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Highlights

Meat Science xxx (2013) xxx–xxx

Modelling of beef sensory quality for a better prediction of palatability

Jean-François Hocquette [a,b,*], Lynn Van Wezemael [c], Sghaier Chriki [a,b,d], Isabelle Legrand [e], Wim Verbeke [c], Linda Farmer [f], Nigel D. Scollan [g], Rod Polkinghorne [h], Rune Rødbotten [i], Paul Allen [j], Dave W. Pethick [k]

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- Beef quality depends in part on the physical and chemical properties of the muscles.
- The most important muscle characteristics associated with beef quality were determined.
- Muscle profiling will allow the production of value-added products.
- The Meat Standard Australia system is effective in predicting beef palatability.
- The combination of these approaches is a promising area to predict beef quality.

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Modelling of beef sensory quality for a better prediction of palatability

Q1 Jean-François Hocquette[a,b,*], Lynn Van Wezemael[c], Sghaier Chriki[a,b,d], Isabelle Legrand[e], Wim Verbeke[c], Linda Farmer[f], Nigel D. Scollan[g], Rod Polkinghorne[h], Rune Rødbotten[i], Paul Allen[j], ~~Dave W.~~ Pethick[k]

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ABSTRACT

Despite efforts by the industry to control the eating quality of beef, there remains a high level of variability in palatability, which is one reason for consumer dissatisfaction. In Europe, there is still no reliable on-line tool to predict beef quality and deliver consistent quality beef to consumers. Beef quality traits depend in part on the physical and chemical properties of the muscles. The determination of these properties (known as muscle profiling) will allow for more informed decisions to be made in the selection of individual muscles for the production of value-added products. Therefore, scientists and professional partners of the ProSafeBeef project have brought together all the data they have accumulated over 20 years. The resulting BIF-Beef (Integrated and Functional Biology of Beef) data warehouse contains available data of animal growth, carcass composition, muscle tissue characteristics and beef quality traits. This database is useful to determine the most important muscle characteristics associated with a high tenderness, a high flavour or generally a high quality. Another more consumer driven modelling tool was developed in Australia: the Meat Standards Australia (MSA) grading scheme that predicts beef quality for each individual muscle × specific cooking method combination using various information on the corresponding animals and post-slaughter processing factors. This system has also the potential to detect variability in quality within muscles. The MSA system proved to be effective in predicting beef palatability not only in Australia but also in many other countries. The results of the work conducted in Europe within the ProSafeBeef project indicate that it would be possible to manage a grading system in Europe similar to the MSA system. The combination of the different modelling approaches (namely muscle biochemistry and a MSA-like meat grading system adapted to the European market) is a promising area of research to improve the prediction of beef quality. In both approaches, the volume of data available not only provides statistically sound correlations between various factors and beef quality traits but also a better understanding of the variability of beef quality according to various criteria (breed, age, sex, pH, marbling etc.).

Q3 1. Introduction

Beef sensory quality is characterized by a high variability, which contributes to consumer dissatisfaction. Consumer demand in relation to beef has shifted increasingly towards products that are safe, of good eating quality, nutritious, and produced through sustainable farming practices. Among those criteria, eating quality is very important to ensure consumer satisfaction and future purchase (Grunert, Bredahl, & Brunsø, 2004). In beef, tenderness and flavour are two of the most important eating quality attributes. Therefore, predicting eating quality (especially tenderness and flavour) at the consumer level is of paramount importance for the industry in order to remain competitive in the market. To achieve this goal, the beef industry, using different methods and tools, has developed meat standards and grading systems which aim to predict quality at different levels of the beef supply chain. One approach to better predict beef eating quality is modelling. Indeed, faced with the quantity of factors influencing beef quality, a systematic and integrated approach, able to correlate all these factors, is absolutely

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necessary. This paper describes the major modelling approaches of beef sensory quality which differ by their objectives as well as by the variables included in the models. The major purpose of such descriptive systems and models is to facilitate trade by describing commercially important attributes along the food chain from farm to fork (Price, 1995).

For accurate discussion, it is helpful to clearly define the terminology used in this manuscript. Quality is the characteristic of products that meets (or better exceeds) end-users' or consumers' expectations (reviewed by Casabianca, Trift, & Sylvander, 2005). Intrinsic meat quality refers to the characteristics of the product itself including their interaction with consumers when eating. Therefore, intrinsic meat quality includes among others tenderness and palatability, which are the subjects of this manuscript. Modelling is a mathematical representation of a biological system (here beef sensory quality) that can be manipulated (Waltemath et al., 2011). In meat science, classification is a set of descriptive terms describing features of the carcass or of meat for trading purposes whereas grading refers to placing different values on carcasses or meat for pricing purposes depending on the market and requirements of traders (Polkinghorne & Thompson, 2010). In this context, prediction of intrinsic sensory quality (a multidimensional variable) means the identification of a number of traits related to the sensory quality of the product, and then integrating them into multicriteria evaluation models (Bouyssou et al., 2000; Roy, 1996). This includes 1/defining the criteria (i.e. the intrinsic quality traits of beef) to be assessed; 2/identifying the indicators (from direct measures and/or their predictors) to assess each criterion; 3/constructing each criterion separately (by interpreting and if necessary aggregating the indicators); and 4/aggregating the different criteria to form an overall judgement (reviewed by Hocquette, Botreau, et al., 2012; ~~Hocquette, Capel, et al., 2012~~).

In this manuscript, we will therefore describe first consumers' expectations and existing examples of carcass and meat quality grading systems. In the third and fourth parts, some multicriteria evaluation methods related to muscle biochemistry and muscle profiling (i.e. characterisation of muscles by physical, chemical and/or sensory analysis) will be presented, and especially how they could contribute to meet consumers' expectations. The last part will concern the Meat Standard Australia system (MSA) which is a more integrated and consumer-driven approach complementary to muscle description. We will argue in the conclusion that all these modelling approaches are not in competition but complementary to each other and to the existing carcass and meat quality grading systems in different countries.

2. Consumers' expectations

Beef quality perception consists of an expected and an experienced quality perception dimension, which together and depending on the match or mismatch between expectations and experience lead to consumer satisfaction or dissatisfaction and willingness to purchase the product again in the future. The study by Banovic, Grunert, Barreira, and Fontes (2009) indicated that expected beef eating quality is positively affected by perceived colour, brand, origin and fat. The more ideally these quality cues were perceived, the higher was consumers' expected beef eating quality. Experienced beef eating quality was a combination of consumers' taste, tenderness and juiciness evaluations, and was found to dominate consumers' future beef purchase intentions (Banovic et al., 2009). European beef consumers' interest in a beef eating-quality guarantee has been investigated in the early qualitative research phase of the ProSafeBeef consumer studies (Verbeke et al., 2010). Using focus groups with consumers in Germany, Spain, France and the United Kingdom, the study concluded that consumers generally welcome the idea of a beef eating-quality guarantee, but that willingness-to-pay is conditional upon the system managing to deliver effectively upon its promises. The study also identified possible differences between consumers, namely that men might focus more than women on the benefits of guaranteed tenderness, while young consumers might be expected to be less interested, and that cross-country differences in interest can be substantial. Sceptical reactions mainly pertained to the practical implementation and feasibility of the system, costs and possible risk of information overload.

Consumers' expectations and liking of different beef muscles were further investigated in the quantitative consumer research phase of ProSafeBeef. A sensory study with beef consumers in Belgium and Norway, including three beef muscles treated with different technologies was conducted. Firstly, the information experiment in which consumers were given different levels of information about the applied technologies indicated that consumers' expectations and liking after sensory testing of beef steaks (i.e. after experiencing) depended on the level of detail of information provided (Van Wezemael et al., 2012). Information positively influenced sensory quality expectations in Norway, while improving liking in Belgium. Although the results showed that both Belgian and Norwegian consumers preferred unprocessed tenderloin over tenderized steaks, consumers' sensory expectations and liking did not differ between the type of technology that was applied to add value to the steaks (muscle profiling versus tenderizing by marination by injection which was perceived as much more invasive).

Secondly, beef consumers differing in their hedonic expectations for different beef steaks were profiled (Almli, Van Wezemael, Verbeke, & Ueland, 2013). In this work, participants indicated their expected liking for three beef cuts: unprocessed tenderloin *Psoas major*, muscle profiled *Infraspinatus* and marinated *Semitendinosus* (muscle profiling is the mapping of the characteristics of muscles, so that the muscles of good quality can be identified; marinating beef by injecting it with a solution will make muscles more tender). Although tenderloin was preferred over tenderized beef steaks by the majority of consumers, up to 27% of the consumers expected to like these value-added steaks as much as tenderloin. The results also indicated that muscle profiled beef generates good hedonic expectations. Four attitudinal profiles of consumers with high expectations for the different steaks were identified. Consumers with high expectations for tenderloin were qualified as 'enthusiastic beef eaters'. They were highly involved with beef and had positive attitudes towards beef safety and beef healthiness. Norwegian consumers with high expectations for muscle profiled steaks had a similar profile. But, in Belgium, this group of consumers was less interested in the healthiness of food and beef and they were very open towards new foods and new food technologies ('open-minded beef eaters'). Finally, consumers with high expectations for marinated beef steaks were qualified as 'indifferent beef eaters' in Norway (as they were indifferent to beef healthiness or beef safety) and 'carefree beef eaters' in Belgium, with a low concern for food risks and the healthiness of foods (Almli et al., 2013). These results indicate that general attitudinal profiles of beef consumers differ between the two studied countries.

Thirdly, sensory evaluations of beef tenderness were more or less linked to shear force measurements and consumer characteristics of the untrained panellists (Van Wezemael et al., in this issue). Tenderness variability in Norwegian Red cattle was significantly higher than in Belgian Blue cattle. Norwegian consumers who evaluated tenderness more optimistically than the "average consumers" were found to be more often male, less food neophobic, to have more positive attitudes towards the healthiness of beef, and to have fewer concerns about beef safety. Consumers who assessed beef tenderness in line with shear force measurements could not be specifically profiled, i.e. their profile matched the characteristics of the overall study sample. The results suggested that consumers evaluated tenderness mainly subjectively at the time of consumption irrespective of the instrumental tenderness of the steak (Van Wezemael et al., in this issue).

3. Examples of carcass and meat quality grading systems

Early grading systems only described carcasses with various traits such as carcass weight, age or maturity of the animal, sex, fatness, fat colour, carcass conformation and sometimes marbling and lean colour and finally saleable meat yield usually predicted by measurements of fatness and/or muscling. USDA Quality Grades are used to predict the palatability of meat from a beef carcass, using carcass physiological maturity and marbling (USDA, 1996). In addition, the USA beef industry developed more than 100 beef brands, some using palatability assurance critical control point plans, total quality management approaches, USDA certification and so on, or combinations of different systems to further differentiate fresh beef products (Smith, Tatum, & Belk, 2008). In North American and Asian countries, emphasis has been put on maturity and marbling. The European system to describe carcasses (the EUROP grid) is mainly based on yield estimation to pay producers. Most of the current grading and classification schemes still use these variables and in some ways, are indicators of finish or fatness rather than indicators of the real beef palatability at the consumer level (reviewed by Polkinghorne, Thompson, ~~Watson, Gee, & Porter, 2008~~).

The UK Meat and Livestock Commission (MLC) Blueprint and New Zealand QMark systems aim to select those carcases expected to provide consumers with good eating quality through process control of factors such as carcase suspension, electrical stimulation and ageing. The USDA system classifies beef carcases into quality grades based on the degree of maturity and intramuscular marbling. In contrast, the more consumer driven MSA system classifies individual beef muscles into eating quality grades as described above. Versions of these four systems were compared for their ability to correctly identify beef with better consumer scores for 36,000 beef samples from 192 animals assessed by 6000 consumers (Farmer et al., 2010). The results showed that, while none of the systems were perfect, the MLC Blueprint system performed well provided that the low conformation animals were not excluded, while the MSA system performed best for the greatest number of muscles and for both roast and grilled beef.

In Europe, reliable systems guaranteeing eating quality at the consumer level as the MSA system does are still lacking, in spite of some advanced carcass grading systems and in spite of numerous private and official quality marks existing at consumer level. Nevertheless, these systems can offer considerable local marketing benefits. Two examples of these official quality marks are the French “Label Rouge” and the Welsh “Celtic Pride” systems.

Among the quality marks, the French “Label Rouge” certifies that the raw or processed agricultural product possesses a specific set of characteristics guaranteeing a higher quality level than that of a similar standard product (INAO, 2009), 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. In beef, the quality mark Label Rouge implies that farmers must follow specific rules to breed meat-producing animals. Therefore, it provides a good part of the benefits for primary producers. The label is awarded to different types of products such as free-range hen's eggs, veal meat from suckling calves and cooked ham. As Label Rouge is the most widely recognised product quality predictor in France, it may provide benefits for primary producers and retailers. Records show that more than 500 registered specifications for the Label Rouge are on the market, mostly in the poultry industry in which it is relatively easy to make a difference between Label Rouge and standard products in terms of palatability. However, in the case of meat, 85 to 93% of the volume of French production has no official quality mark and only less than 2% of beef is sold with the Label Rouge mark. Generally, when French consumers see the Label Rouge quality mark, they know they are getting a superior quality product. However, sometimes, they express a degree of misunderstanding on the real guarantees offered by such quality marks (e.g. safety is not guaranteed by the Label Rouge mark but by sanitary regulations). Clearly, a high price for products with an official quality mark is a negative factor for purchases, especially for younger age-bracket consumers who are less sensitive to the presence of an official quality mark. The main drivers of food product purchases in France over the years have remained safety and a competitive price, which are generally more important than the origin, the brand and/or the quality level (reviewed by Hocquette et al., 2013).

In the UK, there are many specialist beef schemes related to areas of geographical origin, brands, and breeds (for example specialist Hereford or Aberdeen Angus beef and beef products). In Wales, Celtic Pride Beef was established in 2003 to provide a specialised and differentiated product premium beef (http://www.celticpride.co.uk/home/gtwp_section_leader.htm). No such product was available at that time from Wales. The project brought together producers, a food service and animal feed company. The key issue was to establish a strong brand name linked with a beef production and processing protocol which would consistently deliver a high eating quality experience for consumers. The production protocol includes factors such as all animals must be born and raised in Wales, restrictions on the number of movements during an animal's lifetime, target growth rates during main growth and finishing phases, and inclusion of high vitamin E levels in the final 90 days prior to slaughter. The major issue during processing is extended maturation of the prime cuts. The product commands a premium in the market and producers receive a dividend for producing the beef. The project has grown steadily over the last 10 years and currently about 100 animals per week are processed delivering premium cuts and processed products under a strong brand name “Celtic Pride”. Although farmers receive a premium for the producing to the requirements of the “Celtic Pride” protocol, one of the major challenges to such specialised schemes is ensuring that the premium is sufficient to justify the additional requirements of the protocol at the producer end. The majority of the dividend paid is typically achieved from the premium cuts of the carcass. In the last two years with the strong prices available in the market for store cattle, many producers have taken advantage selling animals and avoiding the additional costs and work associated with finishing cattle. This reemphasises the importance of the premium to ensure that the scheme remains attractive to producers. As a premium brand, “Celtic Pride” is identified by consumers. The product is more expensive to purchase due to both increased demands on the Celtic Pride protocol both on farm and at processing.

4. Muscle biochemistry

A great deal of literature exists concerning the relationships between beef palatability and muscle biochemical characteristics, which are themselves regulated by numerous factors such as breed, growth path, sex and muscle type. Unfortunately, many controversies were reported regarding these relationships with many conflicting results (Maltin, Balcerzak, Tilley, & Delday, 2003).

French scientists and professional partners brought together all the data they have accumulated over many years. These data came mainly from the INRA database named FiLiCol (Schreurs et al., 2008) and from the database of the French QUALVIGENE programme coordinated by UNCEIA (Allais et al., 2010). The resulting BIF-Beef (Integrated and Functional Biology of Beef) data warehouse was formed to allow the development of meta-analyses to associate the available phenotype data on animal growth, carcass composition, muscle tissue characteristics and beef quality. This large-volume database contained documented data and a validated interface for (i) appraising the contents of the database, (ii) extracting selected data, and (iii) making robust statistical analyses to establish equations for the prediction of beef quality.

At the beginning of 2012, the BIF-Beef data warehouse contained 331,153 measurements (including more than 15,764 measurements related to animal growth) of which 621 variables were observed across 5 muscle types from 5197 animals (1–120 months of age) belonging to 20 different breeds, and from 43 different experiments (Chriki et al., 2012). The measurements were obtained mainly from the *Longissimus thoracis* muscle and/or young bulls but some females (heifers, cows)

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are also included. The data warehouse was a necessary prerequisite for meta-analyses of relationships between muscle characteristics and beef quality in the European context, and especially in the French context since the French beef industry is characterized by late-maturing and lean beef breeds used as pure breeds.

Since the data from the various studies were not designed to be ultimately pooled to create an integrated warehouse, the heterogeneous nature of the experimental designs and variables gathered must be taken into consideration in order to avoid any bias in analysis and interpretation. Therefore, it has been very difficult to perform meta-analysis with the data. In the future, ontology will help to address these issues by identifying the variables of interest and then setting up an agreed unifying frame of reference, which will be accepted and used by as many people as possible. Meat science is indeed becoming integrative and predictive and, to achieve this goal, should have the ability to uniformly describe the traits of interest. In addition, the new technologies (genomics, etc.) are generating a deluge of data and bio-ontologies are an essential part of information systems because they support data integration and analysis across multiple experiments. This is why the programme entitled "Animal Trait Ontology of Livestock" (ATOL) was set up not only in meat science but also more generally in animal science for all species (Golik et al., 2012). This type of research is the first step for high-throughput phenotyping of farm animals with standard protocols ~~(Hocquette, Botreau, et al., 2012;~~ Hocquette, Capel, et al., 2012).

Data extracted from the BIF-beef database showed that the relationship between intramuscular fat content and flavour was low (partial correlation coefficient $r = 0.11$) but statistically significant especially for Charolais and Limousin young bulls. It was not significant for fatter animals such as steers or females or for young bulls from lean breeds (such as Blonde d'Aquitaine) ~~(Hocquette, Legrand, Jurie, Pethick & Micol, 2011;~~ Hocquette, Meurice, et al., 2011). This confirms previous results showing that flavour was not correlated with intramuscular fat level in young bulls from lean French breeds (on average, 1.2% of intramuscular fat level) compared to fatter French breeds (but with less than 2.5% of intramuscular fat level; Renand, Havy, & Turin, 2002). There is a general agreement in the literature that intramuscular fat content would increase flavour and juiciness (for a review, see Hocquette et al., 2010), most of the authors agreed that there is a curvilinear relationship between flavour score and intramuscular fat level. Whereas about 16% of the variability in flavour could be explained by differences in intramuscular fat level in a dataset with large variability (from 0.3 to up to 15% in intramuscular fat level; Thompson, 2004), no more than 3% of the variability in flavour could be explained by differences in intramuscular fat with our dataset characterized by little variability and low absolute values (on average, 1.5% of intramuscular fat level due to the animal type, i.e. mainly young bulls) ~~(Hocquette, Legrand, Jurie, Pethick & Micol, 2011;~~ Hocquette, Meurice, et al., 2011).

In parallel, three tenderness clusters (high, medium, low) were created from trained-taste-panel tenderness scores of all meat samples consumed from the BIF-beef data warehouse (4366 observations from 40 experiments). As expected, lower shear force values were associated with more tender meat. Tough beef contained more collagen and tender beef contained less insoluble collagen. Muscle in the lowest tenderness cluster had the highest average muscle fibre cross-sectional area. These conclusions were observed across different muscle types or within the *Longissimus thoracis* muscle only. Muscle samples in the highest tenderness cluster had also the highest enzyme mitochondrial activities, the highest proportion of slow oxidative muscle fibres, and the lowest proportion of fast glycolytic muscle fibres, but these latter results were not observed when analysed within the *Longissimus thoracis* muscle only. Generally, tenderness score was shown to be negatively related to the proportion fast oxido-glycolytic fibres (Chriki et al., 2012). In *Longissimus thoracis* muscle, but not in *Semitendinosus* muscle, total collagen content, intramuscular fat content, mean muscle fibre area, and muscle metabolic activities explained a maximum of 2% each of the total variability in the sensory tenderness score. However, in *Semitendinosus* muscle, total and insoluble collagen content, and muscle fibre properties explained 6% maximum each of the variability in the shear force. This confirms that the determinism of tenderness is very complex and mainly muscle dependant (Chriki et al., submitted for publication). The regulation of muscle biochemical characteristics by production factors is also muscle dependent (Cassar-Malek et al., 2004).

As a conclusion of this meta-analysis, the prediction of beef tenderness by muscle biochemical characteristics is low compared to some previous individual studies (Renand, Picard, Touraille, Berge, & Lepetit, 2001). However, meta-analyses were useful to identify muscle characteristics which are of interest for geneticists who are looking for simple predictors of beef eating quality (Fig. 1). In practice, it might be possible to select animals for a low average muscle fibre cross-sectional area and increased intramuscular fat content to improve tenderness in *Longissimus thoracis* muscle through several generations, or for low total and insoluble collagen content to decrease toughness of *Semitendinosus* muscle.

5. Muscle profiling

"Muscle profiling" means precise characterization of the muscles by physical and chemical analysis, with the intent to develop improved understanding and know-how of properties of individual muscles in a carcass so as to better utilise them (Hildrum et al., 2009). A very large number of studies describing the traits of beef muscles have been published in both scientific and popular literature (Jones, Calkins, Johnson, & Gwartney, 2005; Rhee, Wheeler, Shackelford, & Koohmaraie, 2004; Von Seggern, Calkins, Johnson, Brickler, & Gwartney, 2005). Generally speaking, while large differences were observed between muscles in their biochemical and physical traits, muscle characteristics also varied widely within muscles (Rhee et al., 2004; Hildrum et al., 2009). Furthermore, eating quality assessed by the MSA system varies for position within some muscles in addition to the large variations between muscles (Polkinghorne, 2005). This information potentially allows better decisions to be made in the process of selecting individual muscles from the beef chuck and round for the production of added-value products. For instance, there is a potential for selecting muscles of the round

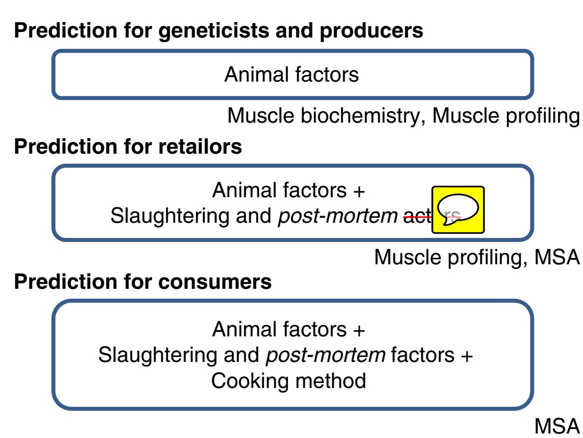

Fig. 1. The different levels of prediction for beef tenderness. Approaches combining knowledge about muscle biochemistry and practical methods of muscle profiling (i.e. assessing beef quality from muscle traits), which both reflect animal factors on beef quality, may be useful at the production levels for geneticists and farmers to select animals with the highest ability to produce beef of high quality from different muscle types. Muscle profiling (i.e. assessing beef quality from muscle traits) or the integrated approach of the MSA grading scheme will allow for more informed decisions to be made by retailers in the selection of individual muscles for the production of value-added products. The Meat Standards Australia (MSA) grading scheme is an integrative approach from the farm to the plate to predict beef quality at the consumer level for each individual muscle × specific cooking method combination using various information on the corresponding animals and post-slaughter processing factors.

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with similar sensory and biochemical traits to those of the *Longissimus thoracis* (Von Seggern et al., 2005). Combined with knowledge about muscle fibre orientation in order to cut muscles across the grain, detailed knowledge on intramuscular tenderness variation could be used in a value added strategy to improve tenderness (Senaratne, Calkins, de Mello, Pokharel, & Hinkle, 2010; Fig. 1). In the USA, the wholesale value increase alone was estimated at approximately $50 per carcass, which means a potential impact exceeding $1 billion per year in the USA only (Beermann, 2009). Therefore, within the ProSafeBeef programme, training and demonstration activities were conducted to adapt cutting process based on knowledge of muscle properties in order to valorise each carcass as much as possible. More precisely, butchers have to be trained to identify the different parts within muscles to better valorise them by separating the tender and tough parts of each muscle.

In scientific papers, the major beef muscles have been often ranked for Warner–Bratzler shear force (WBS) and sensory traits. This was done again based on a comprehensive study of the literature, compiling a large number of observations for each muscle. Muscles with three or more literature sources were ranked for WBS, sensory tenderness, juiciness and flavour. As expected, *Psoas major* and *Infraspinatus* were the top ranked for mechanical and sensory tenderness. *Semitendinosus*, *Gluteus medius*, *Supraspinatus* and *Pectoralis profundus* were major muscles that were among the least tender (Sullivan & Calkins, 2011). Generally, none of the muscles were confined to only one tenderness class. *Infraspinatus* showed superior tenderness, juiciness and colour properties and was the only muscle to be consistent in tenderness with 80% of the samples in the highest sensory quality class. Furthermore, using one muscle and especially *Longissimus thoracis*, as a quality indicator of all muscles in the carcass, is not relevant (Hildrum et al., 2009; Polkinghorne, 2005; Rhee et al., 2004).

Variation among muscles was also observed in many biochemical traits (colour, moisture, pH, total collagen content, intramuscular fat content, total heme-iron concentration and Warner–Bratzler shear force). Quality grade most often had an effect, with weight and yield grade having fewer effects on these characteristics (Von Seggern et al., 2005). As previously discussed, no biochemical characteristics can be used to predict tenderness across muscles. However, *post-mortem* proteolysis (or indicators of this process) supported by other factors (pH, connective tissue characteristics, sarcomere length, fibre type) provides a good indication of the tenderization which occurs during ageing (Anderson et al., 2012). More precisely, tenderness differences across muscles depend on a large part on quality grade and ageing time. Therefore, *post-mortem* ageing should be managed according to individual muscle and quality grade (Gruber et al., 2006).

Apart from the USA (Rhee et al., 2004; Von Seggern et al., 2005), studies regarding muscle profiling have been conducted in different countries including Norway (Hildrum et al., 2009) and Poland (Zając, Midura, Palka, Wesierska, & Krzysztoforski, 2011). Ranking of muscles may differ according to animal gender and age (Hildrum et al., 2009; Patten et al., 2008). Thanks to the development of genomics, more modern techniques such as transcriptomics (Cassar-Malek et al., 2009) and proteomics (Guillemin et al., 2011) are available nowadays to better characterize individual muscles according to tenderness score or to livestock systems. These methods could be considered as modern ones for muscle profiling.

6. Meat standards Australia

In addition to muscle type and cooking method which have a great impact of palatability ~~(Monika~~ Modzelewska-Kapituła, Dąbrowska, Jankowska, Kwiatkowska, & Cierach, 2012; Sullivan & Calkins, 2011; Thompson, 2002), it is possible to explain more than 70% of the variability in beef tenderness by integrative approaches using many factors from production to the consumer plate including breed-cross, production system, use of hormonal growth promoters, carcass suspension and ageing time (Juarez et al., 2012). In fact, *post-mortem* handling of the carcasses may be much more effective in controlling beef tenderness than *pre-mortem* factors (Juarez et al., 2012), but all of them have to be combined together for a better prediction of beef tenderness.

Such an integrative strategy was built up in Australia beginning in 1996, with the development of the MSA grading scheme to predict beef quality for consumers (Fig. 1). This system is based on the development and the use of a large database including the use of a large-scale consumer testing system as well as information on the corresponding animals, carcasses and cuts from the farm, the slaughterhouse and the retailer. The system is based on statistical analyses identifying the critical control points of beef palatability which is indicated for individual muscles and for a specific cooking method and ageing time (Thompson, 2002). Based on the sensory analysis by thousands of consumers, the MSA system predicts the eating-quality score (0–100) of each cut of the carcass, depending on how long it is aged and the type of cooking method chosen. The MSA success is due notably to standardisation of the consumer evaluation protocols (Watson, Gee, Polkinghorne, & Porter, 2008) and the accumulation of large amounts of data over time which have been treated by vigorous statistical analyses in order to identify the main factors governing beef quality (Watson, Polkinghorne, & Thompson, 2008). One important point is that assessment for tenderness and palatability by untrained consumers was the key criteria to be predicted, and not tenderness score determined by trained panellists as in the previous studies. Untrained consumers were asked to assess beef in 4 quantitative areas (tenderness, juiciness, liking of flavour, and overall liking) and then to rate the meat as one of unsatisfactory (ungraded), good every day (3-star), better then 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. Generally, the boundaries between "unsatisfactory", 3-star, 4-star and 5-star categories were found to be ca. 46, 64 and 76, respectively. The best combination to predict the final grade in Australia was initially 0.4 tenderness + 0.1 juiciness + 0.2 flavour and 0.3 overall liking. It was changed in 2008 to 0.3 tenderness + 0.1 juiciness + 0.3 flavour and 0.3 overall liking (Watson, Gee, Polkinghorne, & Porter, 2008).

Various other countries or regions of the world have tested or are testing the MSA system: Korea (Thompson et al., 2008), the USA (Smith et al., 2008), France (Hocquette, Legrand, Jurie, Pethick, & Micol, 2011; Legrand, Hocquette, Polkinghorne, & Pethick, 2011), Japan (Polkinghorne, Nishimura, Neath, & Watson, 2011), South Africa (Thompson et al., 2010), New Zealand, Northern Ireland (Farmer et al., 2009a) and the Irish Republic. The overall conclusion is that, while there are some differences in the weightings applied to flavour liking and tenderness (Polkinghorne, personal communication; Farmer et al. 2009), consumers provide similar responses for the assessment of beef quality when the MSA system is used to assess preferences.

In Japan, the boundaries between 2/3 star, 3/4 star and 4/5 star grades were, respectively: 40.4, 66.8 and 83.1 for grill; 43.4, 68.5 and 83.9 for yakiniku; 43.7, 67.4 and 83.4 for shabu shabu, which means that specific Asian cooking methods did not change significantly the final assessment of beef by Japanese consumers. The best combinations to predict beef quality were however slightly different between cooking methods: Grill MQ4 score = 0.3 tenderness + 0.2 juiciness + 0.2 flavour and 0.3 overall liking, whereas shabu shabu MQ4 score = 0.2 tenderness + 0.2 juiciness + 0.4 flavour and 0.2 overall liking. These differences in weightings have little impact on the prediction accuracy given the high correlation between the different sensory scores (0.76–0.96; Polkinghorne et al., 2011).

In the USA, the boundaries between categories were found to be ca. 41–43, 65–66 and 82–83 for grilled or roasted beef and the best combination to predict the final grade is similar to that in Australia (0.3 tenderness + 0.1 juiciness + 0.3 flavour and 0.3 overall liking)

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(Smith et al., 2008). For consumers from Northern Ireland and the Irish Republic, the best combination puts more weight on flavour (0.2 tenderness + 0.1 juiciness + 0.4 flavour and 0.3 overall liking) than on tenderness (data not shown). Similar results were observed in Poland (data not shown). For consumers from Northern Ireland, the boundary cut-offs for the lower grades were lower than for the Australian consumers (Farmer et al., 2009a). In the Irish Republic, a series of additional experiments was carried out to determine how well the model accounted for the effects of a number of factors known to be important to the Irish industry (electrical stimulation, hanging method, time of boning and ageing time). The meat quality scores were compared with those predicted by the model. The conclusion was that the model fitted Irish beef for Irish consumers at least as well as it does for Australian consumers eating Australian beef and that in general the model accounts for the processing factors adequately, though it could be optimized further.

Despite some minor differences, the MSA model also accurately predicted palatability of beef for Korean consumers: indeed Korean consumers graded a larger proportion of the samples as unsatisfactory and a lower proportion as 5 star (premium). Therefore, some adjustment may be required to minimise current bias in the MSA model (Thompson et al., 2008).

In France, meat operators wanted first to know more about the MSA grading scheme. So, French scientists and professionals were tasked to assess the MSA system: professional experts recognised many qualities of this system, which was judged comprehensive, consistent and scientifically supported. However, the adaptability of the MSA system to France would be difficult due to the complexity of the French beef industry and market (beef from different animal types: young bulls, steers, heifers, cows; beef from the dairy herd or from the beef herd with a great number of breeds) and due to the existence of pre-existing quality marks such as the Label Rouge (Hocquette, Legrand, Jurie, Pethick & Micol, 2011; ~~Hocquette, Meurice, et al., 2011~~). Then, an experiment was set up with six muscles from 18 Australian and 18 French cattle tested as paired samples. Steaks were grilled "medium" or "rare" in France, and "medium" in Australia. In total, 540 French consumers took part in the sensory test. The prediction of the final ratings by the French consumers using the MSA weighted eating quality score (0.3 tenderness + 0.1 juiciness + 0.3 flavour + 0.3 overall liking) was over 70%, which is at least similar to the Australian experience. The boundaries between "unsatisfactory", 3-star, 4-star and 5-star were found to be ca. 38, 61 and 80, respectively. The differences between extreme classes are therefore slightly more important in France than in Australia. Overall the data indicates that it would be possible to manage a grading system in France as there is high agreement and consistency across French and Australian consumers. The "rare" and "medium" results were also very similar indicating that a common set of weightings and cut-offs could be employed. Importantly the "rare" versus "medium" cooking was aligned to consumers who had a preference for that particular degree of doneness. Similar results were obtained comparing "medium" and "well done" beef in Northern Ireland (Farmer et al., 2009b).

The overall conclusion is that consumers from many different countries and cultures have similar responses for the assessment of beef quality when the MSA system is used to assess preferences. However, some minor adjustments are sometimes required to reflect, with a better accuracy, preferences of consumers in some specific countries. In total, more than 90,000 consumers in 9 countries have assessed more than 640,000 meat samples using the MSA protocols, most of them (more than 84%) in Australia (Polkinghorne, personal communication).

7. Conclusion and perspectives

There is great potential to integrate biochemical data, muscle profiling, ageing information and MSA style approaches to model beef quality (meat quality as a composite index, not just tenderness) in Europe. Part of this value is to build a biological basis from which it will be possible to estimate inter-muscle effects and to a lower extent intra-muscle variation of beef quality. Based on a good biological understanding of individual muscles and of intra-muscle variability, it might be possible to establish better hypotheses on how an effect believed to operate on, say for example, proteolysis, connective tissue solubility, or muscle fibre type may translate to other muscles or to other muscle parts based on their relative composition. The early flavour chemistry work also shows relationships with ageing, muscle and intramuscular fat level which might assist in flavour estimation when supported by flavour formation pathway knowledge. The end result may be that flavour could be predicted independently of tenderness using most of the same inputs (e.g. intramuscular fat level, pH, ageing) but weighted differently in an overall model. Similarly, for another complex trait such as tenderness, which depends on many factors (including those related to muscle biochemistry), integrative approaches (such as the MSA approach) are very promising to predict tenderness of each cut or even of each cut part from all the relevant factors eventually weighted differently according to consumers' preference or country, livestock production systems, animal type/gender or breed, or any relevant source of variability. This could be a more precise prediction of quality for each cut adapted to each market including niche markets. In this type of approach, the volume of data available is crucial to provide statistically sound relationships between the different studied factors and the final quality. At last, but not the least, such research should be conducted with the ultimate goal to provide added values to all the players along the entire supply chain from producers until consumers.

8. Uncited references Q24

Brandon et al., 2006
Christensen et al., 2011
Lincoln
Polkinghorne, Watson, Thompson and Pethick, 2008

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