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RESEARCH ARTICLE

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Exploring rearing factors to predict potential sensory quality of heifer meat throughout the farm-to-fork continuum

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ABSTRACT
Sensory beef qualities could be impacted throughout the farm-to-fork continuum. The aim of this work was to predict the sensory quality classes of *Longissimus* muscle established from three sensory descriptors: tenderness, juiciness and flavour intensity. The extreme classes of meat quality were: Q + class including the highest scores for tenderness and juiciness, and an intermediate score for flavour intensity and Q – class including low scores for tenderness, juiciness and flavour intensity. To predict the extreme quality classes, seven decision trees were performed using the individual data related to rearing factors ($p = 50$), carcase traits ($p = 13$) and/or aged meat traits ($p = 9$) of 100 Charolais heifers. The decision trees established from rearing factors and carcase trait data (RF-CARCA-Tree) allowed the highest accuracy of prediction (79.7%) with 90.7% and 66.7% of correctly classified individuals, respectively. Our results showed that different combinations of factors could produce Q + class. Three rearing factors (i.e. the calculated average of concentrates' net energy content in the diet during the pasture period of pre-weaning period (PWP); the number of days concentrates were offered in calf diet during PWP; and the calculated average of concentrates' crude protein content in the fattening diet) and the conformation score could be considered as action levers to improve meat quality. These three rearing factors were related to the pre-weaning and fattening periods of the heifer, slowing a possible management of the potential beef quality from rearing factors throughout the life of the heifer.

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Rearing factors; carcass traits; beef; decision tree; whole life

HIGHLIGHTS

- Beef quality can be improved throughout the heifer's life by rearing factors related to concentrate in the diet.
- Sensory beef quality classes could be managed from rearing factors and carcass traits.
- Raw aged meat data did not allow to improve the prediction of sensory beef quality classes.

Introduction

Beef consumption has been declining in France and Europe for several decades (Prache et al. 2021, 2023). In general, consumer behaviour is influenced by psychological, sensory and marketing factors (Tomasevic et al. 2018). Consumers' reasons for reducing beef consumption include high prices, health risks, environmental and animal welfare impacts of farming, and inconsistent sensory quality (Ellies-Oury et al. 2019). Sensory attributes are crucial to the purchase decisions and consumer satisfaction (Banović et al. 2009). Among the sensory attributes, tenderness, juiciness and flavour are the most important for consumers when evaluating beef quality (Santos et al. 2021). Consequently, a key challenge for the meat sector to maintain meat consumption is to guarantee the sensory quality of the product in order to meet consumer expectations, avoid disappointment and encourage renewed meat consumption. It is therefore necessary to develop easily accessible tools that can guarantee the potential quality of the meat from a carcass, so that those involved in the sector can direct it to the appropriate market (traditional or premium market for high quality meat, market for processing into minced meat or ready meals for lower quality meat), thus avoiding consumer dissatisfaction.

The sensory quality of meat can be managed at different stages of the production process to meet consumer expectations. Recent studies have shown the influence of

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rearing factors (e.g. growth rate during the growth and fattening periods, concentrate content of the fattening diet, fattening duration, live weight at the start of fattening) on the sensory quality parameters of beef (Gagaoua et al. 2019; Soulat et al. 2021; Cabiddu et al. 2022). Relationships between carcass traits (carcase weight, fat score, dressing %, muscle %) and meat tenderness were also found by Gagaoua et al. (2019), although other authors showed a weak or no relationship between fat and conformation scores on the one hand and sensory parameters on the other (Bonny et al. 2016; Janiszewski et al. 2018). Significant correlations displayed between the textural properties of aged meat (hardness, chewiness, adhesiveness, etc.) and several sensory quality parameters such as tenderness, juiciness and flavour (Otremba et al. 2000; Pematilleke et al. 2022). Consequently, each level of the production chain (rearing factors, carcass and aged meat) can be used, individually or in combination to predict the sensory quality of beef.

The first aim of this study was to predict the sensory quality of beef by considering the three main traits of meat assessment (tenderness, juiciness, flavour intensity) using data available before tasting. These data were categorised into three groups: rearing factors, carcass traits and aged meat traits. A second aim was to identify the most accurate prediction from these data groups or their associations. The decision tree method was used to achieve these goals. This statistical method was developed in the 2010s in the field of computer science as a nonparametric supervised learning tool for classification and regression (Yu et al. 2010). It was then used for its operational applicability in the field of medicine (Fan et al. 2011; Song and Lu 2015). Some authors have already used this method to predict carcass quality classes (combination of carcass weight and conformation score), or beef tenderness classes from the combinations of many factors (rearing factors and/or carcass traits) (Gagaoua et al. 2019; Monteils and Sibra 2019a).

Materials and methods

Animals and rearing practices

The study was carried out on the individual data of 100 Charolais heifers reared on 21 farms in the Auvergne-Rhône-Alpes region (France). A face-to-face survey of farmers was carried out on each farm to collect information on the rearing practices applied throughout the heifer's life which is split into three periods: pre-weaning, growth and fattening. Soulat et al. (2022) previously described the survey methodology in detail. The rearing practices applied throughout the heifer's life were characterised by 50 rearing factors, i.e. 30 quantitative factors and 20 qualitative factors (Tables 1 and 2).

Carcass traits and sampling

The animals were slaughtered in four industrial slaughterhouses (Puigrenier, Montluçon, France; SICABA, Bourbon-l'Archambault, France; SICAREV, Roanne, France; SOCOPA, Villefranche-d'Allier, France) in the Auvergne-Rhône-Alpes region in accordance with the regulations in force in France at the time of slaughter (European Commission 2006). The slaughtering process and carcass measurements were described by Soulat et al. (2022). Briefly, each carcass was weighed and graded by an official judge to determine the conformation (from E: very high muscle development to P: very low muscle development) and fat scores (from 1: very lean to 5: very fat) immediately after slaughter using the EUROP classification grid (European Commission 2006). After chilling for 24 h at +2 °C, the carcasses were cut at the 6th rib level and other measurements (e.g. fat, meat texture, colour) were performed as described by Soulat et al. (2022). All the carcass traits collected ($p = 13$) are presented in Table 3. The 4th and 5th ribs were then removed and aged for 14 days at +4 °C and then stored at −20 °C until the next measurements.

Meat analyses

The muscle studied in this work is the *Longissimus* muscle (LM) as a reference muscle for the scientific community.

After thawing, the LM was separated from the rest of the rib to be used for measurement. Colour was measured on raw meat using a spectrophotometer (Konica Minolta CR-400, Osaka, Japan) and expressed according to the L*a*b* system (Schanda 2007). Texture profile analyses (TPAs) were performed to determine six texture parameters (springiness, hardness, cohesiveness, resilience, gumminess and chewiness) according to the method proposed by Chinzorig and Hwang (2018). Raw meat cylinders were compressed twice at 20% using rheometer Kinexus Pro+ (Malvern Instruments, Malvern, UK; rSpace 1.61 software, Kinexus, Malvern, UK) as explained in Soulat et al. (2022). During each sensory session, the sensory properties of eight LM samples were assessed monadically by a panel of 10 trained judges, using a Latin square design. Two or three steaks (2 cm thickness) were cut from each LM sample. Then, each steak was placed in aluminium foil and was cooked in a plancha at

Table 1. Description of the quantitative rearing factors applied according to the life period of heifers ($n = 100$).

Quantitative rearing factors	Description of the rearing factor	Mean	SD
Pre-weaning period, PWP			
Age of the cow, year	Age of the heifer's mother at the heifer's birth	5.68	2.36
Age at the first calving, year	Age of the heifer's mother at first calving	2.98	0.16
Age at the weaning, month	Age of heifer at the weaning	8.72	1.28
Housing_duration_PWP, day	Numbers of days spent in stall during PWP	101.80	48.30
Pasture_duration_PWP, day	Number of days spent on the pasture during PWP	162.30	44.50
Tot_forage_duration_PWP, day	Number of days forages were offered in calf diet during PWP	77.30	72.80
Conc_housing_PWP, day	Number of days concentrates were offered in calf housing diet during PWP	62.40	55.20
Conc_PWP, day	Number of days concentrates were offered in calf diet during PWP	132.20	95.50
Growing period, GP			
Housing_duration_GP, day	Number of days spent in stall during GP	230.50	79.20
Outside_duration_GP, day	Number of days spent outside during GP	417.90	204.50
Pasture_duration_GP, day	Number of days spent on the pasture during GP (heifers graze)	361.00	158.70
GP_duration, day	Number of days between the weaning and the beginning of the fattening	648.40	172.00
Forage_comp_outside_GP, day	Number of days forages were offered during the whole outside period of GP	143.10	110.00
Hay_housing_GP, %	Calculation of the hay percentage in the average housing diet over the whole GP	39.90	30.50
Grass_silage_housing_GP, %	Calculation of the grass silage percentage in the average housing diet over the whole GP	30.10	28.90
Conc_housing_duration_GP, day	Number of days concentrates were offered in the housing diet during GP	162.60	118.10
Conc_duration_GP, day	Number of days concentrates were offered in the diet during GP	198.20	129.70
Conc_quanti_intake_housing_GP, kg	Total concentrate quantity intake per heifer during the housing period	297.70	330.30
Conc_quanti_intake_GP, kg	Total concentrate quantity intake per heifer during the whole GP	355.00	335.20
Conc_CP_housing_GP, %	Calculated average of concentrate's crude protein content over the whole housing period	14.40	7.70
Conc_NE_housing_GP, kJ	Calculated average of concentrate's net energy content over the whole housing period	1.51	0.78
Conc_CP_GP, %	Calculated average of concentrate's crude protein content over the whole GP	14.80	6.90
Conc_NE_GP, MCal	Calculated average of concentrate's net energy content over the whole GP	1.58	0.71
Fattening period, FP			
Age early fattening, month	Age of the heifer at the beginning of FP	30.20	6.00
Slaughter age, month	Age of the heifer at the slaughter	34.10	5.80
Housing_duration_FP, day	Number of days spent in stall during the FP	67.90	74.20
FP_duration, day	Number of days between the beginning of FP and the slaughter	120.40	79.70
Conc_quanti_intake_FP, kg	Total concentrate quantity intake per heifer during the whole FP	681.10	563.70
Conc_CP_FP, %	Calculated average of concentrate's crude protein content over the whole FP	17.80	5.30
Conc_NE_FP, MCal	Calculated average of concentrate's net energy content over the whole FP	1.74	0.42

PWP: pre-weaning period; SD: standard deviation; GP: growing period; CP: crude protein; NE: net energy; FP: fattening period

300 °C to reach an internal temperature of 55 °C. After, the cooked steaks were cut into homogeneous pieces (size 15 × 20 × 20 mm) and kept warm until the tasting. During the sensory session, on a 10 cm unstructured scale, each judge rated tenderness (0 = tough to 10 = very tender), juiciness (0 = dry to 10 = very juicy) and flavour intensity (0 = none to 10 = very intense). These assessments were performed using a Tastel software® (ABT Informatique, Rouvroy-sur-Marne, France). All tests were realised in individual sensory booths in accordance with ISO 8589 (2010). Between each LM sample tested, the judges used mineral water (Evian, France) and unsalted crackers to rinse their mouths. The panel members realised 6 h of training prior to the analyses in accordance with ISO 8586 (2014). In this step, the panel members were trained to recognise different perceptions and to use the perception scales of the sensory descriptors considered in this study.

All the data for both raw and cooked meat ($p = 12$) is presented in Table 4.

Statistical analyses

All statistical analyses were performed using XLstat 2023.1.2 software (Addinsoft, Paris, France).

Meat quality classes were determined from the three sensory parameters (tenderness, juiciness, flavour intensity) using K-means classification method (Likas et al. 2003). Between the meat quality classes obtained, analysis of variance (ANOVA) were conducted for each sensory descriptor to evaluate their dependence on the defined meat quality classes (independent variable). If the result of the ANOVA was significant, a Tukey test was performed to compare the average pairwise. The significance threshold was set at .05.

Predictions were performed using the decision tree method, which is easy to understand and use, and is considered relevant for the study of combinations of several predictors in the field of meat quality (Monteils et al. 2021). Decision trees were established to predict the extreme quality classes (higher quality, Q+ and lower quality, Q−) from the data groups of rearing factors ($p = 50$), carcass traits ($p = 13$) and aged meat data ($p = 9$). These data groups were considered separately and together. As explained by Monteils and Sibra (2019a), decision trees are an integrative method that allows quantitative and qualitative predictors to be considered jointly and in combination. The trees were created using the CHAID (Chi-square automatic interaction detector) method combined with the likelihood

Table 2. Description of the qualitative rearing factors applied according to the life period of heifers ($n = 100$).

Qualitative rearing factors	Modalities	Description of the rearing factor	%
Pre-weaning period, PWP			
Insemination type	Artificial	Artificial insemination using frozen semen	15.0
	Natural	Insemination performed by a bull	85.0
Calving	Easy	Natural calving	69.0
	Help	Farmer intervention during the calving	31.0
Forage_housing_PWP	Yes	Offered forages in housing calf diet during PWP	47.0
	No	No offered forages in housing calf diet during PWP	53.0
Forage_pasture_PWP	Yes	Offered forages in pasture calf diet during PWP	26.0
	No	No offered forages in pasture calf diet during PWP	74.0
Conc_pasture_PWP	Yes	Offered concentrates in pasture calf diet during PWP	52.0
	No	No offered concentrates in pasture calf diet during PWP	48.0
Conc_CP_housing_PWP, %	No	No offered concentrates in housing calf diet during PWP	34.0
	≤16%	Over the whole housing of PWP, the calculated average of concentrate's crude protein content was below 16%	22.0
	>16%	Over the whole housing of PWP, the calculated average of concentrate's crude protein content was above 16%	44.0
Conc_NE_housing_PWP, MCal	No	No offered concentrates in housing calf diet during PWP	34.0
	≤1.8 MCal	Over the whole housing of PWP, the calculated average of concentrate's net energy content was below 1.8 MCal	42.0
	>1.8 MCal	Over the whole housing of PWP, the calculated average of concentrate's net energy content was above 1.8 MCal	24.0
Conc_CP_pasture_PWP, %	No	No offered concentrates in pasture calf diet during PWP	48.0
	≤18%	Over the whole pasture of PWP, the calculated average of concentrate's crude protein content was below 18%	29.0
	>18%	Over the whole pasture of PWP, the calculated average of concentrate's crude protein content was above 18%	23.0
Conc_NE_pasture_PWP, MCal	No	No offered concentrates in pasture calf diet during PWP	48.0
	≤1.7 MCal	Over the whole pasture of PWP, the calculated average of concentrate's net energy content was below 1.7 MCal	37.0
	>1.7 MCal	Over the whole pasture of PWP, the calculated average of concentrate's net energy content was above 1.7 MCal	15.0
Conc_CP_PWP, %	No	No offered concentrates during PWP	26.0
	≤17%	Over the whole PWP, the calculated average of concentrate's crude protein content was below 17%	40.0
	>17%	Over the whole PWP, the calculated average of concentrate's crude protein content was above 17%	34.0
Conc_NE_PWP, MCal	No	No offered concentrates diet during PWP	26.0
	≤1.8 MCal	Over the whole PWP, the calculated average of concentrate's net energy content was below 1.8 MCal	50.0
	>1.8 MCal	Over the whole PWP, the calculated average of concentrate's net energy content was above 1.8 MCal	24.0
Growing period, GP			
Wrapped_haylage_housing_GP, %	0%	Over the GP, the heifers had no wrapped haylage in the housing diet	64.0
	≤50%	Over the GP, the calculated average percentage of wrapped haylage in the housing diet was below 50%	16.0
	>50%	Over the GP, the calculated average percentage of wrapped haylage in the housing diet was above 50%	20.0
Corn_silage_housing_GP, %	0%	Over the GP, the heifers had no corn silage in the housing diet	59.0
	<25%	Over the GP, the calculated average percentage of corn silage in the housing diet was below 25%	26.0
	[25%; 40%]	Over the GP, the calculated average percentage of corn silage in the housing diet was between 25% and 40%	15.0
Conc_outside_GP	Yes	Offered concentrates during the outside period	37.0
	No	No offered concentrates during the outside period	63.0
Conc_quanti_intake_outside_GP, kg	0 kg	No offered concentrates during the outside period	63.0
	≤150 kg	Total concentrate quantity intake per heifer during the outside period was below 150 kg	17.0
	>150 kg	Total concentrate quantity intake per heifer during the outside period was above 150 kg	20.0
Conc_CP_outside_GP, %	No	No offered concentrates outside	63.0
	≤18%	Over the outside period, the calculated average of concentrate's crude protein content was below 18%	17.0
	>18%	Over the outside period, the calculated average of concentrate's crude protein content was above 18%	20.0
Conc_NE_outisde_GP, MCal	No	No offered concentrates outside	63.0
	≤1.8 MCal	Over the outside period, the calculated average of concentrate's net energy content was below 1.8 MCal	22.0
	>1.8 MCal	Over the outside period, the calculated average of concentrate's net energy content was above 1.8 MCal	15.0
Fattening period, FP			

(*continued*)

Table 2. Continued.

Qualitative rearing factors	Modalities	Description of the rearing factor	%
Fattening system	Housing	The fattening was carried out in stall	56.0
	Pasture and housing	The fattening began in pasture and ended in stall	20.0
	Pasture	The fattening was carried out on pasture	24.0
Pasture_duration_FP, day	No pasture	No pasture during the FP	57.0
	≤100 days	During the FP, the number of days on pasture was below 100 days	22.0
	>100 days	During the FP, the number of days on pasture was above 100 days	21.0
Main conserved forage in the FP diet, %	Grass_silage_and_wrapped_haylage	The percentage of the sum of grass silage and wrapped haylage in the FP diet was above 85%	3.0
	Corn_silage	The percentage of corn silage in the FP diet was above 90%	24.0
	Grass_silage	The percentage of grass silage in the FP diet was above 90%	4.0
	Hay	The percentage of hay in the FP diet was above 95% (except for one animal, hay = 64%)	4.0
	Straw	The percentage of straw in the FP diet was above 75%	21.0
	Wrapped_haylage	The percentage of wrapped haylage in the FP diet was above 70%	5.0
	Corn_silag_and_wrapped_haylage	The percentage of the sum of corn silage and wrapped haylage in the FP diet was above 80%	7.0
	Hay_and_wrapped_haylage	The percentage of the sum of hay and wrapped haylage in the FP diet equal 100%	14.0
	No	No offered conserved forages in the FP diet	18.0

PWP: pre-weaning period; GP: growing period; FP: fattening period; NE: net energy; CP: crude protein

Table 3. Carcass traits measured in slaughterhouse (n = 100).

Carcass traits	Description of the carcass traits	Mean	SD
Quantitative traits			
Cold weight, kg		396.40	43.20
Fat score	EUROP classification scale for fat score (1 = lean to 5 = very fat)	2.98	0.32
Assessment at the cut section on the 6th rib			
Longissimus muscle seepage	*Longissimus* muscle seepage assessment (1 = dry with no drop to 5 = important drop)	1.98	1.00
Subcutaneous fat, cm	Measure of the subcutaneous fat thickness	0.78	1.00
Inter-muscular fat	Inter-muscular fat assessment (1 = limited development to 5 = large amount)	2.20	1.07
Overall meat grain	Overall meat grain assessment (1 = smooth, soft, without harshness to 5 = very rough/granular)	2.22	0.78
Longissimus meat grain	*Longissimus* meat grain assessment by touch (1 = smooth, soft, without harshness to 5 = very rough/granular)	1.98	0.99
Rhomboideus meat grain	*Rhomboideus* meat grain assessment by touch (1 = smooth, soft, without harshness to 5 = very rough/granular)	1.62	0.90
Fat colour	Fat colour assessment using the colour chart	2.80	1.52
Colour homogeneity of muscles	Colour homogeneity assessment between muscles (1 = homogeneous, 2 = bicolour, 3 = tricolour and 4 = more than 3 colours)	1.81	0.58
Longissimus marbling	Longissimus marbling assessment using the marbling scale	1.57	0.99
Ultimate pH	pH measured 24 h *post-mortem*	5.65	0.29
Qualitative traits		Modality	%
Conformation score	EUROP classification scale for conformation	E	0.0
		U	18.0
		R	82.0
		O	0.0
		P	0.0
Conformation score – third of class	EUROP classification scale for conformation used with thirds of classes	E+	0.0
		E=	0.0
		E–	0.0
		U+	0.0
		U=	3.0
		U–	15.0
		R+	52.0
		R=	24.0
		R–	6.0
		O+	0.0
		O=	0.0
		O–	0.0
		P+	0.0
		P=	0.0
		P–	0.0

SD: standard deviation

measurement. The quality class assigned to the terminal leaves of the trees corresponded to the class in which the majority of the individuals constituting the leaf were represented. The predictive quality of the trees was assessed using the criteria of accuracy, sensitivity and specificity as proposed by Baratloo et al. (2015). The sensitivity is the percentage of individuals in the Q + class which were well classified in the Q + class. The specificity is the percentage of individuals in the Q – class which were well classified in the Q – class. The accuracy is the total percentage of correctly classified individuals. The splitters identified in the trees correspond to predictors of meat quality class, and therefore to potential levers for action to achieve one quality class rather than another.

Table 4. Meat traits measured on *Longissimus* muscle ($n = 100$).

Meat traits	Mean	SD
Raw meat		
Texture profile analysis		
Springiness	0.48	0.07
Hardness, N	1.54	0.45
Cohesiveness	2.11	1.20
Resilience	0.24	0.09
Gumminess	3.24	1.89
Chewiness	1.52	0.85
Colour descriptors		
L*	42.00	2.90
a*	19.50	3.60
b*	12.40	1.30
Cooked meat		
Sensory descriptors (0–10 scale)		
Tenderness	5.95	0.92
Juiciness	4.60	0.79
Flavour intensity	5.85	0.61

SD: Standard Deviation; L*: Lightness; a*: Redness; b*: Yellowness.

Table 5. Sensory properties of *Longissimus* (LM) meat according to the quality classes.

	LM quality classes			
Sensory descriptors	Q+ ($n = 43$)	Q= ($n = 21$)	Q– ($n = 36$)	p
Tenderness	6.67[a]	5.60[b]	5.29[b]	<.0001
Juiciness	5.18[a]	4.14[b]	4.18[b]	<.0001
Flavour intensity	6.09[b]	6.42[a]	5.23[c]	<.0001

Values followed by different letters (a, b, c) on the same row are significantly different from each other at $p \leq .05$.
Q+: superior sensory quality of *Longissimus*; Q=: intermadiate sensory quality of *Longissimus*; Q-: inferior sensory quality of *Longissimus*

Results and discussion

Characterisation of the sensory meat quality classes

Three sensory meat quality classes were identified by applying the K-means method from data of three sensory descriptors which were (tenderness, juiciness and flavour intensity). The Q + class had the highest scores for tenderness and juiciness, and an intermediate score for flavour intensity (Table 5). The Q = class showed low scores for tenderness and juiciness, and the highest score for flavour intensity. The Q – class had low scores for tenderness and juiciness and the lowest score for flavour intensity.

Prediction of sensory meat quality classes

The extreme sensory meat quality classes (Q + and Q–) were predicted from the data groups available prior to tasting (rearing factors, carcass traits and aged meat data) or a combination of several of these groups, using decision trees. Seven decision trees were performed and their characteristics are presented in Table 6 according to the data groups used, and classified according to the ease of access to the information necessary for their construction.

The carcass data were the most accessible as it could be measured or assessed at the slaughterhouse without the need for laboratory analysis. The decision tree obtained from the carcass trait data (CARCA-Tree)

Table 6. Decision tree characteristics according to the data groups used to perform it and ranked in decreasing order of information accessibility.

					Factor identified as splitter in decision tree		
Decision tree	n	Sensitivity, %	Specificity, %	Accuracy, %	1st level	2nd level	3rd level
CARCA-Tree	79	88.4	36.1	64.6	Conformation score		
MEAT-Tree	79	100	0.0	54.4	None		
CARCA-MEAT-Tree	79	88.4	36.1	64.6	Conformation score		
RF-Tree	79	83.7	66.7	75.9	Conc_NE_pasture_PWP	Conc_CP_FP Conc_PWP	Fattening duration
RF-CARCA-Tree	79	90.7	66.7	79.7	Conc_NE_pasture_PWP	Conc_PWP Conformation score	Conc_CP_FP
RF-MEAT-Tree	79	83.7	66.7	75.9	Conc_NE_pasture_PWP	Conc_CP_FP Conc_PWP	Fattening duration
ALL-Tree	79	90.7	66.7	79.7	Conc_NE_pasture_PWP	Conc_PWP Conformation score	Conc_CP_FP

CARCA-Tree: decision tree obtained from carcass data; MEAT-Tree: decision tree obtained from aged meat data; CARCA-MEAT-Tree: decision tree obtained from carcass and aged meat data; RF-Tree: decision tree obtained from rearing factor data; RF-CARCA-Tree: decision tree obtained from rearing factor and carcass data; RF-MEAT-Tree: decision tree obtained from rearing factor and aged meat data; ALL-Tree: decision tree obtained from rearing factor, carcass and aged meat data.

allowed to discriminate both meat quality classes only with the conformation score and this accuracy was 64.6% (Table 6). The Q + class was well classified (88.4%) whereas the Q − class was much less so (36.1%).

The aged meat data were not easily accessible because, samples had to be collected and aged, and special measuring equipment for TPA and colour descriptors are required. The decision tree built from the aged meat data (MEAT-Tree) was unable to divide initial population into two distinct sub-populations. In MEAT-Tree, all heifers were assigned to the quality class of Q+.

The decision tree obtained from the carcass and aged meat traits (CARCA-MEAT-Tree) was the same as CARCA-Tree (Table 6). The combination of the carcass trait and aged meat date in the same tree did not allow to improve the performances of the model to discriminate the meat quality classes.

The rearing factor data required a survey of farmers in order to collect the rearing management applied throughout the animals' life. The accessibility of these data was therefore much lower than that of the previous data groups because of the need to identify farmers and the time required to collect and analyse the data. For the decision tree established from the rearing factors (RF-Tree), 75.9% of individuals were accurately classified (Table 6). The RF-Tree improved capacity to discriminate meat quality classes and had a higher specificity compared to CARCA-Tree. The RF-Tree correctly classified 83.7% of Q + meat class and 66.7% of Q − meat class. In RF-Tree, three levels of splitters appeared which were mainly related to the diet type (Figure 1). The pre-weaning and fattening periods contribute to discriminate both meat quality classes. Three pathways allowed to produce mainly meat quality Q+. A pathway that considered only the pre-weaning period (PWP) was: if the concentrate had a net energy value below 1.7 MCal during the pasture phase and if the heifers were fed concentrate for more than 226 days of the whole PWP, then the LM meat obtained was graded as 100% Q+. A pathway with the same concentrate's net energy level and if the heifers were fed concentrate less than 226 days of the whole PWP, only 63.2% of LM meat was graded Q+. Another pathway considered the pre-weaning and fattening periods was: if the heifers did not receive any concentrate or received a concentrate with a net energy level above 1.7 MCal while grazing before weaning and a concentrate with a crude protein level below 16.3% during the fattening period, then the LM meat obtained was graded as 72.2% Q+.

Two other pathways allowed to mainly produce meat quality as Q− (Figure 1). If the heifers did not receive or if the concentrate had a net energy level above 1.7 MCal while grazing before weaning, and if heifers received, during the fattening period, a concentrate with a crude protein level above 16.3% and a fattening duration above 144 days then the LM meat obtained was graded as 100% Q−. The same pathway with a fattening duration below 144 days allowed to produce LM meat obtained was graded as 61.1% Q−.

According to our results, the nutritional value of concentrates during the pre-weaning and fattening periods, as well as the duration of concentrate presence in the diet of calves, can potentially enhance LM meat quality. However, Hennessy et al. (2001) did not observe an increase of tenderness, juiciness and flavour of LM when the young bulls and heifers had access to concentrate supplementation during the PWP. To our knowledge, this is the first instance where that the net energy level of the concentrate during the PWP's pasture has been identified as having a significant impact on the sensory meat quality. Few results on the impact of the PWP on the meat quality were available in the literature (Hennessy et al. 2001; Blanco et al. 2008; Ramírez-Zamudio et al. 2023). An effect of the concentrate intake at pasture before weaning was observed on carcass traits in heifers (Soulat et al. 2018; Monteils and Sibra 2019b; Monteils et al. 2021). Further research is needed to validate our findings concerning the effect of concentrates fed during the PWP on heifer beef quality.

Contrary to our results, previous studies did not observe any influence of protein level in the concentrate intake during the fattening period on the tenderness, juiciness and flavour, in steers and heifers (Berge et al. 1993; Li et al. 2014). However, an effect of concentrate's net energy level in the fattening diet was previously observed on the flavour intensity, in the young bulls and cull cows (Soulat et al. 2016). Although, Li et al. (2014) did not observe any effect of the concentrate's net energy level on the tenderness assessed by shear force, in heifers and steers. An increase of the concentrate quantity or proportion in the fattening diet had no effect on the tenderness, flavour and juiciness of LM, in steers and cull cows for some authors (French et al. 2000, 2001; Kerth et al. 2007; Hernández-Calva et al. 2011). For other authors, a non-linear increase was observed on the sensory properties of LM (tenderness and flavour) in young bulls and steers, with no effect on juiciness (Roberts et al. 2009; Gagaoua et al. 2018). Moreover and in accordance with our results; an increase of the

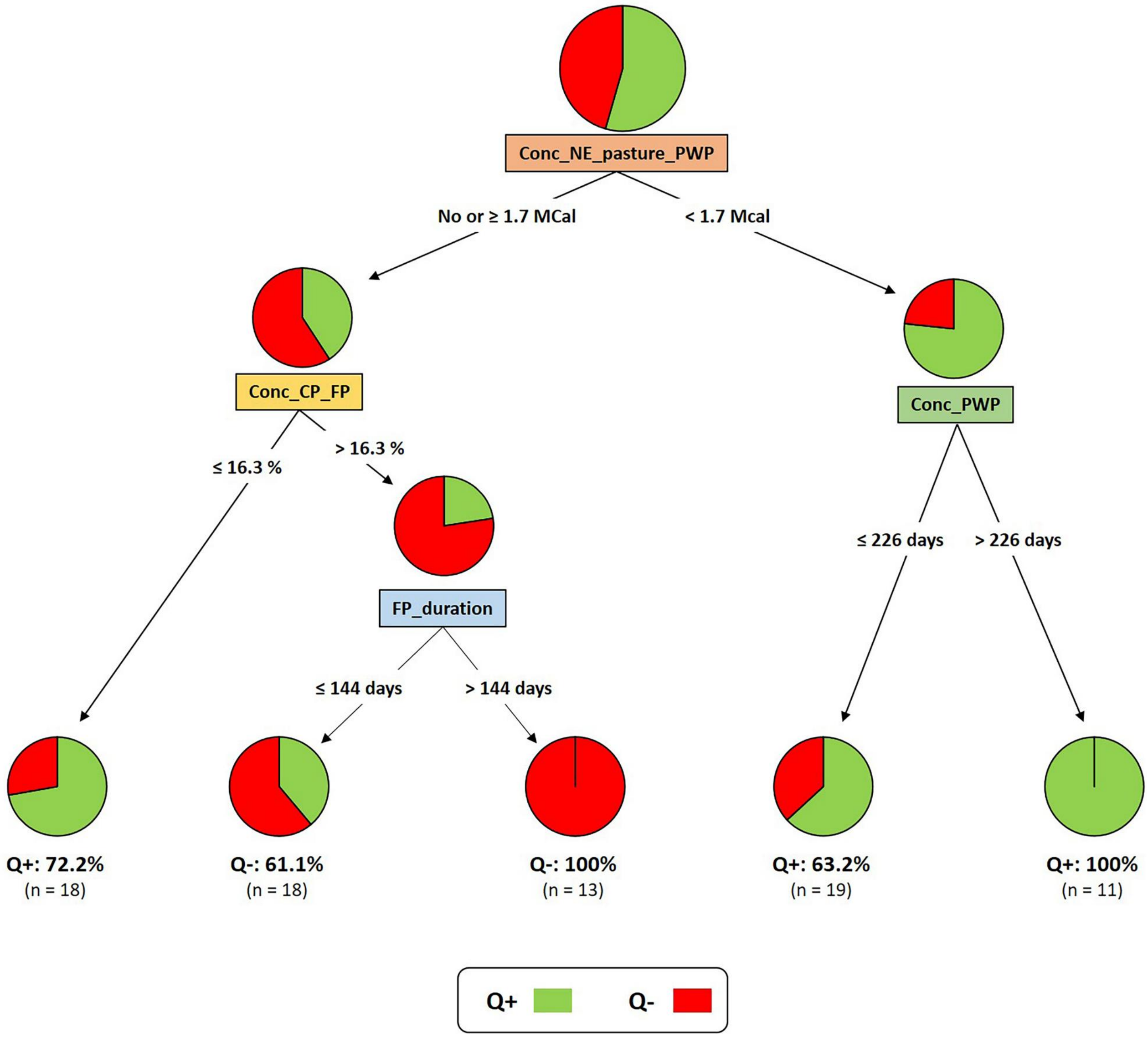

Figure 1. Decision tree to predict *Longissimus* meat quality classes from rearing factors (RF-Tree). Conc_NE_pasture_PWP: calculated average of concentrates' net energy content in the diet during the pasture period of pre-weaning period (PWP); Conc_PWP: number of days concentrates were offered in calf diet during PWP; Conc_CP_FP: calculated average of concentrates' crude protein content in the fattening diet; FP_duration: number of days between the beginning of fattening period (FP) and the slaughter; Q+: superior sensory quality of *Longissimus*; Q−: inferior sensory quality of *Longissimus*; *n*: number of animal.

concentrate proportion in the fattening diet decreases the flavour of LM, in the young bulls and the cull cows (Soulat et al. 2016).

Consistent with our results, many works showed that the beef quality (tenderness, juiciness and flavour) decreased when the fattening duration of young bulls was longer (Soulat et al. 2016; Gagaoua et al. 2018, 2019). In addition, Soulat et al. (2021) observed that rearing managements (including different fattening duration) had no effect on the tenderness and juiciness of LM, in heifers.

The tree generated from the rearing factors and aged meat data was the same tree that RF-Tree (Table 6). The combination of rearing factors and aged meat data in the same tree did not enhance the RF-Tree model's ability to discriminate the sensory meat quality classes.

For the decision tree established from the rearing factors and carcass traits (RF-CARCA-Tree), 79.7% of individuals were accurately classified with 90.7% of Q + class and 66.7% of Q − class (Table 6). This tree had a higher accuracy than the RF-Tree by improving the sensitivity for discriminating the sensory meat quality classes. The specificity was the same for both RF-CARCA-Tree and RF-Tree. The tree obtained from all data (i.e. rearing factors, carcass traits and aged meat data; ALL-Tree) was identical to RF-CARCA-Tree (Table 6).

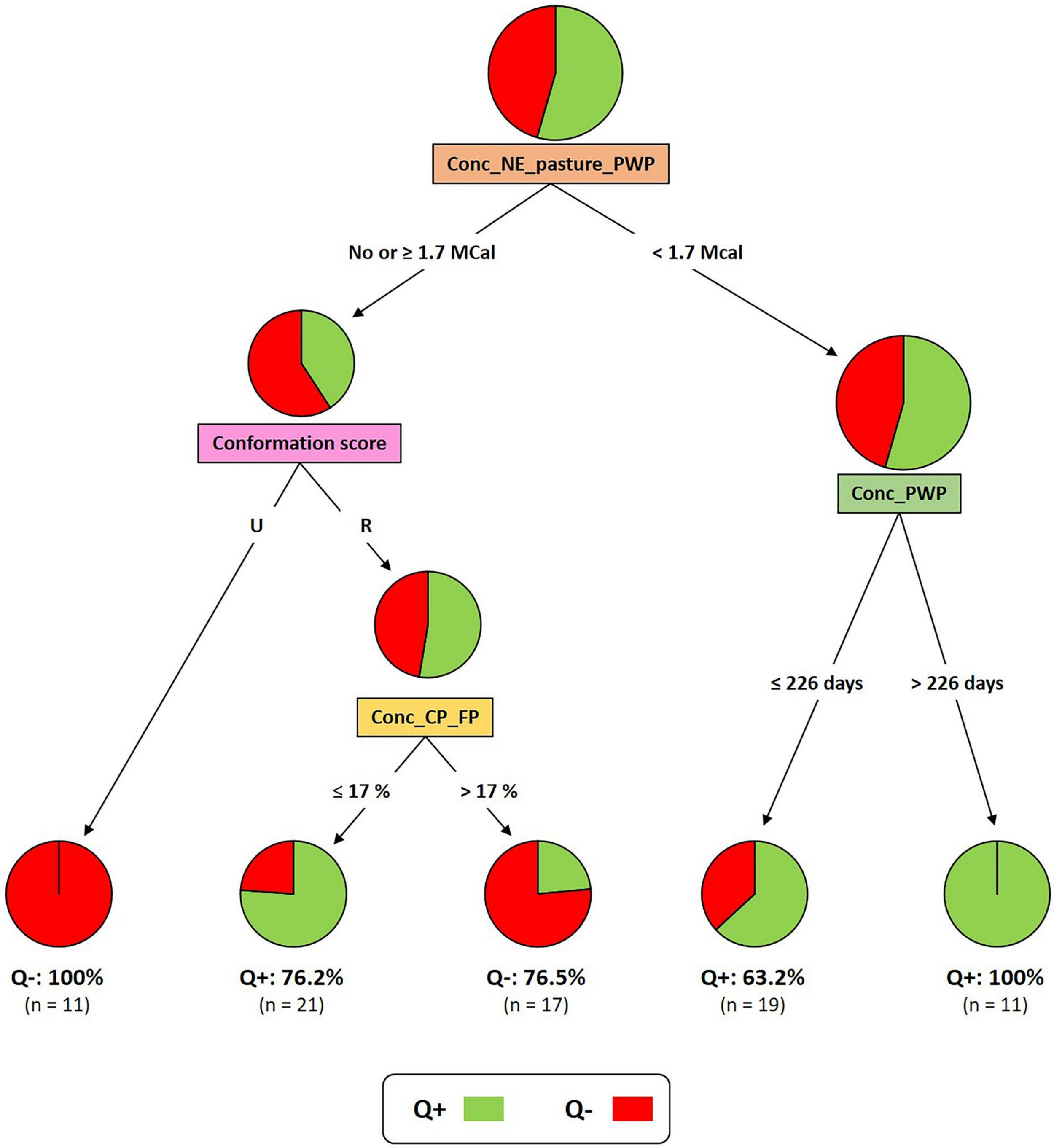

Figure 2. Decision tree to predict *Longissimus* meat quality classes from rearing factors and carcass traits. Conc_NE_pasture_PWP: calculated average of concentrates' net energy content in the diet during the pasture period of pre-weaning period (PWP); Conc_PWP: number of days concentrates were offered in calf diet during PWP; Conc_CP_FP: calculated average of concentrates' crude protein content in the fattening diet; Conformation score: EUROP classification scale for conformation from E (very high muscle development) to P (very low muscle development); Q+: superior sensory quality of *Longissimus*; Q−: inferior sensory quality of *Longissimus*; *n*: number of animal.

Three rearing factors (namely: Conc_NE_pasture_PWP, Conc_PWP and Conc_CP_FP) and a carcass trait (conformation score) allowed to discriminate the sensory meat quality classes in RF-CARCA-Tree (Figure 2). Three pathways in RF-CARCA-Tree allowed to produce mainly Q+meat quality (Figure 2). Two pathways were identical to RF-Tree's description (Figure 1), only considering rearing factors during the PWP. In another pathway, heifers could be fed a pasture diet with no concentrates or a concentrate containing less than 1.7 MCal of net energy during the PWP. In addition, in this pathway, the conformation score must be class R according to EUROP system and the fattening diet must contain a concentrate with a crude protein content of less than 17%. This pathway results in 76.2% of Q + meat quality. This decision tree also included two other pathways that produced mainly Q – meat quality (Figure 2). According to our results, if the heifers did not receive concentrates or if the concentrate's net energy exceeded 1.7 MCal while grazing before weaning, and if the carcass conformation score was class U according to EUROP system, then the LM meat quality was inferior (100% Q–). Moreover, if the heifers did not receive concentrate or if the concentrate's net energy exceeded 1.7 MCal while grazing before weaning, if the carcasses were class R in the EUROP system, and if the concentrate's crude protein level in fattening diet was above 17%, then the LM meat quality was mainly Q– (76.5%).

In RF-CARCA-Tree, the pathways leading to Q + meat quality considered the same dietary factors as those for the RF-Tree. In this tree, the conformation score of the carcass was also selected. Our results revealed that when carcasses had a higher conformation, the quality of LM meat produced decreased. Bonny et al. (2016) did not find any effect of the conformation score (classes U and R according to the EUROP system) on the global sensory quality of the LM muscle. However, Soulat et al. (2020, 2021) observed that heifers with a high-quality carcass (defined as a combination of three traits: weight, dressing% and conformation score) produced more tender raw and cooked meat.

As observed by Soulat et al. (2018), several rearing factors applied during the pre-weaning and fattening periods had an impact on the meat quality of heifers, highlighting the potential for managing meat quality throughout their life. Our study identified three potential action levers at dietary level for enhancing meat quality during life (Conc_PWP, Conc_NE_pasture_PWP and Conc_CP_FP) which can easily implement by farmers. Currently in Europe, suckler farmers' income is based on three carcass traits: weight, conformation and fat scores (European Commission 2006). carcasses with a higher conformation score have higher prices. So, it is not economically attractive for farmers to produce carcasses with a low conformation score, even if a combination of factors including a low conformation score can produce a high meat quality.

Conclusions

In this study, seven decision trees were performed to discriminate two extreme classes of sensory meat quality (Q + and Q–) from data representing the farm-to-fork continuum. The best prediction of potential meat quality classes was obtained for the tree constructed from the combination of rearing factors and carcass traits. During the PWP, a net energy of the concentrate (<1.7 MCal) fed during the pasture period mainly produced high meat quality. When this factor was combined with an increase in the number of days on concentrates (>226 days) in the diet, 100% of the meat was graded in the highest quality class. It was also possible to produce a high meat quality (76.2%) when the calves fed no concentrate or a concentrate containing more than 1.7 MCal net energy at pasture during the PWP, combined with a concentrate's crude protein of less than 17% in the fattening diet and a carcass conformation score of R. Our results confirm the importance of considering the rearing management (from birth to slaughter) of heifers to manage the sensory meat quality.

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Author contributions

Valérie Monteils: funding acquisition, project administration, supervision, conceptualisation, formal analysis, validation, methodology, writing-original draft and writing-review and editing. Brigitte Picard: funding acquisition, project administration and supervision. Julien Soulat: data curation, project administration, resources, writing-original draft and writing-review and editing.

Disclosure statement

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [VM], upon reasonable request.

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