{(d)}$ is the effect of animal k of breed i , λ is the effect of age
173 introduced as a continuous variable, $\delta_l^{(d)}$ is the effect of panel l and $\varepsilon_{ijkl}^{(d)}$ is a random error term
174 whose distribution is assumed to be normal.

175 For simplicity, only the Spanish sensory panel data were used to compare the two modelling
176 approaches with the presence or the absence of the $\delta_l^{(d)}$ panel effect.

177 The first analysis of variance (ANOVA) model with mixed effects (ME) included all the effects of (1),
178 with the exception of the panel effect. In this model, breed and age effects were considered as fixed
179 effects because they were factors of interest in the study. Whereas the animal effect and the panel
180 effect, resulting from the sampling process, were considered as random effects, i.e. characterized by
181 a normal distribution (2):

182
$$(2) \beta_j^{(d)} N(0, \sigma_a^{2(d)}) \text{ and } \gamma_{k(i)}^{(d)} N(0, \sigma_b^{2(d)})$$

183 where $\sigma_a^{2(d)}$ and $\sigma_b^{2(d)}$ are unknown variances and $N(0, \sigma^2)$ is a normal distribution of mean 0 and
184 standard variance σ^2 .

185 The panelist random effect differs, however, from the animal random effect, which is nested (or
186 hierarchical). Indeed, each panelist scored several beef samples of the $I = 15$ breeds tested,
187 whereas any k animal can only belong to a single i breed, hence the presence of the index i in the
188 animal effect score namely $k(i)$.

189 To estimate the mixed effects (ME) parameters, the *lmer* function of the *lmerTest* package version
190 3.1-0 was used with the REML optimization criterion (Kuznetsova et al., 2017) in R software version
191 3.6.1.

192 The second analysis of variance (ANOVA) model had only fixed effects (FE), and is the most
193 commonly used model in the literature to analyse meat quality sensory data:

194
$$(3) y_{i.k}^{(d)} = \mu^{(d)} + \alpha_i^{(d)} + \lambda age_k + \varepsilon_{ik}^{(d)}$$

195 where $y_{i.k}^{(d)}$ is the average of all the scores given by the J panelists for an animal k . For both models,
196 the age of the animal at slaughter was introduced in the model as a continuous variable only when
197 the effect was significant.

198 To evaluate the two models, we compared the p-values, testing the breed effect. The pairwise breed
199 comparison was then tested using Tukey's *post-hoc* test when the previous null hypothesis was
200 rejected. The *lsmean* function in the *emmeans* package (Lenth 2020) was used to perform this test,
201 and a synthesis of significant differences was allowed by adding a superscript letter to the *cld*
202 function in the *multcomp* package (Hothorn et al., 2008). A threshold of 5% was chosen to reject the
203 H0 hypothesis.

204 Based on the previous comparison of the models, the breed effect was analyzed either by including a
205 panelist random effect (ME) if the differences between the two models were significant, or based on
206 the fixed effect model (FE) if no or little difference was observed between the models. This second
207 choice is consistent with data in the literature and thus allowed the comparison of the results with
208 published information. In the second analysis, the panel (country) effect was taken into account. As
209 this effect has only two levels, it was not appropriate to model as a random effect with only two
210 observations.

211 Finally, a multivariate analysis of all descriptors was conducted to identify similarities and differences
212 between breeds. The averaged (lsmean) centered and reduced data were analyzed by hierarchical
213 ascending classification (CAH), using the "Ward.D" agglomeration criterion.

214 A Principal Component Analysis (PCA) was then carried out according to Destefanis et al. (2000) to
215 assess correlations between the **sensory scores** and the mean values of shear force and compressive
216 force measured on raw and cooked meat previously obtained on the same samples (Christensen et
217 al. 2011), which were included as supplementary variables.

218 3. Results

219 3.1. Statistical model comparison

220 Each of the 4 descriptors used for the sensory quality of meat discriminated at least one breed from
221 the others, independent of the statistical model used (Table 1). The tenderness descriptor was had
222 the lowest p-value discriminating breeds.

223 *Table 1: P-value testing the null hypothesis H0 of equality of the mean of each breed with the two models tested.*

Descriptors	<i>Mixed Effect Anova</i>	<i>Fixed Effect Anova</i>
Tenderness	8.5e-06	9.2e-06
Juiciness	1.9e-04	3.2e-04

Beef flavor	2.6e-03	2.5e-03
Off-flavor	2.8e-04	3.6e-04

224

225 Few differences were found between the two statistical approaches, although the model that
 226 included panelist as a random effect (ME) had slightly lower p-values, on average, than those using
 227 averaged data (FE), except for beef flavour (Table 1). Taking into account the panelist effect did not
 228 change the discrimination between breeds, as p-values observed for both models were similar.

229 Pairwise comparisons of breeds showed that only the most significant differences changed between
 230 the two models (Table 2). The Simmental breed differed significantly from the Pirenaica for
 231 tenderness and juiciness with the model including a panelist random effect (ME) with p-values of
 232 0.049 and 0.047 respectively, whereas for the model without the panelist effect, p-values of 0.065
 233 and 0.058 were obtained. As the model based on mean scores (FE) is widely used, and does not bias
 234 analysis of meat sensory quality data, it was used to assess the effect of breed on meat sensory
 235 quality in subsequent analyses. Animal age (which varied from 398 and 511 days) had a significant
 236 effect on beef flavour (p-value=0.019) but was not significant for the other descriptors. Age was
 237 therefore omitted in the ANOVA analysis (Table 3).

238 The first test (Table 2) was done on the sensory scores from the Spanish panel only whereas later
 239 analyses reported in Table 3 used all the animals. Apart from the English breeds, for which sensory
 240 analysis was only done in the United Kingdom, the other breeds were tested in both the United
 241 Kingdom and Spain. This may explain the differences obtained between the two tests.

242 *Table 2 : P-value of the Tukey test comparing the breed Pirenaica and Simmental with the two statistical models*

Descriptors	Mixed Effect Anova	Fixed Effect Anova
Tenderness	0.049	0.065
Juiciness	0.047	0.058

Beef flavor	0.003	0.007
Off-flavor	0.999	0.999

243

244 *Table 3 : Breed comparison based on LSMEAN (\pm standard deviation) for each descriptor of sensory quality of the meat*

Race	Tenderness	Juiciness	Beef flavor	Off-flavor
Aberdeen Angus	4.6 \pm 1.0 ^{abc}	5.3 \pm 0.9 ^e	5.5 \pm 1.2 ^d	3.4 \pm 1.8
Asturiana de los Valles	4.9 \pm 1.2 ^{bc}	5.0 \pm 0.8 ^{bcde}	4.5 \pm 0.9 ^{ab}	3.2 \pm 0.6
Avileña Negra Ibérica	5.0 \pm 1.1 ^{bc}	4.8 \pm 0.9 ^{abcde}	4.4 \pm 0.9 ^{ab}	3.0 \pm 0.5
Casina	4.0 \pm 1.5 ^{ab}	4.5 \pm 0.8 ^{abcd}	4.5 \pm 0.7 ^{ab}	3.0 \pm 0.5
Charolaise	4.8 \pm 1.0 ^c	5.0 \pm 0.7 ^{bcde}	4.3 \pm 1.1 ^{ab}	2.8 \pm 0.6
Danish Red cattle	4.7 \pm 0.9 ^{abc}	4.6 \pm 0.5 ^{abcde}	4.5 \pm 0.7 ^{ab}	2.9 \pm 0.5
Highland	4.1 \pm 1.0 ^{ab}	5.0 \pm 0.9 ^{bcde}	5.2 \pm 1.2 ^{cd}	3.3 \pm 2
Holstein	4.6 \pm 0.9 ^{abc}	4.4 \pm 0.6 ^{ab}	4.5 \pm 0.7 ^{ab}	2.9 \pm 0.5
Jersey	4.9 \pm 1.79 ^{bc}	5.0 \pm 0.7 ^{bcde}	4.8 \pm 1.0 ^{bc}	3.6 \pm 1.9
Limousin	4.8 \pm 0.9 ^{bc}	5.0 \pm 0.8 ^{bcde}	4.2 \pm 1.0 ^a	2.9 \pm 0.5
Marchigiana	3.8 \pm 1.3 ^a	4.3 \pm 0.8 ^{abc}	4.3 \pm 0.9 ^{ab}	2.9 \pm 0.6
Piemontese	4.9 \pm 1.0 ^{bc}	4.7 \pm 0.7 ^{abcde}	4.2 \pm 0.9 ^{ab}	3.2 \pm 0.6
Pireneica	5.3 \pm 1.0 ^c	5.0 \pm 0.9 ^{de}	4.5 \pm 0.9 ^{ab}	3.1 \pm 0.5
Simmental	3.7 \pm 1.3 ^a	4.2 \pm 0.7 ^l	4.2 \pm 0.8 ^{ab}	3.0 \pm 0.6
South Devon	4.9 \pm 0.7 ^{bc}	5.1 \pm 0.4 ^{cde}	4.8 \pm 1.4 ^{abcd}	2.9 \pm 1.4

245 *For a given descriptor, two breeds are significantly different from each other if none of the*
 246 *superscripts letters between brackets are identical. Scores range from the least (1) to the highest (8)*
 247 *intensity.*

248

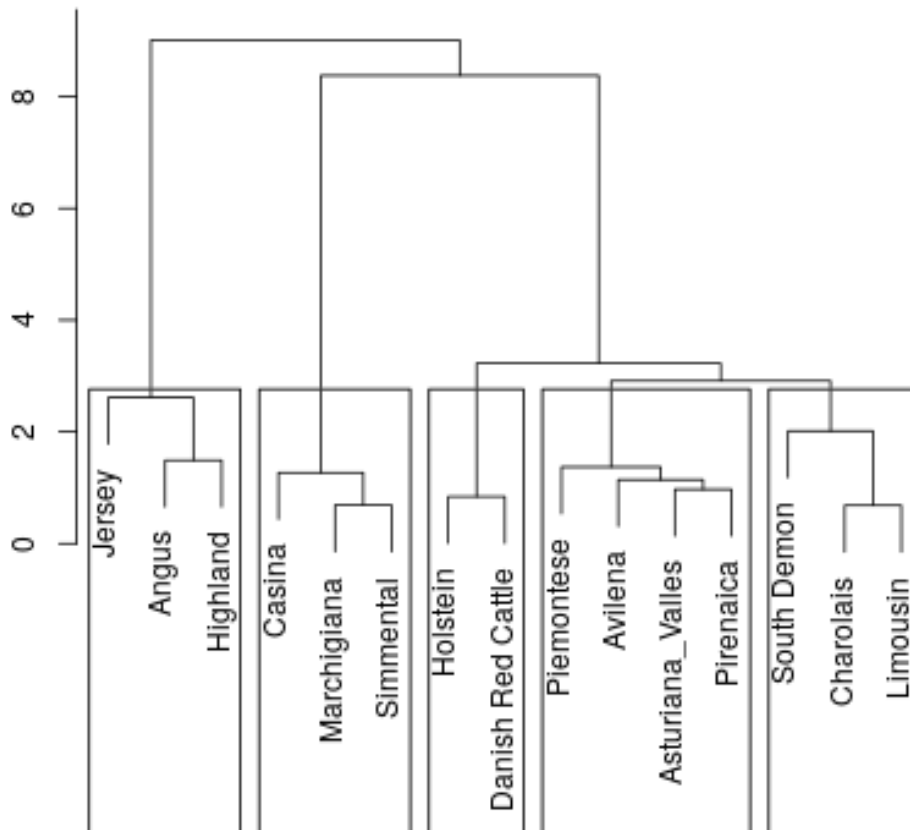
249 3.2. Impact of cattle breed on sensory meat quality

250

251 The hierarchical classification of the sensory profile of the meat from the 15 breeds revealed that
252 they form five groups (Figure 1).

253 **Aberdeen Angus, Highland and Jersey fall** into the first group (Figure 1). These breeds are
254 characterized by high beef flavour intensity and juiciness (Table 3). Breeds in the second group
255 include a dual-purpose and two rustic breeds (Simmental, Casina and Marchigiana) which are
256 characterized by the toughest and the driest meat. The dairy breeds, Holstein and Danish Red cattle,
257 form group 3, and are characterized by intermediate juiciness and tenderness scores (Figure 2). The
258 double muscled breeds, Asturiana de los Valles and Piemontese and fast-growing beef breeds
259 Pirenaica and Avileña Negra Ibérica, group 4, are characterized by a tender and juicy meat. The highly
260 specialized French beef breeds (group 5), Limousine and Charolaise, have similar sensory scores and
261 the lowest beef flavor intensity (Table 3).

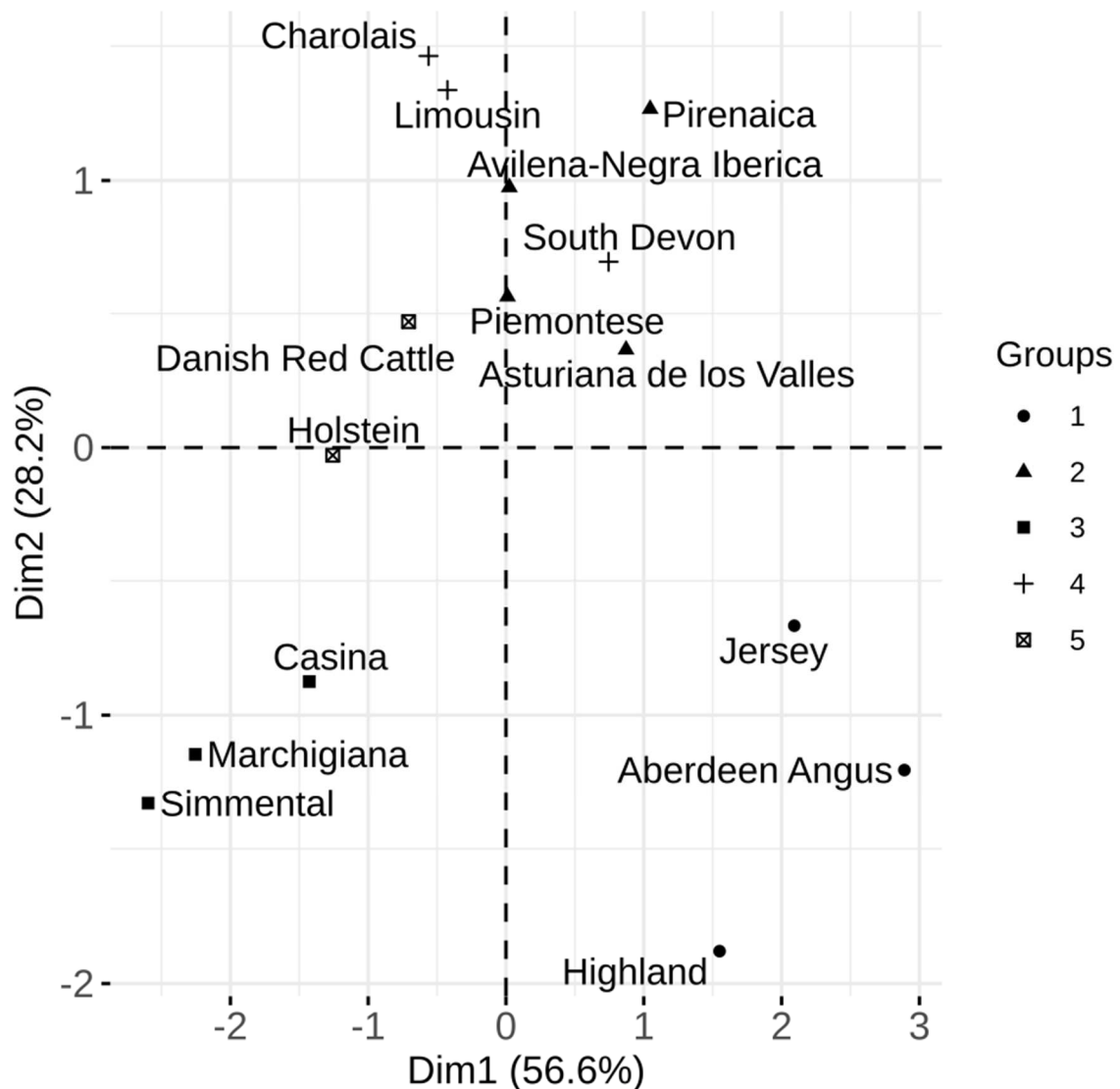
262 Principal Component Analysis (PCA) that included previously published mean values of shear force
263 and compressive force measured on raw and cooked meat (Christensen et al., 2011) showed three
264 distinct groups (Figure 2) corresponding to the five discriminatory associations on the first two
265 dimensions, which explain 84% of the variation. The groups which were closest together in the
266 hierarchical agglomerative clustering (groups 3, 4 and 5) are also grouped together in the PCA.
267 Breeds which produce the juiciest and the most tender beef (scores > 4.8), including Asturiana de los
268 Valles, Avileña Negra Ibérica and South Devon are grouped in the upper right-hand corner of the
269 PCA. Breeds producing beef with both intense beef flavour (> 4.8) and off flavor (> 3.3), Jersey,
270 Aberdeen Angus, and Highland (Group 1), are grouped in the lower right-hand side (Figure 2)
271 whereas breeds with the lowest beef tenderness scores, Casina, Marchigiana, Simmental (Group 2)
272 are grouped in the lower left-hand side.



273

274 *Figure 1 Dendrogram of the hierarchical agglomerative clustering (HAC) of breed based on the scale mean data (lsmean)*

275 *given in the table 3, where five clusters were from each other.*

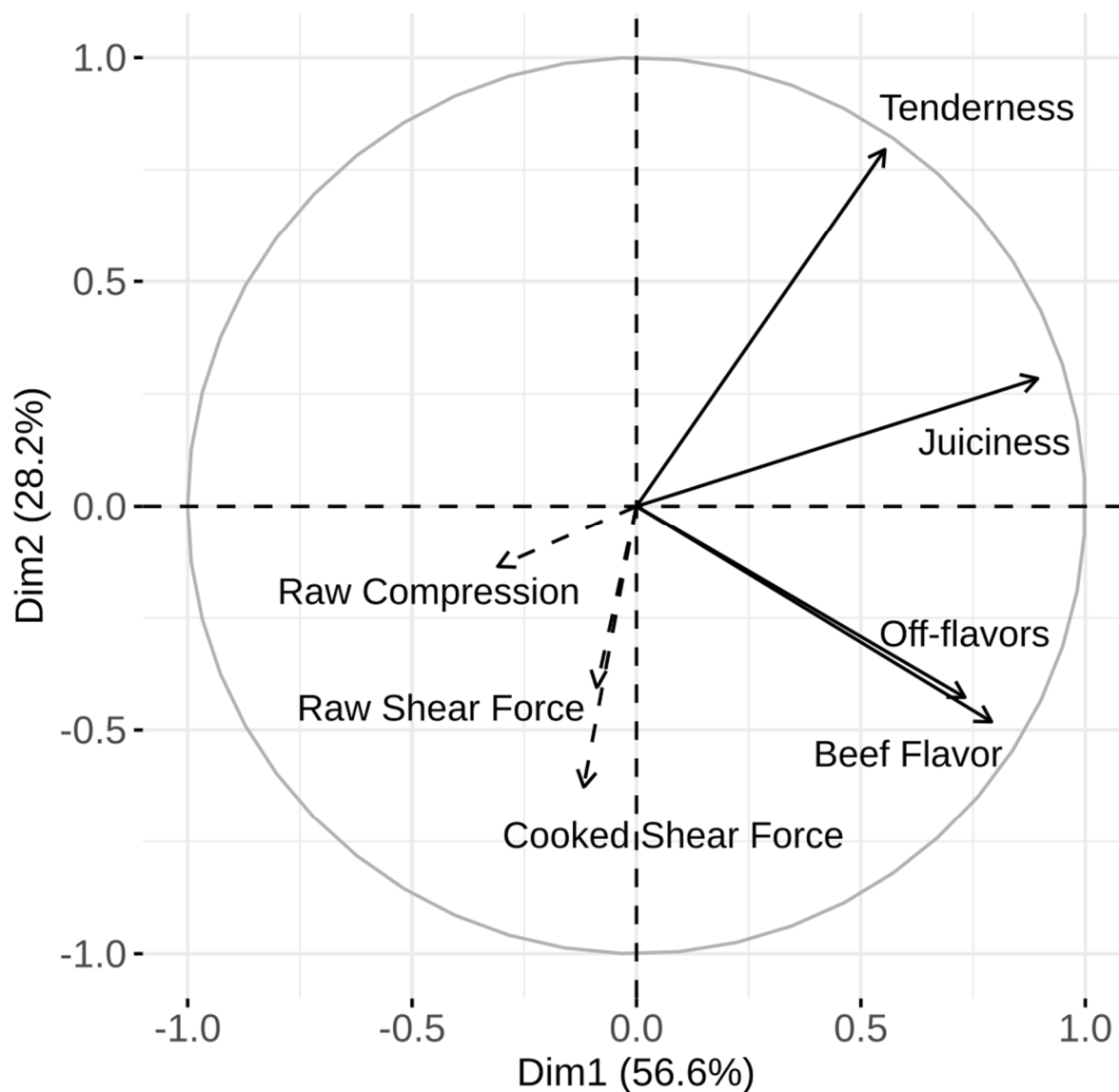


276

277 *Figure 2: Principal component analyses showing variability between breeds in sensory analysis descriptors (presented in*
 278 *Table 3 and in Figure 1) and in mechanical descriptors (shear force and compressive force measured on raw and cooked*
 279 *meat published by Christensen et al., 2011). The breed associations produced by the hierarchical ascending classification are*
 280 *represented by symbols.*

281 Based on the Principal Component Analysis, a significant correlation was found between tenderness
 282 and juiciness ($r=0.63$, $p\text{-value}=0.01$) (Figure 3). The negative correlation observed between
 283 compression values and tenderness was not significant ($r=-0.21$, $p\text{-value}=0.44$), nor was the
 284 correlation between raw shear force and tenderness ($r=-0.33$, $p\text{-value}=0.22$). However, the negative
 285 correlation observed between tenderness score and shear force for cooked meat was significant ($r=-$

286 0.60, p-value=0.02). This indicates that meat texture is affected by the cooking process. A positive
287 correlation between beef flavor and off-flavor was also observed ($r=0.60$, p-value=0.02) meaning that
288 the breeds with the highest beef flavor intensity also had the highest off-flavor, which may be
289 because the sensory panels assess both of these descriptors in a similar way.



290
291 *Figure 3: Correlation circle of sensory analysis descriptors (Table 3), illustrated by black arrows, combined with previously*
292 *published rheological data (Christensen et al. 2011) as supplementary variables (in dotted arrows).*

293

294 4. Discussion

295

296 4.1. Breed clustering is trait-dependent

297 Hierarchical ascending classification placed breeds into groups according to their sensory traits, as
298 did a Principal Component Analysis similar to those used in other studies (Destefanis et al. 2000).
299 These analyses indicated the impact of the breed on the variations in meat sensory characteristics.
300 This information can be used compare the relative standards of one breed with respect to other
301 breeds, and by the whole supply chain to choose the breed that best suits their needs and
302 consumers' expectations.

303 **Animal and carcass characteristics and their classification according to the European carcass (EUROP)**
304 **grid placed the breeds assessed in the GemQual study, into 3 groups** (Albertí et al. 2008). Using
305 muscle and mechanical characteristics of beef produced by these breeds and **on the chemical**
306 **analysis of samples from the same animals**, the dairy breeds, Danish Red Cattle, Holstein, Jersey,
307 were grouped together as they had the highest total and insoluble collagen contents (Christensen et
308 al. 2011) whereas doubled muscle, Piemontese, Asturiana de los Valles, and the Limousine breeds
309 have the lowest contents. Aberdeen Angus, Highland and the dairy breeds have been shown to have
310 the highest intramuscular lipid content whereas Piemontese, Limousine and Asturiana de los Valles
311 had the lowest (Christensen et al. 2011). From the classification of breeds based on animal and
312 carcass characteristics, or muscle and beef characteristics (Albertí et al., 2008), it was expected that
313 breeds would differ significantly for sensory traits. However, this study found only minor differences
314 between breeds, which were much lower than expected.

315 The small differences **in sensory scores** among breeds maybe be due to the within breed **variability**
316 **being high and that the subjective nature of evaluating** sensory traits leading to greater variation in
317 values when compared with animal, carcass, muscle and beef characteristics. Results from sensory
318 panels are known to be highly variable (Gagaoua et al., 2016a) which makes standardization and

319 accuracy of measuring the phenotype difficult, which is essential to investigate variation (Hocquette
320 et al., 2012). In this study, we compared two statistical models to assess the technical variability
321 associated with the experimental design. This comparison showed that the inclusion of panelist as
322 factor does not improve significantly the robustness of the statistical model, and does not allow the
323 detection of additional differences between breeds than the model without panelist as a factor.

324 The contribution of animal, carcass and muscle characteristics to explain the variability in sensory
325 scores is known to be low or moderate as has been seen for carcass traits (Judge et al., 2021), the
326 EUROP grid scores (Bonny et al., 2016a), marbling (Liu et al, 2020), muscle biochemical traits
327 (Gagaoua et al., 2016b) or mechanical measurements (Destefanis et al., 2008).

328

329 4.2. Muscle growth potential and muscle characteristics of breeds have some impact on 330 sensory quality

331 This work found that fast growing breeds such as Pirenaica (Campo et al. 1999) as well as the double-
332 muscled breeds produce the most tender beef. This may be related to proportion of total and
333 insoluble collagen, which is higher when muscle mass is low which contributes to beef toughness
334 (Purslow, 2005), while low total and insoluble collagen contents are known to increase tenderness
335 scores (Chriki et al., 2012). Higher collagen content per g of tissue has been reported in the
336 longissimus muscle from Angus compared to Limousin steers (Chambaz et al., 2003) and in Limousin
337 compared to double-muscled Belgian Blue cattle (Raes et al., 2003). Other differences in sensory
338 traits between breeds may be explained by differences in intramuscular fat content. The high
339 intramuscular lipid content of the Aberdeen Angus, Highland and Jersey breeds could explain in part
340 the high flavour, whereas the low intramuscular fat content of the Limousin breed could be related
341 to the less intense beef flavour(Gagaoua et al., 2016b). Differences in lipid, intramuscular collagen
342 content and also in fibre type are thought to explain differences in sensory quality of beef (Chriki et

343 al. 2012, Chriki et al. 2013), although. there is inconsistency in these differences associated with
344 muscle, animal type and the productive function related to the breed (dairy or meat type).

345 Tenderness of meat from Simmentals has been reported to be lower than that of other breeds
346 (Shackelford et al., 1994; Chambaz et al., 2003; Zwambag et al., 2013, Xie et al. 2012) which is in
347 agreement with our results. Interestingly, Chambaz et al. (2003) reported that the Simmental breed
348 produced less tender meat than Angus and Limousin breeds when slaughtered at the same level of
349 intramuscular fat. Beef from Angus has been reported to be more tender, juicy and flavorsome than
350 that of Holsteins (Bures and Barton, 2018), which is also in agreement with our data.

351

352 4.3. Knowing breed characteristics might be important at the consumer end

353 Comparing breeds based on their sensory characteristics is a factor, among others, on which
354 consumers choose the beef. However, comparing breeds is difficult as there is little information
355 available. Collecting reliable information has been hampered by animals being reared in different
356 ways. Cattle management differs among breeds and is dependent both on breed, resources and
357 practices in different regions. Breeds that originated in specific regions where particular feed,
358 resources and condition were available, are now found internationally. Many studies have compared
359 different types of cattle and systems, confounding breeds, sexes and management systems (Gagaoua
360 et al., 2016b) rather than strictly comparing the breeds. Compare breed-management effects on beef
361 sensory quality is important, but must be explained to the consumer (Panea et al. 2018). In order to
362 make an unbiased comparison between a large number of breeds, the GemQual project established
363 protocols that were as standardized as possible with entire bulls only. Nevertheless, some biases are
364 likely to have persist. In addition to differences in management and breed, it is necessary to recruit
365 members of sensory panels that give consistent results. Some descriptors have been shown to have
366 moderate correlation, e.g. tenderness $r=0.67$, juiciness $r=-0.14$, flavour $r=0.1$, abnormal flavour $r=0.2$.
367 Meta-analyses of several studies are also possible, although this requires that the diversity of

368 protocols is accounted for in the analysis. A recent work showed that standardization of scoring
369 scales is only partially successful and a random effect associated with the experiment is necessary in
370 the analysis model (Judge et al. 2021) Other sources of variability such as meat ageing time and sex
371 of the animal make it difficult to determine of the contribution of breed to differences in sensory
372 quality. Increasing the ageing period, reduces difference in meat between breeds. It has been shown
373 that with 21 days aging differences between breeds cannot be detected (Campo et al. 1999). In the
374 GemQual study, the meat was aged for 10-days, at which time the breed effects on sensory quality of
375 beef should still have been observed.

376 At the consumer level, availability of information on breed and sex of the animal and on
377 management, such as feeding is important as these have factors influence consumer assessments,
378 irrespective of sensory quality. Generally, meat from traditional beef breeds is better appreciated by
379 consumers over that from dairy breeds, although little differences in eating quality have been found
380 for beef from dairy and beef breeds by untrained consumers (Bonny et al., 2016b).

381 5. Conclusion

382 We have shown that there is little variability in sensory quality of beef of young bulls from the
383 diversity of European cattle breeds despite significant differences in animal, carcass, muscle and beef
384 characteristics of the same animals. The choice of analysis methods, using averaged sensory values or
385 including panelist as a random effect in a mixed model gave similar results.

386 Five groups were observed for the 15 breeds studied based on meat sensory attributes. The breeds
387 having high lipid content are characterized by superior beef flavour intensity. The rustic breeds
388 produce meat with lower tenderness and juiciness. Double muscled, fast growing and meat-type
389 breeds tend to produce more tender meat. Breed groups formed based on sensory quality traits
390 could help the consumers to choose among them depending on their quality expectations.

391 6. Ethics statement

392 All animal work was reviewed and approved by the ethics committees of the organizations involved.

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396 CRediT authorship contribution statement

397 Conanec Alexandre: Analysis, Writing-original draft. Ellies-Oury Marie-Pierre: Investigation, Writing -
398 review & editing. Hocquette Jean-François: Investigation, Writing - review & editing. Chavent Marie:
399 Methodology, Writing - review & editing. Saracco Jérôme: Methodology, Writing - review & editing.
400 Campo Marimar and Ian Richardson: Investigation, Writing - review & editing. Others: Investigation,
401 review & editing. John Williams project design and management.

402 Declaration of Competing Interest

403 The authors declare to have no conflicts of interest.

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