Has breed any effect on beef sensory quality?

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Highlights

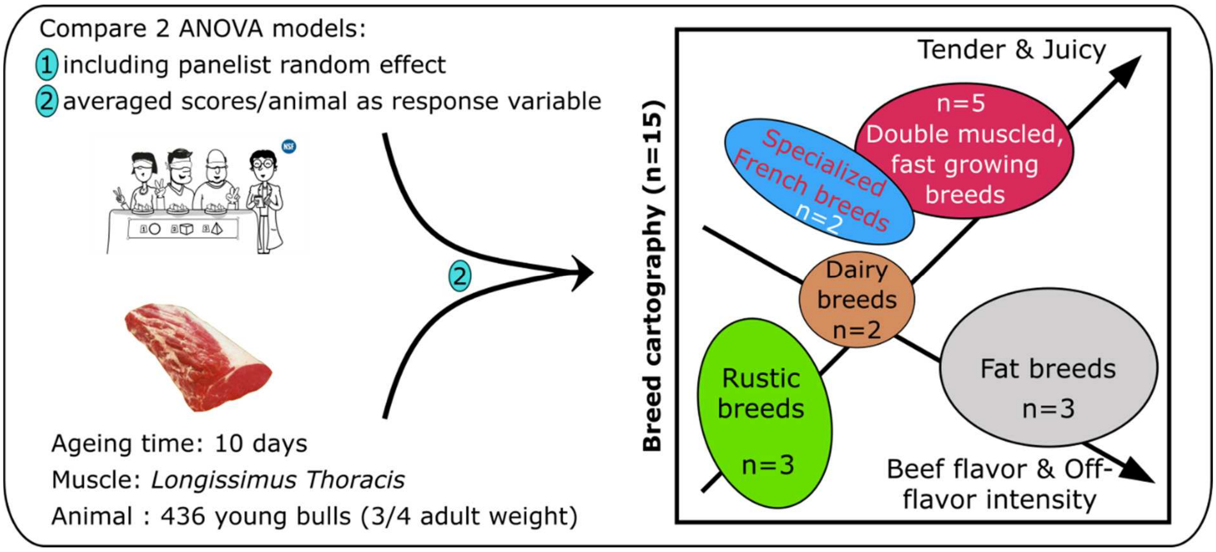
- The 15 studied beef breeds can be categorized in five groups of sensory quality.
- After ten days of ageing, beef from rustic breeds is slightly less tender than those from the other breeds.
- Fat breeds like Aberdeen Angus, Highland and Jersey produce meat with the highest beef flavor intensity.

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

Abstract

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

Graphical abstract



Keywords

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

Abbreviations

- ME: Mixed Effect
- FE: Fixed Effect

1. Introduction

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

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

Studies that have compared f beef eating quality between breeds have generally been limited in size, and in the number of breeds compared. While comparisons among studies is impaired by the different experimental protocols used. Work carried out so far has rarely studied more than 7 breeds under similar experimental conditions (Judge et al. 2021) and in larger studies comparisons could not be made, as rearing conditions were country specific (Panea et al. 2018). The differences observed between breeds are generally small and not always consistent between studies, which is most likely due to the different animal management and meat sensory protocols used. The European consortium GemQual (GEnetics of Meat Quality) addressed these issues by studying the influence of breed on meat quality with all animals managed under similar husbandry conditions and as close as possible the same rearing conditions. The sensory quality of meat from young bulls from15 European breeds was compared by testing in the same laboratories or by the same taste panels. Data related to growth, carcass properties, muscle biochemical contents and physical measurements from these animals have been published (Alberti et al. 2008; Christensen et al. 2011) and these data are used here to test the grouping of breed by sensory parameters.

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

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

2. Materials & Methods

2.1. Experimental design

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

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

2.2. Sensory analysis and texture measurements

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

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

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

Values for Warner–Bratzler shear force and compressive force measured on raw and cooked meat obtained for samples from the same animals (Christensen et al. 2011) were used in the statistical analyses. For these measurements, frozen samples were thawed overnight and equilibrated to room temperature (25 °C) prior to texture analysis. For Warner–Bratzler shear force, slices were cooked in a water bath at 80 °C until the internal temperature reached 75 °C. The sample was then cooled for 45 min in running tap water and stored at 4 °C until analysed. Shear force measurements for raw and cooked samples were performed on 10 blocks (2 cm in length and 1 cm by 1 cm of cross section) cut perpendicular to the fiber direction. For the compression test, samples (1 cm^2 in cross section), were cut with muscle fibers, parallel to the longitudinal axis, and were analyzed using a modified compression device that avoids transversal elongation of the sample. Shear force and compression data are described in Christensen et al. (2011).

2.3. Statistical treatment

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

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

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

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

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

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

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

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 standard variance σ^2.

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

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

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

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

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

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

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

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

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

3. Results

3.1. Statistical model comparison

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

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

Descriptors	*Mixed Effect Anova*	*Fixed Effect Anova*
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

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

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

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

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

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$^{(}$	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

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

3.2. Impact of cattle breed on sensory meat quality

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

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

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

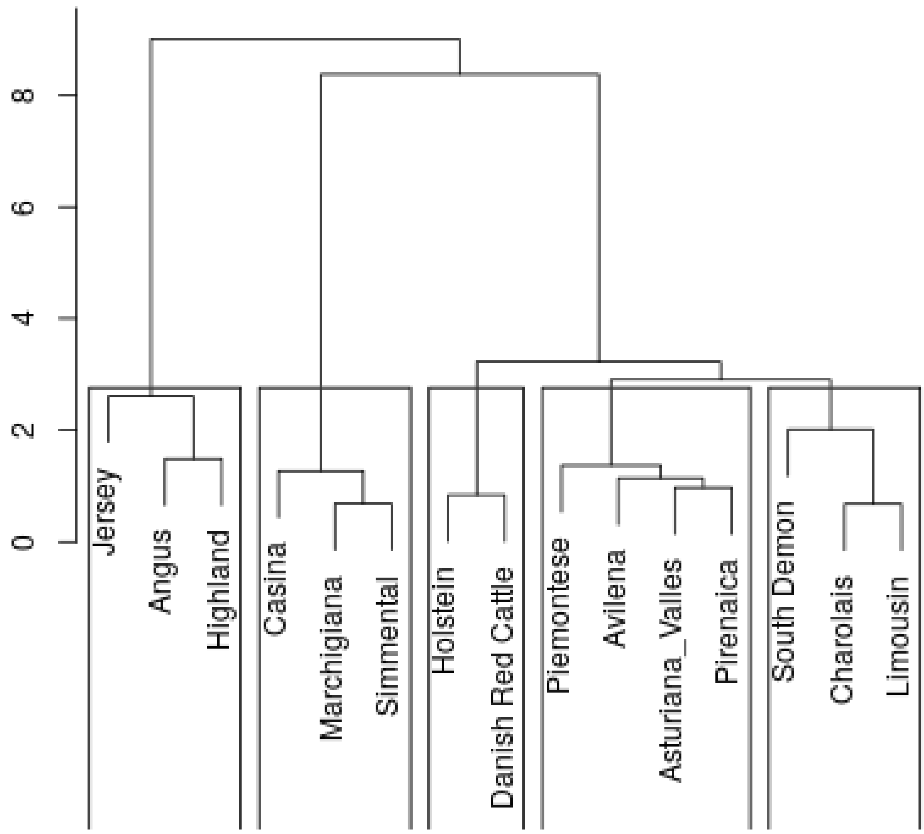


Figure 1 Dendogram of the hierarchical agglomerative clustering (HAC) of breed based on the scale mean data (lsmean) given in the table 3, where five clusters were from each other.

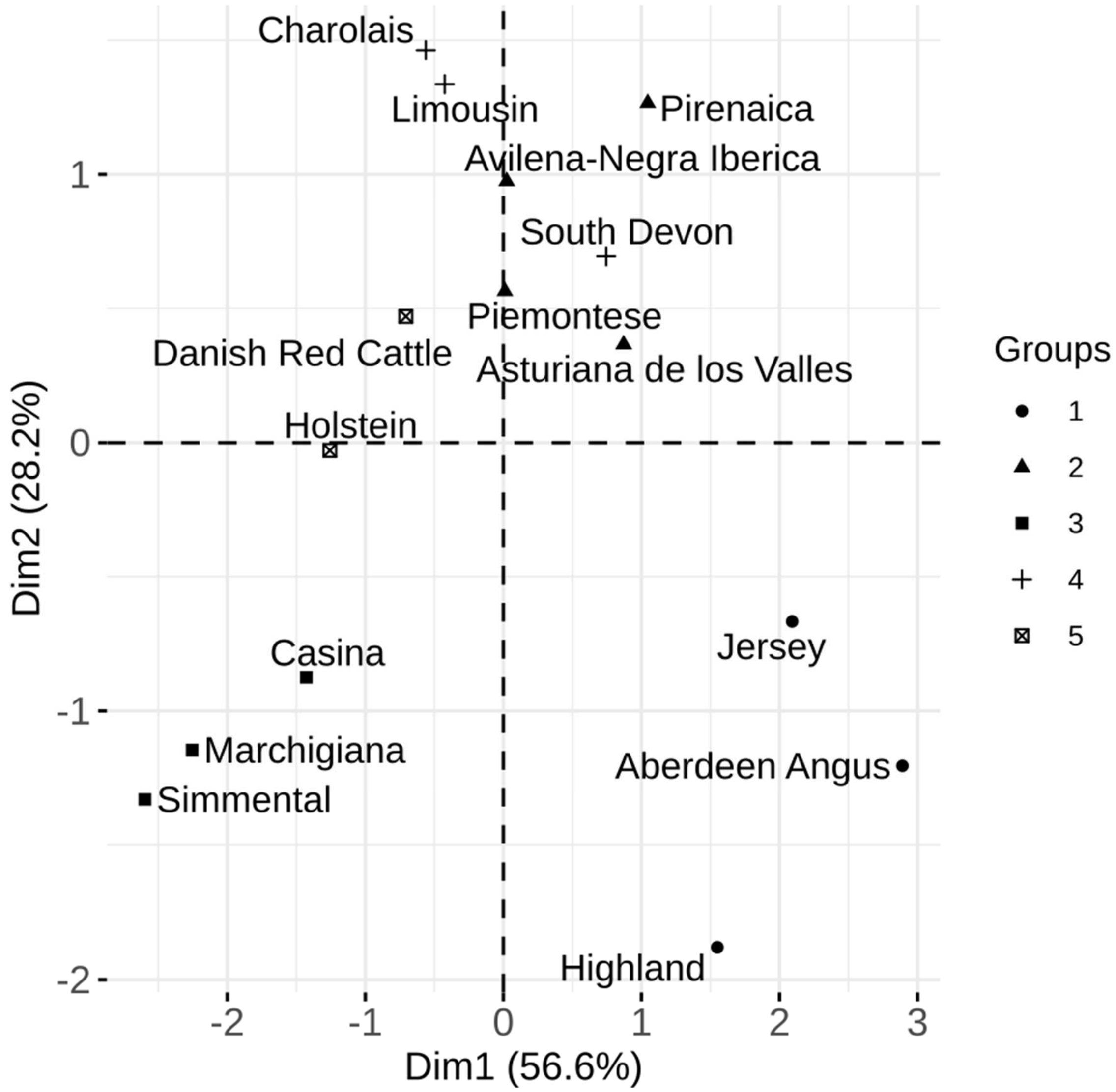


Figure 2: Principal component analyses showing variability between breeds in sensory analysis descriptors (presented in Table 3 and in Figure 1) and in mechanical descriptors (shear force and compressive force measured on raw and cooked meat published by Christensen et al., 2011). The breed associations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

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

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

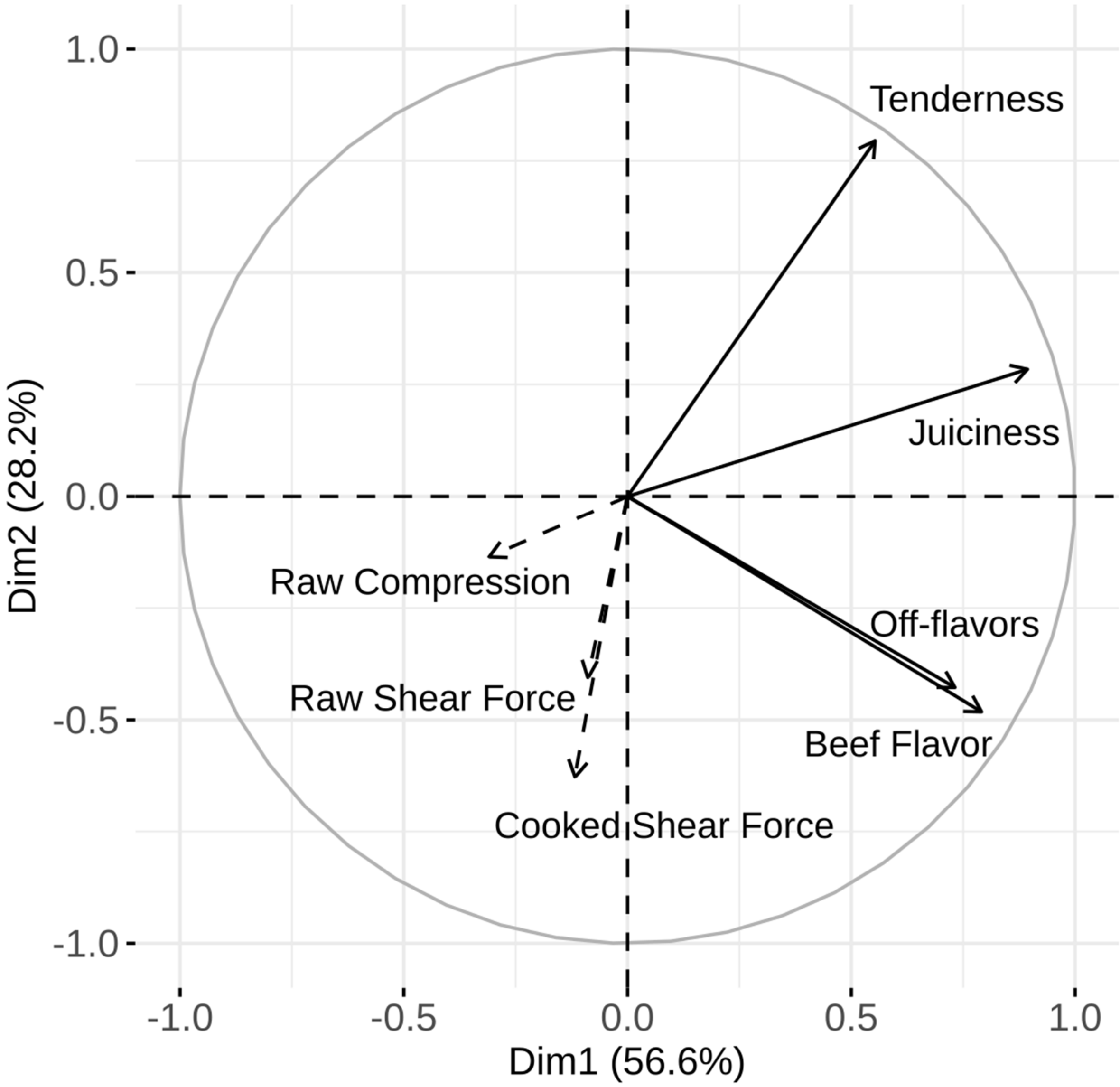


Figure 3: Correlation circle of sensory analysis descriptors (Table 3), illustrated by black arrows, combined with previously published rheological data (Christensen et al. 2011) as supplementary variables (in dotted arrows).

4. Discussion

4.1. Breed clustering is trait-dependent

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

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

The small differences in sensory scores among breeds maybe be due to the within breed variability being high and that the subjective nature of evaluating sensory traits leading to greater variation in values when compared with animal, carcass, muscle and beef characteristics. Results from sensory panels are known to be highly variable (Gagaoua et al., 2016a) which makes standardization and accuracy of measuring the phenotype difficult, which is essential to investigate variation (Hocquette et al., 2012). In this study, we compared two statistical models to assess the technical variability associated with the experimental design. This comparison showed that the inclusion of panelist as factor does not improve significantly the robustness of the statistical model, and does not allow the detection of additional differences between breeds than the model without panelist as a factor.

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

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

This work found that fast growing breeds such as Pirenaica (Campo et al. 1999) as well as the double-muscled breeds produce the most tender beef. This may be related to proportion of total and insoluble collagen, which is higher when muscle mass is low which contributes to beef toughness (Purslow, 2005), while low total and insoluble collagen contents are known to increase tenderness scores (Chriki et al., 2012). Higher collagen content per g of tissue has been reported in the longissimus muscle from Angus compared to Limousin steers (Chambaz et al., 2003) and in Limousin compared to double-muscled Belgian Blue cattle (Raes et al., 2003). Other differences in sensory traits between breeds may be explained by differences in intramuscular fat content. The high intramuscular lipid content of the Aberdeen Angus, Highland and Jersey breeds could explain in part the high flavour, whereas the low intramuscular fat content of the Limousin breed could be related to the less intense beef flavour(Gagaoua et al., 2016b). Differences in lipid, intramuscular collagen content and also in fibre type are thought to explain differences in sensory quality of beef (Chriki et al. 2012, Chriki et al. 2013), although. there is inconsistency in these differences associated with muscle, animal type and the productive function related to the breed (dairy or meat type).

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

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

Comparing breeds based on their sensory characteristics is a factor, among others, on which consumers choose the beef. However, comparing breeds is difficult as there is little information available. Collecting reliable information has been hampered by animals being reared in different ways. Cattle management differs among breeds and is dependent both on breed, resources and practices in different regions. Breeds that originated in specific regions where particular feed, resources and condition were available, are now found internationally. Many studies have compared different types of cattle and systems, confounding breeds, sexes and management systems (Gagaoua et al., 2016b) rather than strictly comparing the breeds. Compare breed-management effects on beef sensory quality is important, but must be explained to the consumer (Panea et al. 2018). In order to make an unbiased comparison between a large number of breeds, the GemQual project established protocols that were as standardized as possible with entire bulls only. Nevertheless, some biases are likely to have persist. In addition to differences in management and breed, it is necessary to recruit members of sensory panels that give consistent results. Some descriptors have been shown to have moderate correlation, e.g. tenderness r=0.67, juiciness r=-0.14, flavour r=0.1, abnormal flavour r=0.2. Meta-analyses of several studies are also possible, although this requires that the diversity of protocols is accounted for in the analysis. A recent work showed that standardization of scoring scales is only partially successful and a random effect associated with the experiment is necessary in the analysis model (Judge et al. 2021) Other sources of variability such as meat ageing time and sex of the animal make it difficult to determine of the contribution of breed to differences in sensory quality. Increasing the ageing period, reduces difference in meat between breeds. It has been shown that with 21 days aging differences between breeds cannot be detected (Campo et al. 1999). In the GemQual study, the meat was aged for 10-days, at which time the breed effects on sensory quality of beef should still have been observed.

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

5. Conclusion

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

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

6. Ethics statement

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

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CRediT authorship contribution statement

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

Declaration of Competing Interest

The authors declare to have no conflicts of interest.

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