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Review: On-farm and processing factors affecting bovine carcass and meat quality

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ABSTRACT

This paper reviews the current state of knowledge on beef carcass and meat quality, with particular emphasis on on-farm and processing factors associated with its high and inconsistent variability. The diversity of livestock systems comes from the diversity of breeds (dairy or beef), ages and gender (bulls, steers, heifers, cull cows) used to produce either mainly beef or beef and milk. In addition, there are factors linked to farming practices (including diet, especially grazing) which significantly influence the sensory, nutritional, technological and extrinsic (such as image) quality attributes of meat. These can become factors of positive differentiation when controlled by the application and certification of technical specifications. Finally, preslaughter (such as stress), slaughter (such as the chilling and hanging method of carcasses) and postslaughter (such as ageing, packaging and cooking) conditions have a strong influence on the microbiological, sensory, technological and image quality attributes of beef. In this review, potential synergisms or antagonisms between the different quality attributes are highlighted. For example, finishing cattle on grass, compared to indoor fattening on a high concentrate diet, has the advantage of producing leaner meat with a higher proportion of omega-3 fatty acids while exhibiting superior oxidative stability, but with the consequence of a darker meat colour and lower productivity, as well as higher seasonality and land surface requirements. Moreover, the control of on-farm factors is often guided by productivity (growth rate, feed conversion ratio) and carcass quality attributes (weight, conformation and fatness). Genetic selection has often been oriented in this direction, without taking other quality attributes into account. Finally, the interactions between all these factors (and especially between on-farm and slaughter or processing factors) are not considered in the quality grading schemes in European countries. This means that positive efforts at farm level may be mitigated or even eliminated by poor slaughtering or processing conditions. All these considerations explain why between-animal variability in quality can be high, even when animals come from the same farming system. The ability to predict the sensory and nutritional properties of meat according to production factors has become a major objective of the supply chain.

Implications

This review aims to globally analyse the factors determining bovine carcass and meat quality in all its components (commercial, sanitary, sensory, nutritional, technological and image) and to identify the synergisms and antagonisms between some of these components. The origin of the variability in the quality of beef is very often multifactorial, depending on the multitude of factors of variation throughout the value chain. These factors related to stakeholder expectations and the farming system have to be better controlled in order to provide beef of constant quality.

Introduction

While the consumption of animal-derived foods has been the subject of intense debate, little work has simultaneously described the various dimensions of quality (Hocquette et al., 2012), nor has it covered the full range of interactions between the production factors in the product development chain.

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One particularity of beef, shared with sheep meat, is its low level of processing. "Unprocessed or minimally processed" beef corresponds to the term "fresh meat" as defined by the European Regulation No. 853/2004, i.e. meat that has not undergone any preserving process other than chilling or freezing or quick-freezing, including meat that is vacuum-wrapped or wrapped in a controlled atmosphere.

Variability in the quality of bovine carcasses and meat is high, inconsistent and multifactorial in origin. Consumers are particularly attentive to variations in the quality of the products they consume. When unsatisfactory, they can result in rejection of the product (Bonny et al., 2018).

The aim of this review was therefore to describe and prioritise the different factors that determine the variability of unprocessed or minimally processed beef quality traits from on-farm livestock systems to consumption and the interactive effects of all these factors. Six quality components are reviewed namely commercial, microbiological, sensory, nutritional, technological and image quality traits.

Commercial quality attributes

Commercial properties are the basis for payment to breeders and are of particular interest to livestock professionals. Beef production varies greatly across Europe (Hocquette et al., 2018) with the consequence of a high variation in the characteristics of the carcass. According to EC Regulation No. 853/2004, the carcass is the body of an animal after slaughter and dressing. In the EU, the commercial quality attributes of the carcass are based on the "European classification", which is comprised of four criteria: weight, sex (+age), conformation and fat score. While conformation depends mainly on breed type (dairy, beef or dual-purpose), the fat score depends on breed (including double-muscled genotype), age and degree of finishing of the animal. Carcass weight is used as a quantitative or even qualitative reference in commercial transactions and is often used on a national or international scale as an indicator to express meat production or consumption in carcass weight equivalent. It corresponds to the live weight of cattle without the digestive content and the fifth quarter (consisting of these parts, e.g., skin, internal fat, red and white offal, blood, digestive tract, head, which are removed during the slaughtering process). Depending on the type of "presentation" of the carcass, the tail and the fleshy parts of the diaphragm (thick skirt, thin skirt) may or may not be removed. Other grading systems also based on visual classification are used outside Europe, notably in the U.S.A. (USDA Beef Grading System; www.usda.gov), Japan (Japan Meat Grading Association; http://www.jmi.or.jp) and Australia (Meat Standards Australia (**MSA**); www.mla.com.au). Unlike the European system, which only considers the carcass itself, these systems incorporate meat quality criteria, particularly in the Australian system. Nevertheless, in Europe, many operators in the sector apply some additional criteria (e.g. pH, meat and/or fat colour), which are often set out in a specification. The criteria used in these systems are summarised in Table 1.

At the slaughterhouse, half carcasses of cattle may be cut into quarters or a maximum of three pieces. The "quartering" may be considered as a primary cut. The cutting and boning of the quarters generate pieces that, for the most noble of them, correspond to individualised muscles. The sensory quality traits vary greatly from one muscle to another, with the result that the way in which they are used varies (meat for grilling, roasting, braising, boiling) and influences their commercial value. Since 2000, in application of the European Regulations No. 1760/2000 and No. 1825/2000, the origin of beef must be communicated to the consumer, except when it is incorporated into a processed product. This requirement

Table 1
Main bovine carcass grading systems used around the world (adapted from Polkinghorne and Thompson, 2010).

Country	Europe	RSA[1]	Canada	Japan	South Korea	USA	Australia
Scheme	EUROP	South Africa	Canada	JMGA[2]	Korea	USDA[3]	MSA[4]
Grading unit	Carcass	Carcass	Carcass	Carcass	Carcass	Carcass	Cut
Preslaughter factors							HGP implants[5] *Bos indicus*
Slaughterfloor	Carcass weight Sex (+age) Conformation Fat cover	Carcass weight Sex Dentition Rib fat	Carcass weight Sex Conformation	Carcass weight Sex	Carcass weight Sex	Carcass weight Sex	Carcass weight/maturity Sex Electrical stimulation Hang
Chiller			Marbling score Meat colour Fat colour and fat thickness Texture	Marbling score Meat colour Fat colour and fat thickness Eye muscle area Meat brightness Fat lustre Fat texture Fat firmness Rib thickness	Marbling score Meat colour Fat colour and fat thickness Eye muscle area	Marbling score Meat colour Ossification score Eye muscle area Meat texture Rib fat Kidney fat Perirenal fat	Marbling score Meat colour Ossification score Fat thickness Hump height Ultimate pH
Postchiller							Ageing time Cooking method

[1] Republic of South Africa.
[2] Japanese Meat Grading Association.
[3] United States Department of Agriculture.
[4] Meat Standards Australia.
[5] Hormonal growth promotants.

Table 2
Main factors modulating the commercial quality attributes of bovine carcasses.

Factors	Carcass weight	Carcass yield	Fatness	Cutting yield
Genetics[1]	++	++	++	++
Sex[2]	+	+	+	+
Age[2]	++	++	++	++
Feeding – farming system	++	+	++	+
Preslaughter conditions	–	–	–	–
Slaughtering conditions	–	–	–	–

++: major factor of variation; +: weaker factor of variation; –: not a factor of variation.

[1] Breed (+ double-muscled genotype).

[2] These factors are often combined (e.g. young bull vs cull cow).

relates to birth, fattening, slaughter and cutting. This information is shown on the packaging of prepackaged meats. It must be displayed at retail level in other cases.

Although this is an important element in differentiating the quality of beef, the breed is not subject to mandatory labelling. However, it is very often communicated to the consumer, whether or not in compliance with a specification and labelling that includes this characteristic (Raulet et al., 2022). Carcass characteristics are strongly influenced by different animal-related factors such as sex, age and genetic factors, especially breed. During growth and fattening, there is successively a growth of muscle tissue (increase in the muscle to bone ratio), followed by a growth of adipose tissue (increase in the fat to muscle ratio) (Lonergan et al., 2019). Nevertheless, this evolution varies from breed to breed depending on their maturity. Late-maturing breeds, such as continental European breeds (notably the French Charolais, Limousine, Blonde d'Aquitaine breeds and the Belgian Blue breed), produce heavy carcasses with little fat. Conversely, early-maturing breeds, such as the traditional Anglo-Saxon breeds, can be slaughtered at lower weights. Dairy breeds have higher internal fat deposits, while beef breeds have higher subcutaneous fat deposits (Irshad et al., 2013). During growth and development, fat deposits are first intermuscular, then subcutaneous and finally intramuscular, leading to marbling (Pethick et al., 2007). Consequently, early-maturing breeds have higher intramuscular fat deposition than late-maturing breeds (Irshad et al., 2013). Therefore, the age at which an animal is slaughtered determines the weight and composition of the carcass based on the stage of maturity reached (Pethick et al., 2007).

So-called "beef breeds" have a higher proportion of muscle than dairy breeds, which gives the carcass a higher conformation associated with higher carcass and meat yields. This difference is even more pronounced in double-muscled cattle, which have muscle hyperplasia and hypertrophy associated with low fat deposition (Clinquart et al., 1998; Lonergan et al., 2019). The double-muscled trait is explained by a mutation in the gene encoding for myostatin or Growth and Differentiation Factor 8 (Grobet et al., 1997). This mutation can exist in several different forms depending on the breed where it has been identified (Belgian Blue, Asturiana, Piedmontese) (Bellinge et al., 2005). Animals homozygous for this mutation show very important muscular development.

Farming practices including feeding and especially energy intake can also influence the commercial quality attributes of the carcass, often through its effect on growth rate and degree of maturity. It is even possible to predict specific carcass and meat characteristics in young cattle, heifers and suckler cows based on factors related to farming practices (Soulat et al., 2016). However, all the prediction models displayed different effects of rearing factors depending on the animal categories (young bulls, heifers or cull cows for instance). As a consequence, these prediction models show the need to adapt rearing factors during the fattening period according to animal categories to optimise the carcass traits for different animal categories.

The main factors of variation in commercial carcass quality attributes are summarised in Table 2.

Microbiological quality attributes

Food products from the bovine sector are, like other sectors, confronted with numerous microbiological hazards. Among these, Shiga-toxin-producing *E. coli* (**STEC**) and *Salmonella enterica* are the hazards of greatest concern (Tesson et al., 2020). *Toxoplasma gondii* and *Taenia saginata* are the main parasitic hazards for bovine meat (Trevisan et al., 2019).

The prevalence of *Salmonella* in cattle in Europe is around 2% (Gutema et al., 2019). Certain serovars are more represented in the bovine sector (notably the Dublin serovar). Risk factors at farm level are difficult to identify, with the exception of feed which may be a significant source of *Salmonella* (FAO-WHO, 2016). However, the presence of infected herds in an area close to farms and the presence of pests appear to be risk factors (FAO-WHO, 2016).

The relative risk factors linked to the presence or the level of excretion of STEC are also difficult to identify at farm level but the presence of "carrier cattle" and the movement of animals seem to be risk factors (Widgren et al., 2015). Unlike *Salmonella*, STEC do not cause clinical signs in cattle. Colonisation in cattle is generally transient and the concentration and frequency of excretion of STEC vary among animals (Anses, 2017). For example, the presence of STEC in the farm environment is attributable to super-shedding animals (more than 10^4 *E. coli* colony forming units (**CFU**)/g of faeces). STEC, such as *E. coli* O157:H7, are considered to be a serious public health concern due to their low infection dose (10–100 CFU) and the severity of the syndromes caused (EFSA Panel on Biological Hazards, 2020).

The role of cattle in sporadic cases of human campylobacteriosis remains to be clarified, but genomic data indicate that a significant proportion of cases are associated with cattle (Thepault et al., 2018).

Animal stress during transport to the slaughterhouse and the length of the stall period have been identified as factors influencing faecal excretion of *Salmonella* and pathogenic *E. coli* as well as contamination of livestock before slaughter (Niyonzima et al., 2015).

In a national survey conducted in France in 2007, 2009 and 2013, the observed seroprevalence of *Toxoplasma* in cattle at slaughter was 11%. It was significantly higher in older animals (over 9 months) than younger ones. This is probably related to the oral mode of contamination of animals, and the cumulative exposure over the life of the animal (Blaga et al., 2015).

Controlling the initial state of cleanness of animals arriving at the slaughterhouse and the hygiene of slaughter procedures are essential elements in controlling all biological hazards. The EU hygiene package regulations define the obligations of professionals (application of good hygiene practices, HACCP, product traceability) and control services (ante- and *postmortem* inspection). As in the sheep and pig sectors, the application of good hygiene practices and HACCP in the beef sector is an essential element in the control of microbial flora. The time–temperature profile of products at the exit of the slaughterhouse determines the levels of pathogenic and spoilage bacterial flora (*Pseudomonas*, lactic flora) (EFSA Panel on Biological Hazards, 2014 and 2016).

The absence of pathogens is particularly sensitive for minced meat, which can be contaminated throughout and eaten raw or undercooked. This quality criterion is an absolute prerequisite for the consumer. For this purpose, minced meat and meat preparations intended to be eaten raw must at least meet the microbiological criteria laid down in EC Regulation No. 2073/2005 concerning food safety criteria (*Salmonella*) and process hygiene criteria (*E. coli*, total microflora). Among these products, ground beef is a particularly sensitive product, especially because grinding is likely to disperse the surface bacterial flora within the product itself (Loukiadis et al., 2017). Appropriate cooking of burgers and avoidance of raw meat for susceptible individuals would considerably alleviate the burden of disease associated with beef (Augustin et al., 2020).

The effects of factors influencing the microbiological quality attributes of beef are summarised in Table 3.

Table 3
Main factors modulating the microbiological quality attributes of bovine carcass and meat.

Factors	Biological hazards
Genetics	–
Sex[1]	–
Age[1]	–
Feeding – farming system[2]	+
Preslaughter conditions[3]	+
Slaughtering and carcass chilling conditions[4]	++
Muscle/meat cut[5]	+
Storage conditions[6]	++
Consumption mode[7]	++

++: major factor of variation; +: weaker factor of variation; –: not a factor of variation.

[1] These factors are often combined (e.g. young bull vs cull cow).

[2] Shiga-toxin-producing *E. coli* (STEC) carriers.

[3] Hygiene and cleanness of animals, pathogen excretion.

[4] Good hygiene practices and microbial contamination, chilling and microbial growth.

[5] Variation in microbial contamination depending on the muscle location on the carcass, meat preparation (e.g. minced meat or meat cuts submitted to mechanical tenderisation).

[6] Ageing conditions (duration, temperature) + packaging mode (vacuum, high-oxygen modified atmosphere) and control of cold chain (microbiological and physico-chemical quality).

[7] (Minced) beef consumed as raw, degree of doneness of cooked minced beef (STEC).

Sensory quality attributes

Sensory quality attributes are those which are perceived by the senses of the consumer. A distinction is generally made between colour, tenderness, juiciness and flavour (Monin, 1991). Variation in the sensory quality attributes of beef results from the combined effects of animal, rearing and technological factors. The former are factors responsible for differences between animals such as breed, age and sex, and between muscles within the same animal – i.e. anatomical location and physiological function (Monin, 1991). Rearing factors include growth rate, growth strategy (which can be periodic) and diet, especially during the finishing period; these factors are key to optimising productivity and quality. Technological factors correspond to all the treatments applied to the animals to transform them into meat (Ouali et al., 2006), from transport to the slaughterhouse, slaughtering, storage and final preparation of the meat.

Beef colour

Colour is chronologically the first criterion for consumer appreciation of meat at the time of purchase. With the development of meat distribution in supermarkets and medium-sized stores, this parameter is becoming increasingly important. When buying a piece of beef, consumers look for a bright red colour which they associate with the wholesomeness of the product (Suman and Joseph, 2013).

The colour of the meat varies not only according to the myoglobin content of the muscle but also according to its state of oxygenation or oxidation. Reduced deoxygenated myoglobin is purple red. Reduced oxygenated myoglobin is bright red: it has a favourable influence on the acceptability of meat by consumers, who consider this colour to be a criterion of freshness. Oxidised myoglobin, or metmyoglobin, is reddish-brown which causes a rejection reaction from the consumer (Mancini and Hunt, 2005).

Myoglobin content varies between species (cattle > pig > poultry) and the muscles of the same animal (Renerre, 1990). This variation is linked to the metabolic type of muscle fibres: the higher the proportion of so-called "red" muscle fibres, rich in myoglobin and with high respiratory activity, and the lower the proportion of so-called "white" muscle fibres, poor in myoglobin and with glycolytic activity, the redder the meat appears and vice versa. Within the bovine species, the variation in muscle fibre composition (and therefore meat colour) is largely explained by breed, sex, type of muscle, or even by farming factors (Ripoll et al., 2018). Both age and gender have an influence on pigment content, and therefore with parallel effects on colour. Pigment content increases more rapidly with age in females than in males (Monin, 1991). In practice, however, female meat is often obtained from suckler or dairy cows which are slaughtered at an older age than young male cattle. In this case, the beef is darker because of the age.

The colour of meat can also be related to the ultrastructure of the muscle, which is itself influenced by pH. Beef with a high final pH is abnormally dark in colour.

The oxygenation or oxidation state of myoglobin is mainly related to the processing conditions applied after slaughter. The sensitivity to oxidation is, on the other hand, influenced by animal factors (age and sex, muscle) and nutritional factors, in particular by the intake of antioxidants via animal feed (Castillo et al., 2013).

The muscles of forage-fed and especially pasture-raised animals are generally considered to be darker in colour. In the case of pasture, it is likely that exercise related to animal movements may play a role in increasing the proportion of "slow-oxidative" red fibres. Generally, the darker colour can be explained by a change in the distribution of muscle fibres, which are more oriented towards oxidative metabolism (Mancini and Hunt, 2005). However, it is not easy to assess the effect of this factor alone since it is often combined with those of age, breed and muscle type (Dunne et al., 2011). In addition, grass is an important source of antioxidants which contribute to the colour stability of meat (Mancini and Hunt, 2005).

The visible fat, both on the outside (covering fat) and inside (marbling) of the muscle, can vary in colour from white to more or less pronounced yellow. This variation is mainly due to age and feeding practices. Cattle from extensive grazing systems tend to have more yellow fat than cattle from intensive systems fed with concentrates. This is due to the deposition in the fatty tissue of naturally occurring carotenoids in forage (Dunne et al., 2009).

The storage conditions of meat strongly influence the oxidative stability of myoglobin and therefore the evolution of colour, in particular the temperature–time combination and atmosphere. Vacuum packaging allows oxygen to be evacuated and therefore limits oxidation. On the other hand, it leads to a disappearance of the bright red colour, linked to the oxygenation of the myoglobin and gives the meat a purple red colour. This packaging method is not always well received by customers. An alternative consists of modifying the packaging atmosphere, most often by increasing the oxygen concentration, in particular for beef, which has a very pronounced red colour. A high oxygen concentration is often combined with 20–30% carbon dioxide to produce an antimicrobial effect against spoilage microbial flora, 80% O_2:20% CO_2 being the most common gas mixture (Belcher, 2006). At a high partial pressure of oxygen, oxidation of myoglobin is limited and therefore it is possible to increase the shelf life of meat (Mancini and Hunt, 2005). However, at this concentration, oxygen promotes lipid and protein oxidation and can increase toughness (Lagerstedt et al., 2011). This type of packaging is therefore more suitable for red and lean meats.

Beef tenderness

Tenderness is the measure of how easily meat can be cut. Many consumers rank this parameter as the most important criterion determining the quality of meat.

Paradoxically, tenderness is often expressed by its opposite: toughness. The latter depends essentially on two protein structural components (Ouali et al., 2006). The first is collagen, the main constituent of connective tissue. No significant *postmortem* modification of collagen is observed, at least for the most frequent ageing times. Its mechanical strength is therefore considered to be constant and is associated with what is often called 'basic toughness'. The second component is formed by the myofibrils, more particularly by the myofibrillar proteins. Their mechanical strength is not constant *postmortem*. Three periods are generally distinguished. The first precedes the state of *rigor mortis*, it is called the 'prerigor state' because during this period, the muscle structure is relaxed. It is followed by *rigor mortis* which becomes maximal at 1–2 days *postmortem* in cattle. The muscles are then irreversibly locked in the state of tension to which they were subjected. The tension exerted via the tendons on the muscles of the carcass suspended by the Achilles tendon can be reduced by an alternative mode of suspension ('tenderstretch') consisting of hanging the carcass via the pelvis (Warner et al., 2010).

Then there is a decrease in the mechanical strength of the meat which results from a weakening of the myofibrillar structure, itself explained by a partial proteolysis of certain key proteins involved in the structure of the myofibrils. Various endogenous proteolytic enzymes are involved in this process. The main ones are 'calcium dependent proteases' commonly referred to as 'calpains' (Ouali et al., 2006). The proteins involved in apoptosis, the programmed death of cells in response to a signal, which is triggered by depriving the muscles of nutrients and oxygen after killing, also play a role in tenderising, more particularly capsases, serpins and HSPs ('Heat Shock Proteins') (Lian et al., 2013). The cooling of the carcasses after slaughter and the refrigeration of derived meat cuts, imposed by EU legislation to limit the development of microorganisms, slow down this process considerably. It is therefore necessary to maintain this process beyond the time required for cooling the carcasses and cutting them up in order to allow the meat to tenderise. Beef produced in Europe is usually aged for one to 2 weeks and, at the industrial level, this is often carried out after the carcass has been cut and vacuum-packed to limit the development of aerobic microbial flora, the oxidation of pigments and lipids, as well as water loss through evaporation. Meat cuts can be vacuum-stored for a relatively long time (up to several months for fresh meat imported from South America or Oceania). In recent years, there has been the development, on a small scale, of a practice consisting of ageing meat cuts in contact with ambient air for a very long time ("dry-aged beef") (Perry, 2012). This process is generally applied to noble cuts from mature animals of relatively fatty and meaty breeds in order to achieve optimal tenderness and accentuate their flavour (Perry, 2012).

The respective contribution of basic and myofibrillar toughness and the evolution of the latter *postmortem* may vary depending on biological (breed, sex, age, muscle) and technological (slaughtering, carcass and meat processing) factors. Chilling, in particular, can be considered as a critical factor. Slow or delayed chilling is associated with an accelerated pH decline and adverse impact on beef tenderness, producing so-called heat-induced toughening (Kim et al., 2014). Inversely, when the cooling applied prerigor to the carcasses is too rapid, meats rich in red muscle fibres, such as beef, are sensitive to the phenomenon of "cold shortening", resulting in irreversible toughness. In this context, carcass fatness could be taken into consideration, as sufficient fat cover insulates the carcass and can prevent it from cooling down too quickly. Applying electrical stimulation to the muscles during the slaughter process helps prevent this phenomenon by accelerating the onset of *rigor mortis*, rapidly depleting muscle energy reserves (Savell et al., 2005).

Tenderness is also influenced by genetic factors. In general, but not always, deletion of the myostatin gene in cattle results in increased tenderness, explained by a lower collagen content and greater solubility thereof due to lower crosslinking. The effect of the 'culard' gene on tenderness is therefore more particularly expressed in less noble muscles, usually richer in collagen (Warner et al., 2010). Besides the effect of major genes, there is no strong evidence that breed influences the sensory quality of meat (Dransfield et al., 2003) but differences in ageing have been observed between breeds (Monson et al., 2004) suggesting that any difference in tenderness between breeds is mitigated by a longer ageing time.

The tenderness of the meat changes little at a young age and tends to decrease as the animals mature. The effect of age is only significant if the age differences are large. Its effect is therefore limited in relatively young animals. Thus, between 12 and 24 months of age in young male cattle and between 12 and 35 months of age in young females, tenderness does not appear to be altered to a great extent by increasing age at slaughter (Oury et al., 2007). In older animals, the age effect on the tenderness of meat appears to vary depending on the breed and, when it occurs, it is not necessarily explained by collagen characteristics (Oury et al., 2007). It is possible that the effect of age is partly linked to a decrease in the speed of the tenderising process, which justifies a longer ageing period than for young cattle.

Fat content has been considered an important trait contributing to beef tenderness. Beef from cattle with a high intramuscular (marbled) fat content often has a low shear force and therefore high tenderness (Venkata Reddy et al., 2015).

A conclusion on the possible effect of the feeding mode (forage vs concentrates) is difficult to draw due to the interaction of this factor with other factors linked to the farming system (age, growth rate, physical activity). Indeed, a high variability in tenderness between animals for the same muscle (*longissimus thoracis*) was previously observed with a mean value of 4.7 and 7.1 ± 0.5 on a scale of 0 to 10 for the worst and best quality classes (Chriki et al., 2012). This high variability explains at least in part the difficulty in highlighting significant differences between farming systems.

The meat storage conditions can affect its tenderness. In addition to the effect of the ageing time and the temperature applied during this process, a limited effect of the packaging method cannot be excluded: an atmosphere rich in oxygen can induce protein oxidation with direct effects (formation of bonds between myofibrillar proteins) or even indirect effects (by reducing the activity of proteases involved in the tenderising process) (Kim et al., 2010).

Genetic and extrinsic factors modulate tenderness. In addition, each of these factors often produces non-linear effects and acts in interaction, making the prediction of tenderness difficult.

Beef flavour

The flavour of meat is determined by its chemical composition and its evolution during cooking. It has been shown that the typical flavour of meat, for all animal species combined, is linked to the water-soluble components, while the differences observed between species come from the lipid fraction (Pearson et al., 1994). Raw meat generates little flavour but it becomes more pronounced during cooking depending on the temperature and the cooking method (Arshad et al., 2018). Many volatile aromatic components are produced during cooking by lipid degradation or oxidation, thermal degradation and interactions between proteins, peptides, amino acids, sugars and ribonucleotides (Maillard reactions) (Resconi et al., 2013). Since flavour depends on both the precursors initially present in the meat and on the cooking method, the consumer plays an important role in determining the final flavour profile of cooked meat (Gardner and Legako, 2018).

Lipids play an important role in the development of the flavour of meat. This is strongly influenced by the intramuscular lipid content and fatty acid composition, and therefore by all the factors influencing them (see section relating to nutritional value) and by the modifications of the fatty acids during storage, especially oxidation.

The water-soluble flavour precursor compounds are mainly peptides, amino acids, reducing sugars, nucleotides and thiamine (Dinh et al., 2018). By generating free amino acids, the proteolysis associated with ageing can enhance the flavour of meat, especially when it is of long duration (Khan et al., 2015).

Need for sensory quality grading

In conclusion, the factors that determine the sensory quality attributes of beef are very numerous and affect all stages of the chain, from animal production to processing and final preparation by the consumer (Table 4). Some of them play a major role, including breed, age, muscle type and cooking method. Due to the multiplicity of factors and their interactions, it is important to develop or apply methods that predict the quality on the basis of breeding and technological factors (Ellies-Oury et al., 2016 and 2020). It should be remembered that the grading method for bovine carcasses applied in EU slaughterhouses does not predict the sensory quality of meat from such carcasses, unlike the MSA method applied in Australia. The latter, tested experimentally in France, Ireland, UK, Poland and other countries outside Europe, offers interesting perspectives in terms of predicting meat quality from animal and carcass characteristics. Furthermore, the MSA system not only addresses consumer satisfaction but also reduces variability in eating quality (Bonny et al., 2018).

Nutritional quality attributes

Beef provides a wide range of essential macro and micronutrients, in particular proteins of high biological value, haem iron, zinc, vitamins B3, B6 and B12. The concentrations of some nutrients vary according to animals and cuts, in relation to the muscle metabolic type (haem iron, vitamin B12) or the composition of the muscle (lipids, zinc) (Bauchart et al., 2008). Beef is a good source of highly digestible proteins of high biological value. In addition, its level of haem iron, zinc and vitamins B3, B6 and B12 contributes to its nutritional quality.

The protein digestibility of bovine meat, measured at the end of the small intestine, is very high (90–95%) as measured for the first time in humans by Oberli et al. (2016). Cooking bovine meat at a high temperature (~90 °C) for a long time (>30 min) can moderately decrease protein digestibility (90%) compared to cooking at a lower temperature for a short time (55 °C, 5 min) (95%) and does not affect postprandial exogenous protein metabolism in young adults. A ’digestible indispensable amino acid score’ of between 80 and 99% depending on the cooking methods confirms that beef is a source of high quality protein (Hodgkinson et al., 2018). Recently, a new score was proposed that also takes into account the essential amino acid profile: ‘protein digestibility corrected amino acid score’, a score adopted by the FAO to express the value of a protein in food (Huang et al., 2018; Schaafsma, 2000). The score for beef is 92, higher than soy and wheat (91 and 42, respectively) but lower than egg and cow’s milk (118 and 121, respectively) (Schaafsma, 2000).

In cattle, as in all animals, protein deposition in the muscle is dependent on feed intake. When intakes are below requirements, deposition is limited but the composition of the proteins, and therefore their nutritional value, is not changed. The variation in the protein content between muscles, animals and farming systems is explained by the variation in the intramuscular fat content: the higher the fat content, the lower the protein content and vice versa (Salim et al., 2019).

Table 4
Main factors modulating the sensory quality attributes of beef.

Factors	Colour	Juiciness	Tenderness	Flavour
Genetics[1]	++	++	++	++
Sex[2]	+	+	+	+
Age[2]	++	++	++	++
Feeding – farming system[3]	++	+	+	+
Preslaughter conditions[4]	++	+	+	–
Slaughtering and carcass chilling conditions[5]	–	–	++	–
Muscle/meat cut[6]	++	+	++	++
Storage conditions[7]	++	+	++	++
Cooking mode	++	++	++	++

++: major factor of variation; +: weaker factor of variation; -: not a factor of variation.

[1] Breed (+ double-muscled genotype).

[2] These factors are often combined (e.g. young bull vs cull cow).

[3] Carotenoid pigments, antioxidants, grass or forage *vs* concentrate.

[4] Possible impact on glycogen reserves (“*dark firm dry*” meat).

[5] Sensitivity of red meat to “*cold shortening*”.

[6] Collagen content and solubility.

[7] Ageing conditions (duration, temperature) + packaging mode (vacuum, high-oxygen modified atmosphere).

The majority of the muscles provide less than 10% of lipids, once the visible fat is removed (Bauchart et al., 2008). Although its fatty acid composition is often the subject of criticism due to the high proportion of saturated fatty acids (**FA**s) including palmitic FA (C16: 0) and monounsaturated FAs which represent 42 to 52% and 43 to 48% of total fatty acids, respectively (Gruffat, 2018), it remains a source of n-6 and n-3 polyunsaturated fatty acids, especially n-3 recognised as providing health benefits (Bauchart et al., 2008).

The intramuscular fat content of meat determines partly its nutritional properties, beyond its impact on its sensory properties (Wood et al., 2008). It varies greatly between breeds and muscles within the same breed, depending on the metabolic type. Other factors related to the farming system are also involved: sex, age and diet. The variability of intramuscular fat content is mainly related to the number and size of intramuscular adipocytes. The effect of sex can be explained by the level of testosterone production. Thus, in castrated males, lower testosterone production is associated with greater fat deposition (Venkata Reddy et al., 2015). Breed is a major factor of variation: the intramuscular fat content is low in animals with significant muscle development associated with high glycolytic activity (Hocquette et al., 2010). Nutritional factors such as lipid sources, starch concentration and the rate of incorporation of concentrate, forage and vitamins also play a role in the modulation of lipogenesis (Manni et al., 2018).

The fatty acid composition of beef is influenced by genotype. For example, the lower intramuscular fat content observed in 'culard' animals is associated with a higher proportion of polyunsaturated fatty acids (**PUFAs**), which can be explained by a higher proportion of membrane lipids (polar lipids, rich in PUFAs) and a lower proportion of reserve lipids (non-polar, rich in monounsaturated FAs) (Clinquart et al., 1998; De Smet et al., 2004). More recently, the variability in the FA composition of beef has been linked to genetic polymorphism and candidate genes have been identified, such as *ACACA*, *FASN*, *SCD*, *FABPs* and *SREBP-1* genes (Mannen, 2012).

Diet is another factor that determines FA composition. In general, grazing cattle are reported to have a higher PUFA/saturated FA ratio and a more nutritionally favourable n-6/n-3 ratio (Venkata Reddy et al., 2015).

Although rumen bio-hydrogenation of FAs limits the impact of the incorporation of lipids rich in PUFAs, it is possible to increase the PUFA content of beef using vegetal sources, in particular linseed or linseed oil, which are very rich in α-linolenic acid (18:3n-3) (Clinquart et al., 1991; Scollan et al., 2014). The incorporation rate in the diet should however be limited to 2% of DM in order to avoid an unfavourable impact on the texture of the fat and excessive sensitivity to oxidation. It is also possible to modulate rumen bio-hydrogenation of FAs, in particular by incorporating tannins into the diet (Morales and Ungerfeld, 2015).

Beef is a source of rumen-produced Conjugated Linoleic Acids (**CLAs**) that are potentially beneficial to human health (Gruffat, 2018). The production of these FAs can be modulated by diet as a result of bio-hydrogenation of dietary PUFAs by the rumen microbial system. The main CLA isomer in ruminant muscle is cis-9, trans-11 CLA and strategies to increase its content in bovine muscle adipose tissue include pasture- and grass silage-based diets with or without dietary supplements of linseed/linseed oil, rapeseed oil/cakes containing elevated levels of 18:3n-3, fish oil or marine algae (Scollan et al., 2014).

The main factors influencing the nutritional quality attributes of beef are summarised in Table 5.

Technological quality attributes

The technological quality attributes of meat are generally considered to encompass its storage and processing capacity (Monin, 1991), namely water holding capacity and fat holding capacity. The degree of processing of beef is generally lower than that of pork, so the technological aptitude for processing is regarded as less important for beef. However, water holding capacity and storability at refrigeration temperatures are essential. In addition, the relative contribution of *postmortem* factors (ageing time/temperature, carcass suspension and their interaction) to the variability in instrumental and sensory tenderness is generally quite high (about 70%) (Juárez et al., 2012).

The pH plays a very important role in the control of the technological quality, as it largely determines shelf life and processability, as well as water holding capacity. It also has a major impact on sensory quality attributes, in particular colour and tenderness but also flavour. The glycolysis that occurs *postmortem* is associated with a decrease in pH from 7 to about 5.5 if the animal's muscle glycogen stores were normal and therefore sufficient at the time of death. A lower glycogen reserve leads to "**DFD**" meat, corresponding to its dark, firm and dry characteristics. Temperature of transportation, long waiting time in rest pens prior to slaughter increase the incidence of this DFD meat (Flores et al., 2008).

The final pH value can vary slightly (in the order of a tenth of a pH unit) from one muscle to another depending on its glycolytic potential. The glycogen concentration varies depending on the muscle fibre type. Muscles where type I (=red oxidative) fibres predominate have a lower glycogen concentration than muscles where type II (=glycolytic) fibres predominate; they therefore have a slightly higher final pH (Ferguson and Gerrard, 2014). This could also explain the differences between breeds and genotypes and, at

Table 5

Main factors modulating the nutritional quality attributes of beef.

Factors	Proteins and amino acids	Lipids	Fatty acids	Minerals, vitamins and oligo-elements
Genetics[1]	+	++	+	–
Sex[2]	+	+	+	–
Age[2]	+	++	+	–
Feeding – farming system[3]	+	++	++	+
Preslaughter conditions	–	–	–	–
Slaughtering and carcass chilling conditions	–	–	–	–
Muscle/meat cut	+	++	+	–
Storage conditions[4]	+	+	++	–
Cooking mode	+	++	++	+

++: major factor of variation; +: weaker factor of variation; –: not a factor of variation.

[1] Breed (+ double-muscled genotype).

[2] These factors are often combined (e.g. young bull vs cull cow).

[3] Grass or forage vs concentrate rich in lipids and/or antioxidants.

[4] Ageing conditions (duration, temperature) + packaging mode (vacuum, high-oxygen modified atmosphere).

least partially, the effect of the rearing method. Indeed, an extensive production mode is associated with a higher proportion of type I fibres and lower proportions of IIa (=fast oxido-glycolytic) and IIb (=fast glycolytic) fibres compared to an intensive production mode, and this difference could be linked to the physical exercise associated with grazing (Ferguson and Gerrard, 2014). The more oxidative nature of muscle metabolism in these animals, however, is not related to a greater abundance of mitochondria (Wicks et al., 2019). Taking into account the lower glycogen concentration of type I fibres, this could explain the higher final pH observed in the meat of cattle raised on pasture when compared to cattle fed on concentrates, which does not exclude increased sensitivity to stress, another important factor decreasing glycogen concentrations and therefore inducing a high ultimate pH. The ultimate pH of meat from cattle raised on pasture may indeed be higher than that of cattle fed on concentrates, which could result in detection of "false" DFDs if a very low threshold ($pH \geq 5.6$) is used (Wicks et al., 2019).

The sex of the animal can also influence the frequency of high pH meats. Monin (1991) reported a higher frequency of carcasses with a pH above 6 in several muscles, in bulls but less so in cows, heifers or steers. This is due to the more excitable temperament of entire males which leads to increased glycogenolysis in the period immediately preceding slaughter.

In addition to the ultimate pH value, a too rapid *postmortem* reduction in pH can also impact the quality of the meat. Cattle are less sensitive than pigs to this type of defect called "PSE" (pale, soft and exudative) but it can occur when the muscle pH reaches a value below 6 while the body temperature is still high (35–40 °C), leading to denaturation of myofibrillar and sarcoplasmic proteins, resulting in an alteration in colour, water holding capacity and tenderness. The tenderising potential and colour stability of these meats are reduced due to decreased proteolytic enzyme activity and decreased redox stability of myoglobin, respectively. These defects affect more particularly the muscles deep in the carcass where cooling is slower (Jacob and Hopkins, 2014).

The rate of *postmortem* pH decrease can also be influenced by muscle fibre type, which can explain the different rates between muscles or breeds. It apparently does not explain the faster evolution observed with the 'culard' genotype since the higher proportion of IIb fibres and the lower proportion of IIa fibres that characterise this genotype should be associated with a slower evolution, whereas the reverse is observed. This paradox could be explained by the large muscle mass of 'culard' animals, which compensates for this effect by strongly delaying the decrease in temperature (Ferguson and Gerrard, 2014).

The main factors influencing the technological quality attributes of beef are summarised in Table 6.

Table 6
Main factors modulating the technological quality attributes of beef.

Factors	Processing capacity	Storage capacity
Genetics[1]	++	+
Sex[2]	+	+
Age[2]	++	+
Feeding – farming system[3]	+	++
Preslaughter conditions[4]	++	++
Slaughtering and carcass chilling conditions[5]	+	++
Muscle/meat cut[6]	++	++
Storage conditions[7]	+	++

++: major factor of variation; +: weaker factor of variation; –: not a factor of variation.

[1] Breed (+ double-muscled genotype).

[2] These factors are often combined (e.g. young bull vs cull cow).

[3] Antioxidants, grass or forage vs concentrate.

[4] Possible impact on glycogen reserves ("*dark firm dry*" meat).

[5] Effect of chilling on microbiological growth.

[6] Processing: collagen content and solubility; storage: sensitivity of lipids and myoglobin to oxidation.

[7] Ageing conditions (duration, temperature) + packaging mode (vacuum, high-oxygen modified atmosphere) and control of cold chain (microbiological and physico-chemical quality).

Image-value attributes

Image attributes encompass the extrinsic ethical, cultural and environmental dimensions associated with how a food is produced and processed, and its origin. As with other species, the controversy over beef consumption appears to be dominated by issues related to production, more than consumption itself (Legendre et al., 2017). Compared to monogastrics, beef production is less of a debate in terms of food competition with humans but more in terms of the environment, more particularly with regard to greenhouse gas (**GHG**) emissions, especially methane which contributes strongly to the greenhouse effect. Nevertheless, the close link between ruminants and grazing contributes highly to the "green" image associated with this mode of production compared to non-ruminant species used for meat production. All grasslands (permanent or temporary) provide ecosystem services, for example in terms of soil stabilisation (water erosion), regulation of water flow and pollutants, nitrogen and phosphorus cycle regulation or even preserving pollinating insects. In addition, these grasslands provide many amenities, including biodiversity, carbon sequestration, limiting nutrient leakage into water but also in terms of landscape and cultural identity (Hercule et al., 2017).

In terms of animal welfare, the farming system applied to cattle, which is more closely linked to land and the soil and often more extensive than that of monogastrics, is an asset for the sector and this can be reinforced by certain official quality signs, focused on suckler beef cattle and grazing (Raulet et al., 2022). Conversely, slaughter is more often controversial, in particular ritual slaughter without prior stunning, authorised in some EU countries, e.g. France. Animal welfare, especially during transport and at the slaughter facility, is also a decisive factor for image-value quality attributes. A growing interest in on-farm slaughter has emerged in recent years, both among breeders concerned about the conditions of slaughter of their animals and some consumers who are willing to pay more for beef slaughtered on the farm (Carlsson et al., 2007). By avoiding animal transportation, mobile slaughter may have the potential to reduce animal stress. EU legislation allows mobile slaughter of all kinds of domestic animals. Several mobile cattle slaughter units have been in operation in Europe for several years, for example in Norway and Sweden. An experimental phase has been underway in France since 2019. Although animal transport on road is avoided in mobile slaughter, special attention should be paid to the conditions immediately preceding the killing of the animal (Hultgren et al., 2020). To control the quality and microbiological safety of the meat, these mobile slaughter units are usually combined with a carcass cooling unit.

Synergisms and antagonisms between the dimensions of beef quality

In the previous sections, the dimensions of beef quality were presented separately, and for each of them, the factors associated with their variability were discussed. These factors can have a positive effect on one quality attribute and a negative effect on another, or vice versa. The variation in one factor can therefore produce different effects on the different dimensions of beef quality, and synergisms or antagonisms may arise between them. The origin of the variation in the quality of beef is very often multifacto-

Table 7
Main factors modulating bovine carcass and meat quality attributes.

Factors	Commercial	Microbiological	Sensory	Nutritional	Technological	Image
Genetics[1]	++	–	++	+	+	++
Sex[2]	+	–	+	+	+	+
Age[2]	++	–	++	+	+	+
Feeding – farming system[3]	++	+	++	++	+	++
Preslaughter conditions[4]	+	+	+	–	+	++
Slaughtering and carcass chilling conditions[5]	+	++	+	–	++	++
Muscle/meat cut	++	+	++	++	++	–
Storage conditions[6]	+	++	++	+	+	++
Cooking mode	–	++	++	++	NA	–

++: major factor of variation; +: weaker factor of variation; –: not a factor of variation; NA = not applicable.

[1] Image: local breeds (official sign of quality and origin).

[2] These factors are often combined (e.g. young bull vs cull cow).

[3] Image: specifications + (official) sign of quality and origin.

[4] Image: animal welfare (transport).

[5] Image: slaughtering without stunning.

[6] Image: beef with extended ageing ("dry-aged beef").

rial, depending on the multitude of factors of variation which follow one another throughout the value chain (Table 7). These factors can be related to stakeholder expectations, from the farm to the consumption stages, and to the farming system. The synergisms and antagonisms between the dimensions of beef quality will be illustrated below by taking two examples: the effect of the genetic factor alone (highly muscled breeds, local breeds), and the comparison of several farming systems (pasture vs indoor, organic vs conventional on grass).

Overall, the genetic selection of meat-producing animals has been guided by objectives or criteria of productivity (growth rate, feed conversion efficiency) and commercial quality (carcass weight, conformation, fatness). In beef production, genetic selection has often been carried out based on the optimisation of growth rate and feed conversion efficiency, without taking into account the other dimensions of the quality, apart from commercial quality expressed in terms of carcass weight and conformation, associated with a high cutting yield. The effects of genetic selection can be positively or negatively associated with the criteria or expectations for the other dimensions of quality. Synergisms or antagonisms are therefore possible between carcass quality and certain meat quality attributes. Genetic selection of cattle based on increased carcass conformation is generally associated with a reduction in the fat and collagen content of the meat with positive effects on nutritional quality, tenderness, respectively (Clinquart et al., 1998). In contrast, a lower fat content is associated with less flavour and juiciness (Raes et al., 2003). In terms of image attributes, animals with high conformation, in particular double-muscled animals, can be perceived as less "natural" by the consumer, given the spectacular muscle development and calving difficulties associated with the high incidence of dystocia (Bellinge et al., 2005). Higher feed conversion efficiency is associated with lower GHG emissions per kg of meat produced, which can be considered as a positive effect from an environmental point of view, but the consumer does not see it in this way (Cantalapiedra-Hijar et al., 2020).

On the other hand, breed can have a positive effect on image quality, in particular when considering local breeds which can be used as a positive differentiator from standard beef (Raulet et al., 2022). Local breeds are perceived by consumers as being closer to the terroir.

Synergisms and antagonisms between the dimensions of meat quality vary from one farming system to another. For example, fattening cattle on grass, compared to fattening in the barn on a high concentrate diet (Table 8), has the advantage of producing a more "typical" meat in terms of sensory quality (darker colour), leaner and containing more n-3 fatty acids, while exhibiting superior oxidative stability. This production mode also has many advantages in terms of image: "naturalness" associated with production on pasture and low use of inputs. However, the latter is not without its drawbacks: the reduction or even absence of the use of concentrated feed limits the growth rate and fat deposition which characterises the "fattening" period. Moreover, due to the very seasonal nature of grass production, this farming system does not allow continuous production throughout the year. Its carbon footprint can be considered unfavourable when expressed per kg of meat produced with the current calculation, but can be much more positive if carbon sequestration by grassland is taken into account (Kondjoyan and Picard, 2019).

Table 8
Positive and negative effects associated with cattle finishing on pasture (vs indoor finishing on a high concentrate diet).

Quality attributes	Positive effects	Negative effects
Commercial		Lower fatness/less fat (if adiposity is required) Lower conformation and/or weight
Sensory	Darker meat[1]	Darker meat[1] Yellow fat Higher variability[2]
Nutritional	Fatty acid composition[3] Leaner	Higher variability[2]
Convenience	Higher oxidative stability[4]	Meat availability[5] Higher cost
Image	Naturalness Lower use of inputs Lower environmental impact (except GHG[6]emissions/kg of meat)	GHG[6] emissions/kg of meat

[1] Depending on consumer preference.

[2] Depending on the season, grass quality/availability/degree of maturity and availability of concentrate.

[3] Higher n-3 fatty acid content.

[4] Antioxidants naturally present in grass.

[5] Production depending on the season, grass availability, feed autonomy.

[6] GHG = greenhouse gas.

If the differentiation is solely based on the organic nature of the production, and if this is compared to the conventional grass production system, the antagonisms appear weaker (Table 9). They mainly relate to feed autonomy which can constitute a hurdle for farms that do not have the land and/or pedoclimatic conditions

Table 9
Positive and negative effects associated with organic cattle production on pasture (vs conventional on pasture).

Quality attributes	Positive effects	Negative effects
Commercial		Lower fatness (if adiposity is required) Lower conformation and/or weight
Sensory	Less flavour (when leaner)[1]	Higher variability[2]
Nutritional	Leaner	Higher variability[2]
Convenience	Higher oxidative stability [3]	Higher cost
Image	Naturalness Lower environmental impact (except GHG[4] emissions/kg of meat) Differentiated product (official sign of quality and origin)	GHG[4] emissions/kg of meat

[1] Depending on consumer preference.
[2] Depending on the season, grass quality/availability/degree of maturity and availability of concentrate (feed autonomy).
[3] Antioxidants naturally present in grass.
[4] GHG = greenhouse gas.

to produce the feed needed to supplement the grass-based diet and obtain a sufficient degree of finishing. The lower productivity level in organic production results in a higher impact on global warming potential, but this is more than offset by the decrease in the impact linked to lower fertilisation levels and the absence of synthetic fertilisers, with an overall lower global warming potential in organic beef production (van Wagenberg et al., 2017). The additional production cost can be recovered by valuing organic beef in the form of a differentiated product, linked to specifications and submitted to certification.

Regarding sanitary quality, it is generally assumed that organically raised animals are less exposed to the chemical hazards associated with pesticides and antimicrobials. Nevertheless, during a representative sampling of French bovine production carried out on the *M. rectus abdominis* muscle, Dervilly-Pinel et al. (2017) observed that conventional meat was devoid of any of the pesticides studied and they were unable to draw any conclusion for antimicrobials as the number of positive samples was found to be very low. On the other hand, organic production, favouring older animals and/or outdoor access, also undergoes environmental contamination when it comes to age- or fat-accumulating contaminants (Pussemier et al., 2006). In the study mentioned above (Dervilly-Pinel et al., 2017), organic meat was associated with significantly higher contamination of persistent organic pollutants in cattle although all levels were far below regulatory limits. In organic beef, a higher content was also observed for zinc. Another hypothesis may also be related to the fact that in conventional production, some animals (e.g., young bulls) are raised without any grazing period and are therefore less exposed to environmental contaminants.

Conclusions and perspectives

The variability in cattle carcass and meat quality traits is very high and the origin of this variability is multifactorial. It should be noted that these factors are very often connected with the purpose of the farming system. For example, the meat of dairy cattle comes from older female animals of dairy breeds, whereas the meat of beef cattle comes from animals of beef breeds, which may be relatively younger. In addition, certain factors linked to the livestock system (in particular feed, especially the effect of grazing) significantly influence the sensory, nutritional and even technological quality of beef. These factors can generate positive differentiation when they are used as criteria in a specification.

The conditions applied during the preslaughter period or during slaughter strongly influence the microbiological quality of the meat and its suitability for storage. Controlling the latter is essential when considering that beef can be eaten raw (tartare, carpaccio) and that it requires more or less long ageing to obtain optimal tenderness. Another particularity of beef, shared with sheep meat, is its very low degree of processing, apart from its use on a small scale in the preparation of cooked dishes (meat simmered in sauce, lasagna), this meat is consumed in the form of fresh meat, minced meat or meat preparations. The method of preparation, in particular the cooking, has a very strong influence on the sensory and microbial quality at the consumption stage, which is taken into account in only one beef grading system in the world (the MSA grading scheme).

Quality variability can be significant between animals, even when they are from the same livestock system or genotype, and it is not easy for the consumer to assess this variation, except visually, but only in terms of colour and fat. The consumer pays special attention to the tenderness of beef, a characteristic which varies widely and is difficult to assess at the time of purchase. Predicting the sensory characteristics of meat using a multicriteria approach is a major objective for operators in the value chain. This can be achieved in different ways, including quality prediction models from data collected during the production and slaughter of animals and previously determined relationships between these data. Such existing models (MSA in Australia), to be adapted or developed in Europe, would provide additional useful information for consumers to guide them in their choice. It could be useful to allow consumers to make an objective choice at the time of purchase. It could also allow producers to predict eating quality in order to pay farmers accordingly, as in Australia, thereby encouraging farmers to produce better beef, and not more beef.

Ethics approval

Not applicable.

Data and model availability statement

None of the data used in this review were deposited in an official repository.

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All authors contributed to the writing of the original draft.

Declaration of interest

None.

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