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Opportunities for predicting and manipulating beef quality

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Abstract

Meat quality is a complex concept and can be defined as the characteristics of meat which satisfy consumers and citizens. The quality concept can be divided into intrinsic quality traits (which are the characteristics of the product itself) and extrinsic quality traits (which are more or less associated to the product for instance the price, a major determinant of purchase, or any brand or quality label). Quality can also be generic for the mass market or specific for niche markets. The relative importance of the different quality traits varies with human culture and time with a general trend of an increasing contribution of healthiness, safety and extrinsic quality traits. This review underlines the need for the development of methods to interpret and aggregate measures under specific rules to be defined in order to produce an overall assessment of beef quality. Such methods can be inferred for example from genomic results or data related to muscle biochemistry to better predict tenderness or flavor. A more global assurance quality scheme (the Meat Standards Australia System) based on the aggregation of sensory quality traits has been developed in Australia to ensure palatability to consumers. We speculated that the combination of indices related to sensory and nutritional quality, social and environmental considerations (carbon footprint, animal welfare, biodiversity of pasture, rural development, etc) and economic efficiency (incomes of farmers and of others players along the supply chain, etc) will provide objective assessment of the overall quality of beef (i.e. incorporating an all encompassing approach) not only for the mass market but also to support official quality labels of niche markets which are so far mainly associated with the geographical origins of the products.

1. Introduction

The great challenge in developed countries is that the livestock sector is faced with a general saturation of its market and with an increasing demand by consumers for high-quality products with enhanced safety and healthiness and from food production systems with improved environmental and carbon footprint (Grunert, 2006). In this context, at least for fresh meats, the ability of producers to deliver and guarantee products which are safe, and more importantly which are perceived as such by consumers is an important prerequisite for underpinning consumer demand (Verbeke & Viane, 1999). Emphasis on carbon footprint is increasing (Grunert, 2006). In particular for beef, this is reflected by criticisms for greenhouse gases (GHG) emissions from cattle production systems. Moreover, two factors can make it difficult and confusing for the beef supply chain to deliver on quality: (i) the safety crises (BSE, foot and mouth disease, etc) with their effects amplified by the media, and (ii) the drive to differentiate beef on the basis of GHG emissions in addition to the aspects classically taken into account (product brandings, geographical origin, sensory or processing characteristics). Hence the definition of quality is evolving and expanding. A major current question for scientists is therefore how to define and predict quality, and also how to control and manipulate quality of beef to satisfy these emerging requirements of consumers and citizens. In beef production, from the farm to the point of consumption, it is important to consider the whole meat supply chain in addition to consumers, which includes the farmers, processors, butchers, wholesalers and retailers. In addition to the retail sector which is globally a big driver and, in some countries, butchers who play major roles by choosing animal types and by advising consumers, consumers are often considered the most important part of the chain. However, it is recognized that their requirements vary with gender, incomes, country, culture, age, habits, and purpose of the meal (for every-day, exceptional meals, or festive meals). In addition, consumers' demands for low prices can conflict with demands for high-quality products (Hocquette & Gigli, 2005).

A second major factor for consideration is the increasing number of quality attributes which must be considered and their variability depending on the culture of a country. To provide further definition, some experts distinguish between intrinsic and extrinsic quality attributes. The former refers to the characteristics of the product itself and includes for instance, safety, healthiness, sensory traits (e.g. tenderness, flavor, juiciness, overall liking), convenience, etc. The latter refers to traits which are associated with the product, namely (i) production system

characteristics (from the animal to the processing stages including for example animal welfare, carbon footprint), and (ii) marketing variables (including price, brand name, distribution, origin, packaging, labelling, and traceability) (reviewed by Luning, Marcelis & Jongen, 2002; Grunert, Bredahl, & Brunso, 2004).

This review considers quality as “the properties of a product that contribute to and satisfy the needs of the end-user” (reviewed by Luning *et al.*, 2002). In other words, quality is the characteristics of products that consistently meets (or better exceeds) end-user or customer expectations (reviewed by Casabianca, Trift & Sylvander, 2005). Thus, quality will be considered as a convergence between end users’ wishes and needs on one hand and the quality attributes of fresh beef and beef products on the other hand (reviewed by Hocquette, Richardson, Prache, Médale, Duffy & Scollan, 2005).

The major question addressed in this review is how to predict overall quality by combining these different quality traits. The first part will deal with the intrinsic quality traits and the second with the extrinsic quality traits of beef. In each section, specific methods to combine the different quality traits will be described where they already exist or noted for further research.

2. Intrinsic quality traits

The physical intrinsic qualities of the meat (colour, shape, appearance, tenderness, juiciness, flavor) as well as its nutritional properties (for instance, fatty acid composition) depend to a large extent on the properties and composition of the original muscle (which vary themselves according to genetics, animal feeding and livestock practices) and on the *post-mortem* processes which are involved in the conversion of muscle into meat. Two complementary approaches may thus be applied to improve meat quality. From the breeder or farmers point of view (often with input from the abattoir), predicting and manipulating muscle characteristics to ensure a better quality for consumers is the way of choice. The challenge here is to combine farming, muscle biology, genetics including new genomic approaches (Hocquette, Lehnert, Barendse, Cassar-Malek & Picard, 2007, Hocquette, Cassar-Malek, Bernard & Picard, 2009) and traditional meat science (Culioli, 1999) to improve beef quality. The second approach is to integrate a number of traits related to quality at the consumer end (consumer perception, intention of purchase, decision-making and consumer satisfaction), which in turn depends mainly on the relationships between quality expectation and quality experience before and after purchase (Grunert, Bredahl, & Brunso, 2004). After the description of these

two points of view, a broader methodology to combine all the previously mentioned quality traits (not only the sensorial traits) will be proposed.

2.1. Predicting and manipulating of properties and composition of the muscle tissue

Variability in meat sensory quality, especially in tenderness, flavor and overall liking depends in part on differences in the biological characteristics of skeletal muscles at slaughter (see reviews by Geay, Bauchart, Hocquette & Culioli, 2001; Picard, Jurie, Bauchart, Dransfield, Ouali, Martin et al., 2007; Guillemain, Cassar-Malek, Hocquette, Jurie, Micol, Listrat et al., 2009). The first objective of such studies is to determine what are the most important muscle characteristics related to meat quality. It is generally accepted that muscle fiber characteristics (cross-sectional area, metabolic enzyme activities, proportions of the different muscle fiber types), muscle glycogen content (which determine the ultimate pH of the meat), collagen content and solubility, and the activities of proteases and of their inhibitors during aging are the most important physiological parameters that determine meat tenderness. Content and composition of intramuscular fat contribute to the determination of flavor as well as the changes (lipolysis, oxidation, etc) occurring during aging of the meat. The content of intramuscular fat does also increase tenderness in beef (Reverter, Johnson, Ferguson, Perry, Goddard, Burrow et al., 2003) and lamb (Warner, Jacob, Hocking Edwards, McDonagh, Pearce, Geesink et al., 2010), but this is more of an indirect effect.

However, these general relationships are more complex than initially thought as shown by conflicting results in the literature depending of the data sets which differ by many factors including the animal populations studied or the muscle cuts examined. Nevertheless, some studies indicated that only one quarter to one third of the variability in tenderness or flavor is related to the variability of various muscle characteristics (Renand, Picard, Touraille, Berge & Lepetit, 2001; Picard et al., 2007). This low level of prediction may be explained by different factors including: (i) measurement errors with respect to both muscle and meat quality traits to better predict the latter by the former; (ii) gaps in the knowledge of the major biological mechanisms that determine the various quality traits.

In order to attempt to solve the first problem, research is continuously developed to implement the latest methods and technologies to characterize at high speed and low cost, and as accurately as possible, the greatest number of muscles and their meats. Emerging technologies such as electrical (such as the measurement of electrical impedance, Lepetit, Salé, Favier & Dalle, 2002) and optical methods (such as Fluorescence and NIR

spectroscopies, Hildrum, Wold, Segtnan, Renou & Dufour, 2006) have been recently developed (and some of them patented) (reviewed by Mullen & Troy 2005 and Hocquette, Renand, Dufour, Lepetit & Nute, 2007b). More generally, to assess meat quality closer to the point of sale, different indicators (pH, color, mechanical properties, ultrasound, electrical impedance and conductivity, etc) and technologies (image analysis, fluorescence and NIR spectroscopy, etc) can be used (Meunier, Picard, Astruc & Labas, 2010; Dian, Andueza, Barbosa, Amoureux, Jestin, Carvalho, Prado et al, 2007; Guy, Prache, Thomas, Bauchart & Andueza, 2011). Final assessments by analytical tests with trained panels or consumer tests are methods that are chosen to evaluate meat sensory quality (reviewed by Hocquette et al., 2007b). In all cases, repeatability, accuracy, speed, on-line application and cost are essential criteria in selecting the most appropriate methods. Considerable efforts have been made to improve and standardize all these methods; however more research is required for most of them. The best methods should be non-invasive, not expensive, automated, accurate and with an assured benefit by being directly related to the trait of interest. Trained panels or consumer tests are very close to consumers' real satisfaction but are both destructive and the least easy methods to implement routinely. On the other hand, the indirect methods are easier to implement at the industrial level, but, in many cases, the results are difficult to be biologically interpretable or to be easily related to the consumers' preferences.

Another way to compensate for technical errors or variability in the determination of muscle and meat quality traits is to identify general laws to predict the latter by the former. To achieve this goal, different initiatives have been established to generate biochemical and beef quality databases with the idea that a high volume of data not only brings statistical strength but also a better understanding of the variability relating to various criteria (breed, age, sex of the animals, cuts, etc). These databases constitute excellent tools for developing meta-analysis approaches (for example see Schreurs, Garcia, Jurie, Agabriel, Micol, Bauchart et al., 2008) to propose general laws concerning the relationships among muscle characteristics and meat quality traits. For instance, in Florida, a strategy relies on a standard profile of the most noteworthy characteristics of muscles from the bovine carcass based on the observation that the differences in muscle characteristics among cuts explain the greatest part of the variability of beef quality. This approach is known as muscle profiling (Von Seggern, Calkins, Johnson, Brickler & Gwartney, 2005). In France, scientists and professional partners together with European partners of the ProSafeBeef program (ProSafeBeef) have taken the initiative to bring together all the data related to muscle biochemistry and meat quality they have accumulated over many years. This goal is not easily achieved since amalgamating disparate

data bases does have its problems (Hocquette, Meurice, Brun, Jurie, Denoyelle, Bauchart et al., 2011). However this type of approach will ultimately deliver models linking muscle characteristics to eating quality.

In order to increase our knowledge about quality traits and to improve the accuracy of the models, new “omics” approaches have been adopted. Genomics brings a better understanding of how biological traits are determined from genes. In fact, genomics is changing our scientific paradigm, because the global expression of genes in cells and tissues generates new biological hypotheses. The net result is a move from hypothesis-driven research (where scientists test the relevance of biological hypotheses) to hypothesis-generated research (in which new biological hypotheses will appear from gene and protein analyses) (Cassar-Malek, Picard, Bernard & Hocquette, 2008). As a first consequence, genomics has a great potential for the discovery of new DNA markers which might be used as low cost and easy-to-use diagnostic tests for the improvement of livestock breeding (reviewed by Hocquette, Renand, Levéziel, Picard & Cassar-Malek, 2006; Hocquette et al., 2007a; Hocquette, Gondret, Baéza, Médale, Jurie & Pethick, 2010). This area is commercially strategic and many DNA genotyping methods for specific genes have been already patented (reviewed by Hocquette et al., 2007a). Genetic research programs have been developed in several countries for detecting QTL of beef and meat quality traits (Burrow, Moore, Johnston, Barendse & Bindon, 2001, Burrow, 2008). However, the association between the detected QTL and the target traits appeared to be different according to breed. For example, the association between DGAT1 and TG markers and meat intramuscular lipids detected in Australia and USA was not validated on the French beef breeds (Renand, Payet, Levéziel, Denoyelle, Hocquette, Lepetit et al., 2007). Moreover, the association between CAPN1 or CAST SNP with tenderness was shown to be breed specific among the French beef breeds (Allais, Journaux, Levéziel, Payet-Duprat, Raynaud, Hocquette et al., 2011). To complement these genetic approaches, functional genomics is clearly a key approach that may help to discover expressional candidate genes or pathways that differ between animals with contrasting meat quality. Over the last years, genomic tools (transcriptomics and proteomics) were developed for applications in meat science particularly to identify markers of beef tenderness (reviewed by Bendixen, 2005 and Cassar-Malek et al., 2008). These approaches revealed a list of potential biological markers which may be used to predict meat quality (for review Picard, Berri, Lefaucheur, Molette, Sayd & Terlouw, 2010). Genomics has indeed revealed that unsuspected genes may be potential molecular indicators of muscle mass (Bernard, Cassar-Malek, Renand

& Hocquette, 2009), sensory attributes (Bernard, Cassar-Malek, Le Cunff, Dubroeuq, Renand & Hocquette, 2007) or marbling (reviewed by Hocquette et al., 2010) of meat. For example, genomic studies revealed that oxidative stress and apoptosis are relevant cellular mechanisms for tenderization processes (Guillemin, Bonnet, Jurie & Picard, 2011). From this knowledge, various biotechnology tools are being developed to assess routinely and simultaneously all the genes known so far to be involved in beef quality (for instance, DNA or protein chips). These tools would be used as predictors of the “meat quality potential” of an animal or a carcass. However, it was not possible to extrapolate the relevance of these genomic markers to all animal groups which differ by many factors (such as sex or environmental conditions of production) from the initial population of reference in which these markers were identified (Hocquette et al., submitted). In conclusion, genomics offers both the potential to discover new predictors of beef quality and the potential to develop new predictive tools which although accurate are still largely too expensive for routine use (reviewed by Hocquette et al., 2009). This research has indeed revealed many genes with small effects for most complex traits such as tenderness. So, there still remains a challenge for genomics which will undoubtedly be solved but it will need time, big data sets coupled to better high quality phenotypes that reach deeper underneath high level traits like tenderness.

2.2. Assessing, predicting and manipulating beef quality

Another and complementary way to predict quality is to identify and then integrate a number of traits related to quality at the consumer end. This implies analyses across the supply chain. To achieve this goal, the Australian red meat industries have created the Meat Standards Australia (MSA) grading systems for beef and lamb (Meat Standards Australia 2010).

The MSA prediction model is based on the sensory answers from untrained consumers to create absolute and quantitative estimates of consumer satisfaction. Consumers were asked to assess beef initially in 4 quantitative areas (tenderness, juiciness, liking of flavour, and overall liking) and then finally to rate the meat as one of unsatisfactory (ungraded), good every day (3-star), better than every day (4-star) or premium (5-star) categories. Statistical analysis resulted in the establishment of a new variable: the MQ4 (a quality score which is a weighted amalgam of the 4 quantitative assessments) which represents the best predictor of consumer satisfaction (ungraded, 3-star, 4-star or 5-star) when eating the meat in question. The MQ4 score, covering a scale of 0-100 units, can be considered to be the best summary of the profiles for tenderness, juiciness, flavour and overall appreciation by the consumer (Watson,

Gee, Polkinghorne & Porter, 2008). Moreover consumers show a clear preference of increasing 'willingness to pay' for the higher satisfaction scores (Lyford, Thompson, Polkinghorne, Miller, Nishimura, Neath et al., 2010).

Based on the sensory analysis of thousands of consumers, the MSA system predicts the MQ4 score of cuts and muscles, depending on how long they are aged and the type of cooking method chosen. Then, the MSA system sorts cuts and muscles into the 4 quality grades, (ungraded, 3-star, 4-star or 5-star). To achieve this, MSA has identified the Critical Control Points (CCPs) from the production, pre-slaughter, processing and value adding sectors of the beef supply chain and quantified their relative importance using large-scale consumer testing. Analysis of the MSA database showed that the variation in palatability explained by muscles was approximately 60 times greater than that explained by the variation among animals for the same muscle. Therefore, the most important CCPs have been incorporated into a model to predict palatability (the MQ4 score) for individual muscles according to the cooking method. The CCPs from production include breed, ossification (estimate of physiological age) and implants of hormonal growth promoters. The CCPs from pre-slaughter and processing include pH/temperature window, alternative carcass suspension, electrical stimulation (both high and low voltage systems), marbling and ageing (Watson, Polkinghorne & Thompson, 2008). This model confirms that a guarantee for eating quality can only be given if the links that most affect eating quality are controlled along the meat production chain (Thompson, 2002).

A strong point of the MSA system is that the sensory results used are derived from untrained consumers. Weak points of this model are linked to the specificities of the Australian market. In Australia, farmers produce *Bos indicus*, pure British bred (e.g. Angus, Shorthorn) or European crossbred animals, and virtually no pure breed European breed type (e.g. Charolais, Limousin) animals. This contrasts with the European situation. Most of the results in the database come from steers and not young bulls or cows as in continental Europe. The breed effect is not taken into account except the *Bos indicus* / *Bos taurus* effect. Nevertheless, various other countries or regions have tested or are testing the MSA system: Korea (Thompson, Polkinghorne, Hwang, Gee, Cho, Park et al., 2008), the USA (Smith, Tatum & Belk, 2008), France (Hocquette, Legrand, Jurie, Pethick & Micol, 2011), Japan, Northern Ireland and the Irish Republic. The overall conclusion is that consumers have similar responses for the assessment of beef quality when the MSA system is used to assess preferences.

With regard to healthiness, the relationships between the content and the composition of dietary fat in animal products and incidence of lifestyle diseases, particularly coronary heart disease are well established and highly discussed in the literature (reviewed by Givens, 2010 and Salter, 2012). This has contributed towards the development of specific guidelines from the World Health Organization in relation to fat in the diet (WHO, 2003). It is recommended that total fat, saturated fatty acids (SFA), n-6 polyunsaturated fatty acids (PUFA), n-3 PUFA and trans fatty acids should contribute <15–30%, <10%, <5–8%, <1–2% and <1% of total energy intake, respectively (reviewed by Scollan, Hocquette, Nuernberg, Dannenberger, Richardson & Moloney, 2006). Alternatively, it is noted that monounsaturated fatty acids (MUFA), SFA and PUFA should be close to the 'ideal' composition: 60, 25 and 15% of total fatty acid in the diet (reviewed by Durand, Scislowski, Gruffat, Chilliard & Bauchart, 2005). In developed countries, consumers are encouraged to reduce the dietary intake of SFA and increase the intake of PUFA (reviewed by Salter, 2012). In general, ruminant fat typically contains a high proportion of SFA (40-60 %; largely as a consequence of microbial biohydrogenation within the rumen) and monounsaturated fatty acids (MUFA; 30-50%) and small amounts of PUFA (5%). This is one reason why the current nutritional recommendations encourage reducing human consumption of beef per capita (reviewed by Scollan et al., 2006). Although it is most important to consider the composition of the total diet (which is itself composed of different products including dairy, vegetables, other meat products, etc), it is tempting to dissect these thresholds product by product. If we do so, beef would be considered too rich in SFA and not enough in PUFA (it contains on average 44, 50 and 6% of MUFA, SFA and PUFA respectively, Durand et al., 2005). However in lean beef muscle, fat can range from less than 1% to 6% as in France, meaning the absolute intake of SFA is low. In addition, most consumers trim undesirable fat either before or after cooking (Pethick, Ball, Banks & Hocquette, 2011; Williams and Droulez, 2010). Ruminant products are also rich in the dominant conjugated linoleic acid (CLA), the *cis*-9, *trans*-11 isomer, which has been identified as possessing a range of health promoting biological properties including anticarcinogenic activity (reviewed by Scollan et al., 2006). Unlike for the sensory traits described in the MSA model, these thresholds related to nutritional values of products have never been aggregated together in a single and simple index easily interpreted by the consumer.

2.3. Aggregation of measures related to the different intrinsic quality traits

As described previously, extensive experimental work has been carried out to characterize beef in terms of sensory and nutritional traits with regard to consumers' needs or wishes and to predict those characteristics by different methods or modeling tools. The same trend exists for other intrinsic quality attributes of beef not detailed here such as safety, technological properties and convenience for the consumer.

The main difficulty is appropriate approaches to combine all this information together. To do so, several methods may be used, in relation to the objective of the evaluation and constraints that have to be faced. Each method presents both strengths and weaknesses. A recent review described existing methods and their application to animal welfare (Botreau, Bonde, Butterworth, Perny, Bracke, Capdeville et al., 2007), but can obviously be applied to other characteristics such as meat quality.

The first method is the analysis by an expert or a group of experts who in turn express opinions to end-users (who may be consumers, retailers, or even farmers). This is a non-explicit aggregation of measures or knowledge, used to advise end-users or help stakeholders choose the most appropriate alternative (e.g. what would be the best piece of meat to buy with respect to the consumer's expectations). This historical approach was well developed in the meat sector where traditional butchers used to advise consumers about beef quality, and consumers used to trust the advice given. Unfortunately, the rationale behind this process of aggregation of knowledge by the expert is not transparent and also not consistent across experts (e.g. the butchers who advise their customers). More importantly, the number of butchers is regularly declining with a loss of expertise, and more and more beef is sold in supermarkets with potentially less trust from consumers.

To move forward in the prediction of quality, minimum requirements on each measure to be considered may be useful to estimate a broader definition of beef quality. Thus, to be considered of good quality, a meat would have to comply with all the minimal requirements set for each measure. This second approach was described in the previous section in the case of beef nutritional value where beef composition in terms of fatty acids proportions is compared to human needs, for each fatty acid category (SFA, MUFA, PUFA, etc). This method has the advantage of being easy to understand and implement, however it generally leads to very rough evaluation, in an "all-or-none" answer (e.g. the nutritional value of the meat considered is good *vs.* bad).

A third approach, with the objective to compare a set of n beef cuts, is to rank these beef cuts in terms of quality from best (rank 1) to worst (rank n), and this has to be considered for each measure or quality trait. We can imagine a ranking system for each quality trait of interest

(tenderness, flavor, overall liking, fatty acid composition, etc) and then a summation of the ranks. If such an approach were to be developed in the beef sector, the traits of interest should be agreed by the whole meat chain and of course this would be difficult to achieve. Reference traits and the methods to assess them should be well defined and finally the method to combine the ranks for the different traits should be also well defined and applied consistently across the meat chain. The main limitation of this method is that the overall ranking depends on the set of beef cuts that are compared, i.e. on the data source. In other words, considering the same two beef cuts A and B included in two different sets, in the first set the beef cut A may be scored better than B whereas in the second set the opposite result may occur (B better than A). This is due to the fact that on each measure, an ordinal value is assigned (rank) and that after, a sum is calculated across traits. This is in fact not correct, because a sum should be only used on cardinal data. In addition, ranking would be likely to strongly differ according to the breeds, the sex of the animals and so on. This method leads to a 'relative' judgment, comparing alternatives among themselves, and not to an 'absolute' assessment. For instance, this method may lead one to conclude that cut of meat A is better than cut of meat B, but it would not be possible to say whether A and B are good or bad, or if A is excellent whereas B is of very poor quality. Another problem with this method is that two cuts of meat with the same overall score could achieve this score with very different attributes. For example, a cut with excellent flavor and poor fatty acid composition could rank the same as a cut with excellent fatty acid composition, but very poor flavor.

The fourth method is to convert quality traits into value-scores (e.g. quantitative information) which are then compounded. The advantage of such a method is that we obtain an absolute judgment, allowing the user to know if the meat is of good or poor quality. However, the calculation process used to combine the scores has a great impact and must be chosen cautiously. For example, by using a weighted sum, full compensation between scores is allowed (it means for instance that a low score in flavor could be compensated for by a high score in tenderness). The MSA system is a modeling tool using this method of a weighted sum to develop scores leading to the MQ4 score. The MSA approach thus assumes that compensation between the four sensory criteria is legitimate (an increase in one score may be compensated for by a decrease in another score). If one considers that compensations should be limited (i.e. considering that a meat with average scores on all of the 4 criterion-scores is better than a very tender meat but absolutely not juicy), then other methods exist and should be used (e.g. the Choquet integral, Grabisch & Roubens 2000). Instead of aggregating the criterion-scores into an overall score, some methods (e.g. ELECTRE TRI, Roy 1991) use

these scores to sort the alternatives into categories. In that case, the objective of the evaluation is not to compare cuts of meat but rather to assign each cut to one quality category. This is what is done in the MSA system via using the MQ4 score (resulting from a weighted sum of the 4 criterion-score) to predict the four quality categories: ungraded, 3-star, 4-star and 5-star. In this review, we will encourage using most of these methods, according to their advantages and limitations so that the most appropriate one (or combination of methods) is used to better predict intrinsic quality traits of beef in substitution of the non-formalized expert assessment (experts being butchers or consumers for example).

More generally, facing such a problem of evaluation of a multidimensional concept (e.g. the intrinsic quality of meat, composed of several dimensions, here called "quality traits"), multicriteria evaluation methods should be applied (Roy, 1996; Bouyssou, Marchant, Pirlot, Perny, Tsoukias & Vincke, 2000). The general procedure to design a multicriteria assessment follows a sequential structure (see Figure 1): 1/ define the criteria (i.e. the intrinsic quality traits of beef) to be assessed; 2/ identify the indicators (from direct measures and/or their predictors) to assess each criterion; 3/ construct each criterion separately (by interpreting and if necessary aggregating the indicators); 4/ aggregate the different criteria to form an overall judgment.

- **Steps 1 and 2**

The intrinsic quality of the meat covers several quality traits (sensory, nutritional, safety, convenience...) that correspond to the different criteria that must be assessed to evaluate the intrinsic quality of beef (see Table 1). This list of criteria would have to be more precisely defined to ensure both the exhaustivity and the non-redundancy of the evaluation (Bouyssou, 1990).

It is obvious that in each domain of expertise previously mentioned (muscle biology, genetics, fatty acid composition of products, etc), a common language with shared, and unambiguous definitions of traits and their measurement methods is highly encouraged to share data and hence to draw robust conclusions (Hughes, Bao, Hu, Honavar & Reecy, 2008). To this end, the "Animal Trait Ontology of Livestock" (ATOL) programme developed in France at INRA with the "Iowa State University" is seeking to produce an accurate definition of traits of phenotypic interest (Hurtaud, Bugeon, Dameron, Fatet, Hue, Meunier-Salaün et al., 2011). This trend for standardization and minimal requirements is poorly developed in classic biology but not in genomics. Indeed, the recent and rapid advent of modern genomics

techniques, that generate large amounts of information with experiments that can be difficult to reproduce due to their complexity, has generated standard protocols that the scientific communities have been invited to adopt. For example, MIAME ("Minimum information about a microarray experiment") describes the minimum amount of data that is essential to communicate on a transcriptomics experiment in order to enable both the interpretation of the experiment results with the least possible ambiguity and to contribute to the reproducibility of the experiment (Brazma, Hingamp, Quackenbush, Sherlock, Spellman, Stoeckert et al., 2001). More recently, some authors have proposed a MIAPE (minimum information about a proteomics experiment) (Taylor, Paton, Lilley, Binz, Julian, Jones, et al., 2007) and a MIBBI (minimum reporting requirements for biological and biomedical investigations) (Taylor, 2007). In Meat Science, the success of the MSA system is due notably to the standardization of the consumer evaluation protocols (Watson et al. 2008a) and the accumulation of large amounts of data over time. Such a long term and shared strategy across sectors of the meat chain throughout the World should be encouraged.

The selection of indicators to assess each quality trait (or criterion) has to be made according to the constraints that are imposed on the evaluation method. For instance, if the aim is to produce a standardized method to be used routinely, it seems impossible to use the expertise of sensory panels. In that case, instead of a direct measure of flavor or juiciness, it may be possible to use predictors. The two approaches presented in the two first sections of "Intrinsic quality" are not exclusive from each other; on the contrary they may be combined to obtain the best predictor.

- **Step 3**

With regards to the different methods previously mentioned to produce an overall assessment of meat quality, scientists and professionals of the meat chain must discuss and agree together when and how each method can be used. We can consider here that intrinsic quality traits are limited to four families of criteria: sensory traits, nutritional traits (similar to healthiness), safety and convenience. The aim here is to discuss how to build up four quality indices (the sensory index, the nutritional index, the safety index and the convenience index) and how to combine them.

In the case of sensory traits, the method of score combination needs to be developed to take advantage of work conducted in the area of muscle biochemistry and genomics. Two approaches can be considered: systems which deliver a commercial or practical application and systems which deliver a primary deep scientific understanding – not always but often they

will be different. They will both be important and should have close relationships. An example of a research model could be the prediction of tenderness and/or shear force from muscle biochemical traits (fiber types, connective tissue, intramuscular fat level), genetic markers and gene or protein expression profiles. We can imagine combining the expression level of a group of genes with muscle fiber cross-sectional area and contents of collagen and intramuscular fat content (which are all quantitative values) in order to better predict quality. This is still a research modeling approach which delivers a better scientific understanding of beef quality. This approach may become more practical in the near future thanks to the development of innovative tools to routinely determine muscle biochemical or genomic traits. On the other hand, a method of score combination can be applied to aggregate different sensory traits (namely tenderness, flavor, juiciness, overall liking) in order to build up an overall sensory score with practical and commercial application. This is the MSA approach which predicts the MQ4 (a sensory score which is a weighed amalgam of the 4 sensory traits). We discussed previously that MQ4 is then converted thanks to a sorting procedure to a classification of four categories (ungraded, 3-star, 4-star or 5-star). We can imagine that the modeling approach to predict beef quality from muscle biochemistry and genomics may be combined in the future with the practical MSA approach to increase the accuracy of the prediction of beef quality.

In the case of nutritional traits, the current state of the art is the comparison of beef composition with minimal requirements set for each trait related to the composition of the product (especially its composition in fatty acids). Thanks to further research, this "all-or-none" system could be easily converted into a more detailed classification system with additional thresholds, which could be for example: far below the recommendation, below the recommendation, close to the recommendation, above the recommendation, far above the recommendation or it could be "source of", "good source of" i.e. in a serve of beef the consumer gets 10% of the RDA (Recommended Daily Allowance) or 25% of the RDA (Food Standards Australia and New Zealand, 2004). For healthiness, we propose that as well as describing fatty acids in beef, it is important to build in other factors such as iron, vitamin and amino acid contents. It is likely that beef would have low to moderate evaluation for fat traits (since beef is perceived as too rich in saturated fat), but rate highly for traits like the content of protein, iron and vitamins (Geay et al., 2001). In fact, it is essential to work more on the competitive advantages of the product for human health (important source of omega-3 fatty acids and minerals such as iron and zinc). One important challenge is to get positive

nutritional value signals of beef into the supply chain (Pethick et al., 2011; Scollan, Greenwood, Newbold, Yáñez Ruiz, Shingfield, Wallace et al., 2011), in addition to the existing ones that are for the moment quite negative, so that the consumer may have a more balanced overall view of nutritional quality of beef. A sequential aggregation (similar to the one proposed for animal welfare in Botreau, Bracke, Perny, Butterworth, Capdeville, van Reenen et al., 2007) should be proposed from simple measures possible to perform routinely (for instance, composition in fatty acids and amino acids), to healthiness sub-criteria (for instance, for fat, protein, vitamins, minerals) to an overall assessment of the criterion “healthiness”. One major difficulty will be to define rules to aggregate values of quality traits which will be determined at each level depending on the nature and number of traits considered and the level of compensation to be permitted. For example, in the area of fat, how to compensate (if possible) for a high content in SFA (which has a negative impact on the healthiness fat index) by a high content of omega 3 and/or CLA (which has a positive impact on the healthiness fat criterion)? Does it make sense to compensate at least in part a high healthiness protein score by a low healthiness fat score to determine an overall assessment of beef healthiness? These problems have been discussed previously for animal welfare (Botreau et al., 2007b), the conclusions being fully applicable here. This approach will encourage dietitians and meat science researchers to work together to truly tackle the relevant trade-offs. For the safety score, we have to combine different sub-criteria related to different contaminants of the products (for instance chemical, residues, microbes, etc). In the case of microbial contaminants, methods have been developed to assess meat contamination by many potentially harmful pathogens (Salmonella, Verocytotoxigenic E. coli in particular E. coli O157:H7, Listeria monocytogenes, and others) on farms and/or at the slaughterhouse. A sorting method may be appropriate to combine the different requirements specific to each pathogen according to regulatory issues.

For the convenience index, a social approach is needed to define convenience, which would include information related to packaging, storage of the product, cooking methods and so on.

The biggest challenge would be to combine the four indices (sensory, healthiness, safety, convenience) related to intrinsic quality traits discussed above taking into account that a very limited compensation should be possible between them. In other words, very bad safety indices would certainly not be compensated for by high sensory indices, while the opposite could be discussed.

- **Step 4**

The four indices (sensory, nutritional, safety and convenience indexes), would have then to be aggregated to obtain an overall evaluation of the intrinsic quality of the meat. As discussed previously, the method to be used to aggregate them should be chosen according to the objective of the evaluation, to the level of compensation to be allowed between the four criteria and to their relative importance.

3. Extrinsic quality traits

3.1. The increasing importance of extrinsic quality traits

Differences exist among countries in the challenges facing their beef industry. Many authors (for instance Thornton, 2010) agree that demand for livestock products in the future is likely to be moderated by socio-economic factors such as human health concerns, the cost of the product and changing socio-cultural values (such as concerns for animal welfare and carbon footprint of the products). Thomas, Scollan & Moran (2011) emphasized the importance of animal agriculture not only for the production of high-quality protein, but also for sustaining rural livelihoods and ensuring food security. Galyean, Ponce & Schutz (2011) noted that emphasis on economic efficiency and innovation in beef production systems, associated with efforts to reduce emissions and maintain the highest animal welfare and food safety standards, will ensure the long-term future of the North American beef industry. In addition, public concern for safety has induced greater concern for animal traceability (Galyean, Ponce & Schutz, 2011). Safety, traceability and product quality are also the main drivers of the beef industry in Brazil (Millen, Pacheco, Meyer, Mazza Rodrigues & De Beni Arrigoni, 2011). In Argentina, healthiness, traceability, the investment and incorporation of research and technology, government policies toward agricultural sustainability and animal welfare, as well as describable beef quality of grass-fed beef are considered as important drivers to sustain beef production (Arelovich, Bravo & Martinez, 2011). For some specific countries such as Australia and New-Zealand, which are already important beef exporters, the projected continuation of increasing global demand for meat (including beef) offers great opportunities for the economic efficiency of their beef industries, but should however remain environmentally and socially sustainable (Bell, Charmley, Hunter & Archer, 2011). In Australia, the five priorities of research on beef are sensory traits, safety and healthiness, but

also the fact that production systems must be ethical from an animal welfare and environmental point of view, and efficient from a cost of production perspective such that quality and price must be perceived to match by consumers (Pethick et al., 2011). The European challenges are similar since the European beef industry will rely on better animals, better feed, and better nutrient utilization with more autonomous farming systems (for instance, based on pasture) to ensure better incomes for farmers while protecting the environment and producing typical products of specific and high quality (Hocquette & Chatellier, 2011). However, we can observe some subtle differences between cultures or countries: indeed in Australia there has been a large and sustained investment in R&D directed at satisfying the eating needs of consumers to ensure a viable animal industry because consumers are the only party to put money into the supply chain. In other words, willingness to pay by consumers is considered as the major driver of the beef industry (Pethick et al., 2011). However with the introduction of a carbon tax in Australia for 2012, there is an appreciation of other dimensions that need to be addressed even though Agriculture will not be included in the tax. In Europe, several other drivers exist, in addition to the market, like cultural considerations, policies and regulations, subsidies, etc. Sustainability of the European beef industry is a complex concept with three major dimensions (environmental considerations, social aspects and economic efficiency), which each results in turn from the aggregation of different criteria related either to the intrinsic or the extrinsic quality traits of the products (Figure 2) (Hocquette & Chatellier, 2011). However, we must consider the heterogeneity across Europe in eating patterns (Balder, Virtanen, Brants, Krogh, Dixon, Tan et al., 2003), in the natural environment, agricultural traditions, and public policies (including import or tariff regulations and farm subsidies). This implies a more local view of beef sustainability. In other words, we need to weight differently the various intrinsic and extrinsic quality traits of beef according to the region. Nevertheless, in the future, European beef production systems are likely to make greater use of more natural resources (such as pastures) in more sustainable livestock systems that include increased attention to environmental, economic, and social issues (Hocquette & Chatellier, 2011).

From this short survey of the challenges facing the beef industry throughout the World, it is clear that not only is the relative importance of some specific intrinsic quality traits (for instance, healthiness, safety, etc) increasing, but also extrinsic quality traits (for instance, typical quality traits of products, environmental issues, animal welfare, traceability, economic efficiency, sustaining rural livelihoods) are becoming more and more numerous, and also

more and more important in relative values to meet the large increase in expectations of consumers and citizens. In addition, extrinsic quality traits influence perception of intrinsic quality traits by consumers (Banovic, Grunert, Madalena Barreira & Aguiar Fontes, 2009). Some authors have also acknowledged the growing importance of symbolic qualities associated with the origin of the product – “that which values the culture and identity” of the food commodity (Muchnik, 2006). Consumers may willingly pay a premium for products which help preserve a traditional way of life and which do not cause environmental degradation. As an example, the quality of Pampean beef made in Argentina includes the symbolic quality of pampas life (Champredonde, 2008). In other words, we have to make a difference between the generic quality of beef sold in the mass market and the specific quality of some typical beef products sold in niche markets (Casabianca, Trift, Sylvander, 2005). The assessment of the generic quality of beef needs low-cost and easy methods to implement in the beef supply chain for a routine use (i.e. the MSA system). The assessment of the specific quality requires clear and concise information to consumers not only about intrinsic quality traits but also about typical quality traits, carbon footprint, livestock practices, culture and human history associated to the product.

3.2. Existing quality labels which contribute to sustainable beef production with regard to extrinsic quality traits

The development of quality labels in France and other European countries was initially motivated (i) by the desire to fight against usurpation of geographical names which were famous (as observed for example for the French wine “Champagne” or the Greek cheese “Feta”), (ii) by the objective to provide products of high and/or typical quality from the consumers’ point of view and (iii) by the need for sustainable development of agriculture. The issue is to maintain or even increase the production of these products and hence to maintain the presence of producers and farmers in the rural territories. Therefore, some labelling schemes for identifying product quality and origin aim at (i) enabling producers and other stakeholders to increase the value of their products by encouraging diversity and specificities of products in association with local environments; (ii) giving consumers the possibility to choose quality foods with a special character and good taste, produced in an animal-friendly way and with respect for the environment. Thus, such a scheme may encourage the development of rural areas and national regions, making it possible to (i) preserve biodiversity and maintain variety in the landscape, local expertise and natural resources; (ii) maintain the

dynamics of rural areas through activity of local producers around common projects by mobilizing them around collective organizations for future progress. It can be considered as a beneficial tool enabling regions to highlight more effectively the value of certain specific forms of traditional production (INAO leaflet, 2010).

Three EU schemes known as PDO (protected designation of origin), PGI (protected geographical indication) and TSG (traditional speciality guaranteed) promote and protect names of quality agricultural products and foodstuffs:

- PDO covers agricultural products and foodstuffs which are produced, processed and prepared in a given geographical area using recognised know-how. The PDO protects a region, a defined location or, exceptionally, a country, where these designate a product whose characteristics are due to a geographical environment and whose production and processing and preparation, are carried out in the defined geographical area. In other words, the PDO identifies a raw or processed agricultural product that is authentic and typical of a clearly-boundaried geographic region of origin, that is well-known or even famous (it cannot be created since it recognizes an existing, long-lasting form of production), has specific characteristics, represents specific know-how, and is subject to regulatory procedures of approval and control.
- PGI covers agricultural products and foodstuffs closely linked to the geographical area. At least one of the stages of production, processing or preparation must take place in the area. PGI refers to products originating from a geographical area for which a defined level of quality, reputation or other characteristics may be attributed to this geographical origin. In other words, the PGI identifies a raw or processed agricultural product that gets its quality, reputation or another characteristic from a given geographical region of origin, that is produced or processed or prepared in this given geographical area of origin and that is manufactured under conditions that are subject to specific control procedures.
- TSG highlights the traditional character, either in the composition or means of production

The concept of designation of origin and geographical indication is based on a combination of the characteristics of the natural environment where production takes place and human factors such as the know-how of producers. This combination is considered as the key which determines the final product quality. In this concept, quality is indeed the result of a combination of a form of production and processing, and a determined geographical area

involving the interaction of, among other things, natural, climatic, physical and human factors giving the product a specific character. This is the concept of “*terroir*” (Figure 3), which has different meanings whether it is viewed from the producers’ or the consumers’ point of view. “*Terroir*” is a French word which comes from the French word “*terre*” which means land. It was originally a French term in wine, coffee and tea used to denote the special characteristics that the geography, geology and climate of a certain place bestowed upon particular varieties (Wikipedia, <http://en.wikipedia.org/wiki/Terroir>). The “*terroir*” can be officially defined as “A geographical area with defined boundaries where a human community generates and accumulates along its history a collective production knowledge based on a system of interactions between bio-physical and human factors. The combination of techniques involved in production reveals originality, confers typicity, and leads to a reputation for a good originating from this geographical area.”(INAO, 2007). The concept of “*terroir*” is thus closely linked to the concept of typicity which is one important quality trait for consumers. “The typicity of an agricultural product is its trueness to a type which is distinguished and identified by a reference human group possessing knowledge distributed among various actors. This includes the knowledge to evaluate that product and the knowledge to appreciate it. It should not be confused with compliance with a standard and it allows variety within the type. Among many expressions of typicity, “typicity linked to terroir” is a particular construction which gives expression to the effect of terroir for a given product.”(INAO, 2007).

The main difference between the PGI and PDO scheme is a less stringent code of practices for PGI, especially for the raw material procurement area, which allows factory-scale production for PGI, while PDO is closer to agricultural origin and small-scale production.

The number of PDO/PGI labels in the meat sector, their production in volume and in values have slightly increased from 2006 to 2008 in the European Union (+5-10%). In 2008, the number of designation was 25 for PDO and 60 for PGI mainly in Italy (29 PO/PGI labels over a total 85, which means 34%), Portugal (28), Spain (10), Germany (8) and France (4) but 0 to 2 only in other European countries (European Commission, 2012). This reflects cultural differences (countries of the South of Europe being more concerned by the geographical indications). The four designations in France are « Taureau de Camargue », « Fin gras du Mézenc », « Maine-Anjou »” and « Boeuf de Charolles ». The first AOP created in France in 1996 « Taureau de Camargue » was created in order to value the animals which are sub-products of bullfighting. These cattle have never been selected on meat quality consequently

they have specific muscle properties and beef qualities (Picard, Santé-Lhoutellier, Fiot, Gatellier, Durand, & Micol, 2009; Santé-Lhoutellier, Gatellier, Fiot, Durand, Micol & Picard, 2010). Both in volume and value, PDO/PGI labels in Italy represent 62 to 65% of the total meat production under PDO/PGI labels in the European Union (which is 3,731 millions Euros) compared to less than 1% in Portugal although these two countries have similar number of PDO/PGI designations (29 and 28 respectively) (European Commission, 2012). This reflects economic differences in the efficiency of the PDO/PGI system. In Portugal, the strategy of differentiated beef is seen as a tool to develop less-favoured areas, to promote development in these rural regions (Banović, Barreira, Fraústo da Silva, Lemos, Aguiar Fontes, M. & Jorge, 2008) or simply to decrease social desertification of rural areas by the enlargement of small niche markets based on the added value of indigenous bovine breeds (Rodrigues, Andrade & Rodrigues, 2003). It was indeed shown that PGI-certified farms tend to be more extensively managed and they are better adapted to mountainous regions (Iraizoz, Bardaji et al., 2011). From an economic point of view, from a Spanish study, it seems that PGI-farms show less pure technical efficiency scores but higher economic performances and profitability especially when subsidies are taken into consideration (since PGI-farms show a heavier reliance on subsidies) (Iraizoz, Bardají, & Rapún, 2011).

The TSG provides protection for products of traditional nature that are not (or no longer) linked to their geographical origin. In other words, TSG identifies a raw material of specific composition, method of production and/or method of processing for human consumption (it is often a recipe) with a traditional name (in use for at least one generation), with well-known specific characteristics, and that is subject to controls (or inspections). TSG is present for different products in several European countries for instance in the meat sector: Serrano ham (Spain), traditional farm-fresh turkey (United Kingdom), Falukorv (a Swedish sausage), and so on (a total of 30 products in Europe). In 2009, the “Traditional pasture-reared beef” (*“Boeuf de tradition élevé à l’herbe”*) was recognised in common by UK, Ireland and France (INAO, 2010). The TSG product must be either manufactured using traditional raw materials, or based on a traditional composition or method of production and/or processing (INAO leaflet, 2010).

The indication "Organic Farming" certifies that the product derives from a mode of production and processing that is protective of natural balances and animal welfare as defined in a highly stringent set of specifications backed by systematic controls. Organic farming is a production system label identifying a raw or processed agricultural product that respects natural cycles and rhythms (environmental balance), and does not employ synthetic

chemicals. It applies to an individual (not collective as for PDO, PGI or TSG), but officially-declared producer initiative, subject to control organism-led controls or inspections, and compatible with some of the other European official labels.

The French agricultural quality label (the famous “*Label Rouge*”) certifies that the product possesses a specific set of characteristics establishing a level of quality higher than that of a similar product of the standard type. In other words, Label Rouge identifies a raw or processed agricultural product that has characteristics determining a ‘superior quality’ level (compared with ‘standard’ products) as indicated by hedonic tests, that guarantees a set of specific characteristics defined for technical aspects (geared to each industry), and that is subject to controls (or inspections). Two aspects play an important role in the Label Rouge: palatability and quality associated with the image of the products. The label is awarded to different types of products such as free-range hen's eggs, canned sardines, veal meat from suckling calves, cooked ham, farm churn butter and smoked salmon. Records show that more than 500 registered specifications for the Label Rouge are on the market, mostly in the poultry industry. The scheme covers nearly 50,000 producers and 31 different product categories (including meat and poultry, pork meat–delicatessen, and others) are concerned by the Label Rouge. The fame and the commercial impact are more important for some products such as poultry, and less for red meat (INAO, report 2010). Label Rouge in France represents 18,684 tons of beef in 2010 compared to less than 10,000 tons for both PDO/PGI and compared to a total production of beef of 492,355 tons in carcasses and 573,473 tons in cuts (Jacquet, personal communication).

Generally speaking, at least in France, consumers have a favourable perception of products with an official quality label, but they express a degree of misunderstanding on the real guarantees offered by official quality labels. At the European level, awareness of the PDO system is quite good among European consumers, especially in France, Italy and Spain. Traditional food consumption patterns are stronger in the South than in the North of Europe whereas consumers from the North of Europe place far more trust in commercial brands (Vanhonacker, Lengard, Hersleth & Verbeke, 2010). The PGI system is well known in Italy but not so much in other countries whereas the TSG system is the less known. Generally, consumer awareness is in line with the market presence of products with geographical indications, with countries such as France, Italy and Spain being in the lead. Furthermore, it was shown that European consumers of products with official quality labels are typically middle-aged to elderly consumers, health-conscious, ethnocentric, food connoisseurs, attached to familiar characters in their food choice and who enjoy cooking (Vanhonacker et

al., 2010). Unfortunately, high price for products carrying an official quality label is a serious limitation to induce purchase. This fact and also the observation that young consumers are less sensitive to the presence of an official quality label and more concerned by the price (Tavoularis, Recours & Hebel, 2007) are not favourable for the further developments of official quality labels into the future despite a real demand by consumers and stakeholders in the food chain for quality guarantee systems (Verbeke, Wezemael, de Barcellos, Kügler, Hocquette, Ueland et al., 2010). With safety, the main reason driving food product purchases have been and will be in the future a competitive price which will continue to be more important than the origin, the brand and/or the quality level depending on the product (Tavoularis, 2008). Brand is however important since consumers may use brand for perception of quality traits (especially intrinsic quality traits) as shown in Portugal (Banovic et al., 2009). In France, the key equally weighted factors driving food purchase are firstly safety and a competitive price. Next come notoriety brought by official quality labels or a trusted brand and being of the French origin (Tavoularis, 2008).

3.3. Future research priorities to better predict and to enhance quality

An International Workshop on ‘Animal Production in a Changing World’ was held in Clermont-Ferrand (INRA-Theix, France) on 9-10 September 2009 to discuss how to balance the need for increased production of animal products coupled with a lower footprint and addressing societal needs in terms of product quality for the consumer.

A first conclusion was that, in the area of product quality, the existing knowledge is not fully applied (Scollan et al., 2011) for economic, social or political reasons and progress should be made in that direction. As an economic example, one can cite the tenderstretch hanging method for carcasses in order to improve beef tenderness. But, it requires more time and resources to be implemented in the meat industry, and in some countries, the supply chain cannot or does not want to spend more money (Sorheim & Hildrum, 2002). From a social and political point of view, in some countries like France which has a long tradition of quality labels, the implementation of any new system (like the MSA system) could affect the existing systems. This is the reason why the beef industry is generally very conservative and thus reluctant to any change. It thus prefers small projects with small changes because there is less investment required and less impact on its own organization (Hocquette et al., 2011a). This is in our opinion a narrow-point of view with a short-term vision without any strategy for the long-term future to sustain beef consumption by consumers. Furthermore, a great change in

mindset is required to develop payment on the basis of beef quality instead of quantitative meat production or carcass conformation and fatness. As discussed below, we suggest the combination of the different existing systems to predict quality in order to take the best from them.

A second priority is the need to develop an environmental index for animal products to take into account the carbon footprint, water and energy use thanks to the increasing environmental impact and role in global climate change of livestock (Scollan et al., 2011). This implies the development of an aggregation of environmental measures related to the diverse inputs and outputs by the livestock/meat supply chain. Variables and methods to assess the inputs and the outputs must first be defined and different methods must be tested to establish the environmental index as previously done for the assessment of animal welfare (Botreau, Veissier, Butterworth, Bracke & Keeling, 2007; Botreau, Veissier & Perny, 2009). Despite important uncertainties in the data and in the methodologies used (which must be improved), such studies have already shown that large variations in greenhouse gas emissions per unit product exist among countries due to differences in animal production systems, feed types and nutrient use efficiencies. For instance, a difference of about 2.4 was noted in greenhouse gas emissions per kg of beef between extreme values among European countries (Lesschen, van der Berg, Westhoek, Witzke & Oenema, 2011). When greenhouse gas emissions are related to milk and meat production by ruminants, the most efficient parts of the World (i.e. which produce the highest proportion of milk and meat but the lowest proportion of greenhouse gas emissions) are Eastern and Western Europe, North America, and the non-EU former soviet Union while the least efficient producers are Asia, Africa and Latin America according to O'Mara (2011).

A third priority of research for the meat industry is a need to support win-win technologies that increase profitability (Thomas, Scollan & Moran et al., 2011) while better predicting, maintaining and/or improving generic quality and/or typicity (specific quality for niche markets). To achieve this goal, we suggest directing R&D efforts in three areas. The first is to take advantage of the new analytical techniques such as metabolomics (Aiello, De Luca, Gionfriddo, Naccarato, Napoli, Romano et al., 2011; Jung, Lee, Kwon, Lee, Ryu & Hwang, 2010) or proteomics (Picard et al., 2010) to better characterise typicity, origin and quality of meat products. The second is to develop scientific and technical tools to better assess sustainability of the beef sector by combining different indices related to the three pillars of sustainability: protection of the environment, social acceptability and economic efficiency. The technical methods behind this concept would be those already described to build up

quality or environmental indices. Such methods have already been used to develop an overall welfare assessment tool (Botreau, Veissier & Perny, 2009). The major challenge would be to combine the sub-indices we are already aware of (quality, environment, welfare) with others which may exist (such as incomes of farmers) or will have to be created (excretion of nitrogen by livestock, etc) and finally evolved into more global indices. The third area of research to support win-win strategies would be to focus much more on the determinants of success of quality labels. Generally, the key success factors of PGI/PDO products are: (i) the quality specificity of the product with a high importance of the concept of origin which must be guaranteed at the consumer level, (ii) the market attractiveness and the public supports (not necessarily public subsidies for farmers, but support to the notoriety of a family of local products, generic help for research and development) and (iii) the effectiveness of the whole chain collective coordination (code of practice, governance structure, variety and quality management, trust-based relationships and direct contacts between the major players from farmers to distributors, promotional and research policies, lobbying ability), and this is probably the weakest point of research (Barjolle, Chappuis & Dufour, 2005; Bardaji, Iraizoz & Rapún, 2009). Indeed, the unequal valuation of typical beef products and their different ability to be recognised by an official quality label (such as PDO or PGI) depend mainly on the local capacity to build up a collective project by convincing all sectors of the supply chain to have a common agreement about the specifications of the product (Trift & Casabianca, 2002). Progress should be made in science and development in the social area to improve recognition of high quality beef products through a labeling system.

Conclusions

Consumer satisfaction when eating beef is a complex response based on objective and emotional assessment of the product. Apart from the product's price which is a simple but a key driver of purchase, especially for young people, other quality traits such as safety and healthiness are very important criteria nowadays in addition to taste and convenience. Some of these quality traits can be easily assessed by consumers when eating (such as taste), but for others (such as safety or healthiness whose relative importance has increased), consumers must trust more and more official quality labels and/or brands and/or the origin of the product. This is the same for extrinsic quality traits which refer to carbon footprint and animal welfare or any other social or environmental issues. Thanks to this general trend, scientific research

can, and must provide objective methodologies to develop true indicators to predict at a low cost and in a trustful manner, intrinsic and extrinsic quality traits of beef.

More precisely, we would suggest combining the different approaches which were developed in this review: the first one which is embodied in the Meat Standard Australia system aims to predict with a better accuracy the generic quality and more precisely the intrinsic quality traits of beef (mainly palatability) to improve the average standard of quality of beef products for the mass market. The second strategy is more integrative by combining intrinsic and extrinsic quality traits since it aims to address quality and typicality of beef for niche markets based on the development of quality labels associated with the origins of the products. Both strategies are not in competition but could help each other. In other words, the MSA system or any other method to aggregate quality traits can be used to objectively ensure a high quality of PDO/PGI products, while the images of origin and the association of “*terroir*” with PDO/PGI products have to be maintained to satisfy the symbolic demand of consumers and citizens. A key issue is that the PDO products which are supported with research must be prepared and organised enough to take advantage of new technologies and research results. Alternatively, just to use the PDO/PGI system, without implementing new R&D outputs, is not advancing the products reputation and competitiveness in the market place. This is clearly a win-win strategy which can be controlled locally according to each product, each country or each region and each consumers’ set of wishes.

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Table 1: Examples of criteria, subcriteria and indicators to be looked at to assess intrinsic quality of meat (Steps 1 and 2)

Indicators	Subcriteria	Criteria	Overall assessment
<i>Tenderness score as evaluated by sensory panel or mechanical test or predictor using proteomics...</i>	Tenderness		
<i>Juiciness as evaluated by sensory panel</i>	Juiciness	Sensory quality	
<i>Flavor as evaluated by sensory panel</i>	Flavor		
<i>Color, shape... as evaluated for instance by a panel</i>	General appearance Etc.		
<i>Fatty acids composition of meat</i>	Fatty acids impact on human health	Nutritional quality	Overall intrinsic quality assessment
<i>Fe, Zn... content</i>	Oligo-elements impact		
<i>Vitamins composition</i>	Vitamins		
	Etc.		
<i>Laboratory analysis for Salmonella, E-Coli, Listeria...</i>	Absence of pathogens	Safety quality	
<i>Antibiotics, dioxine... content</i>	Absence of chemical residues Etc.		
<i>Size, weight...</i>	Packaging easiness		
<i>Shelf life and conditions for storage</i>	Storage capacity	Convenience quality	
<i>Type of cooking required (duration, difficulty...)</i>	Cooking easiness		
	Etc.		

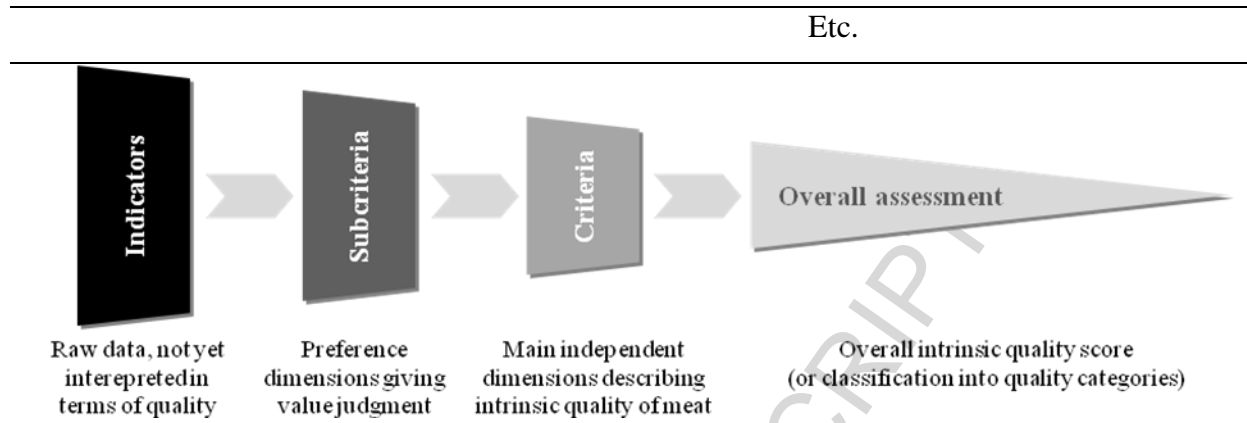


Figure 1: Sequential procedure to design an overall evaluation of intrinsic quality of meat (Botreau, personal communication).

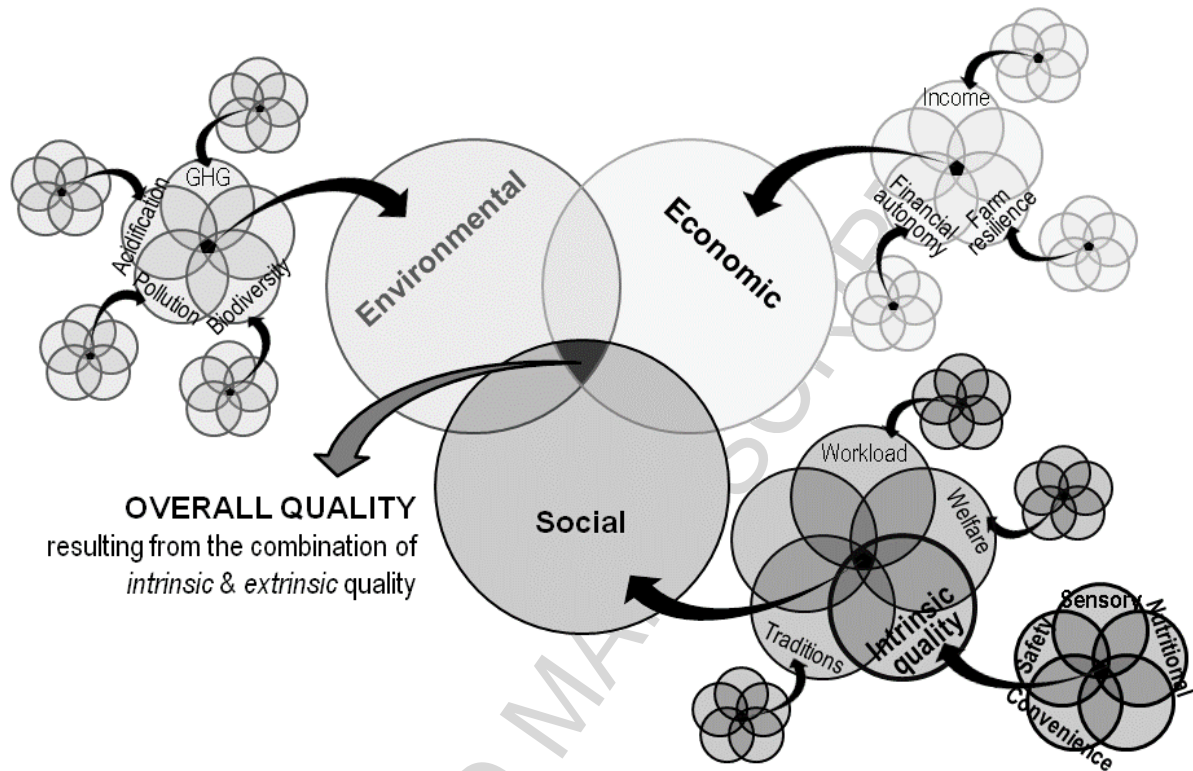


Figure 2: From intrinsic to extrinsic quality of beef (Botreau, personal communication).
GHG: greenhouse gas.

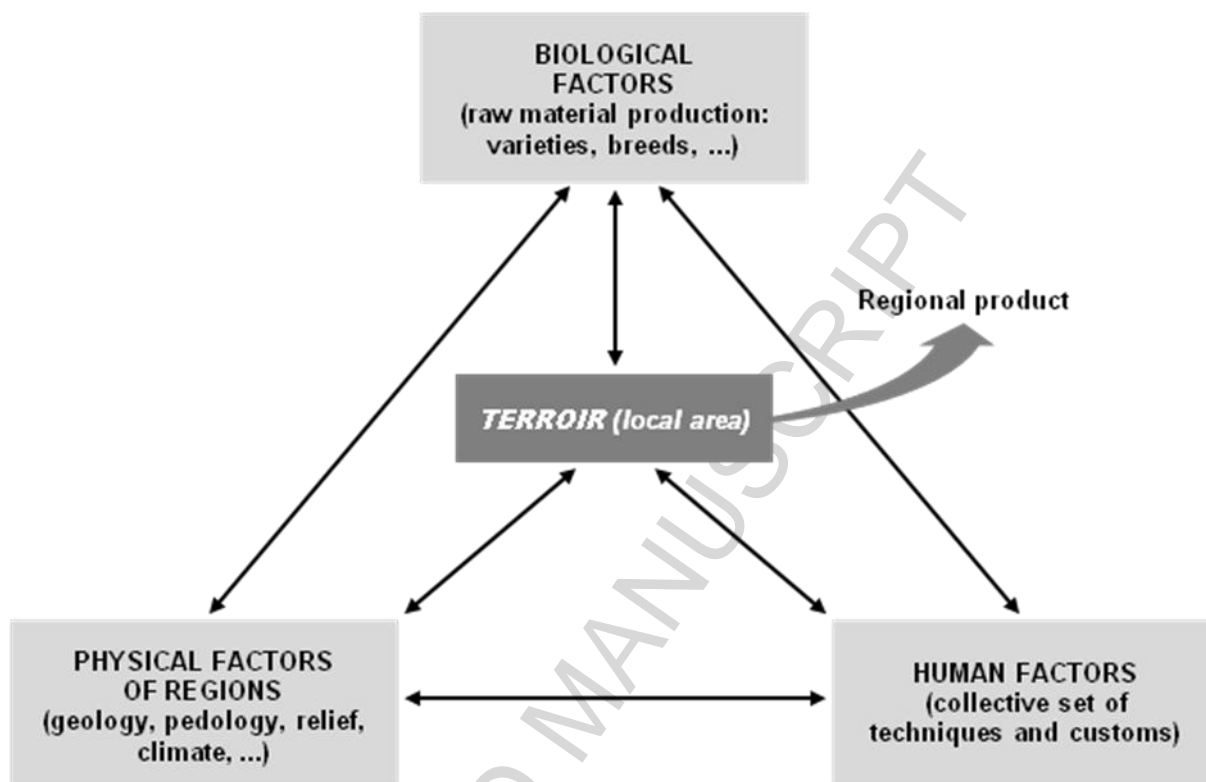


Figure 3: The concept of "terroir" which is the basis of designation of origin

Highlights

A global assurance quality scheme (the Meat Standards Australia) based on the aggregation of sensory quality traits has been developed in Australia to ensure palatability to consumers. We speculated that the combination of indices related to sensory and nutritional quality, social and environmental considerations (carbon footprint, animal welfare, biodiversity of pasture, rural development, etc) and economic efficiency (incomes of farmers and of other players of the supply chain, etc) will provide objective assessment of the overall quality of beef (i.e. incorporating an all encompassing approach) not only for the mass market but also to support official quality signs of niche markets which are so far mainly associated with the geographical origins of the products.