# Prédiction de la qualité de la viande de ruminants

**Compte-rendu du congrès international d'Août 2015 à Paris sur la prédiction de la qualité de la viande de ruminants pour mieux satisfaire les consommateurs**

**Mots-clés :** Qualité, Viande, Bovins, Ovins

**Auteur :** David W. Pethick[1], John Thompson[2], Rod Polkinghorne[3], Sarah Bonny[1], Garth Tarr[4], Peter Treford[5], Duncan Sinclair[6], François Frette[7], Jerzy Wierzbicki[8], Michael Crowley[9], Graham Gardner[1], Paul Allen[10], Takanori Nishimura[11], Peter McGilchrist[1], Linda Farmer[12], Qingxiang Meng[13], Nigel Scollan[14], Koenraad Duhem[15], Jean-François Hocquette [16, 17]

[1] Murdoch University, Murdoch, Australia, D.Pethick@murdoch.edu.au, G.Gardner@murdoch.edu.au, P.McGilchrist@murdoch.edu.au ;
[2] 11/3 Stewart Street, Port Macquarie, NSW, Australia, 2444, jmthommo@gmail.com ; [3] 3 Birkenwood Pty Ltd at 431 Timor Rd Murrurundi NSW 2338, Australia, rod.polkinghorne@gmail.com ; [4] University of Newcastle, Callaghan, NSW 2308 Australia, garth.tarr@gmail.com ;
[5] Meat & Livestock Australia board member, Australia ; [6] Waitrose, Waitrose Ltd, Bracknell, UK ; [7] FNICGV, French Meat Industry and Wholesalers Organisation, France, francois.frette@fnicgv.com ; [8] Polish Beef Association, ul. Smulikowskiego 4, 00-389 Warsaw, Poland, jerzy.wierzbicki@pzpbm.pl ; [9] Meat & Livestock Australia, Australia, mcrowley@mla.com.au ; [10] Teagasc Food Research Centre, Ashtown, Dublin 15, Ireland, paul.allen@teagasc.ie ; [11] Research Faculty of Agriculture, Hokkaido University, Sapporo, Japan, nishi@anim.agr.hokudai.ac.jp ; [12] Agri-Food and Biosciences Institute, 18a Newforge Lane, Belfast, Northern Ireland, Linda.Farmer@afbini.gov.uk ; [13] College of Animal Science and Technology, China Agricultural University, Beijing 100193, China, qxmeng@cau.edu.cn ; [14] Institute of Biological Environmental and Rural Science, Aberystwyth University, Wales SY233EB, UK, ngs@aber.ac.uk ; [15] Institut de l'Elevage, 149 rue de Bercy, 75595 Paris Cedex 12, France, Koenraad.Duhem@idele.fr ; [16] INRA, UMR1213, Recherches sur les Herbivores, Theix, 63122 Saint-Genès-Champanelle ; [17] VetAgro Sup, UMR 1213, Recherches sur les Herbivores, Theix, 63122 Saint-Genès-Champanelle

* E-mail de l'auteur correspondant : jfhocquette@clermont.inra.fr

**Le « Meat Livestock Australia » et l'INRA ont organisé conjointement les 20-21 août 2015 au siège de l'INRA à Paris un congrès international sur la prédiction de la qualité de la viande de ruminants.**

**Résumé :**

Le « Meat Livestock Australia » et l'INRA ont organisé un congrès international sur la prédiction de la qualité sensorielle de la viande bovine et ovine pour le consommateur. Durant deux jours, 19 présentations ont souligné que, de nos jours, la viande de ruminant doit répondre aux attentes gustatives des consommateurs qui achètent de la viande rouge pour leurs repas. L'accent a été mis sur le système de prédiction de la qualité MSA (pour Meat Standards Australia) qui a été conçu comme un système de prévision de la qualité sensorielle pour les viandes cuites à consommer dans diverses occasions sans pour autant nécessiter de connaissances spécifiques de la part des consommateurs. Ce congrès a reconnu unanimement la nécessité d'un tel système de prédiction de la qualité des viandes bovines et ovines afin de fidéliser les acheteurs parfois tentés de consommer des viandes blanches moins chères. Les 80 participants au congrès de 17 pays (Australie, Brésil, Canada, Chine, République tchèque, Danemark, France, Italie, Japon, Irlande, Pologne, Portugal, Afrique du Sud, Espagne, Thaïlande, Royaume-Uni, USA) ont travaillé de façon dynamique et collective. En effet, il a été décidé de créer un groupe de travail international avec les pays actuellement impliqués tout en étant ouvert à de nouveaux partenaires afin de mettre en œuvre les recommandations issues du congrès.

**Abstract: Beef and Lamb carcass grading to underpin consumer satisfaction**

Meat & Livestock Australia and Meat Standards Australia and INRA have organized an International meeting on Beef and Lamb carcass grading to underpin consumer satisfaction. The 2 day meeting consisted of 19 presentations centred on the theme that modern beef and lamb products must meet the expectations of consumers who purchase red meat to cook it as a meal solution. The focus was based around the Meat Standards Australia (MSA) grading platform which is designed as a sensory or eating quality grading system for underpinning a cooked meal performance that is matched to the occasion and requires no specialist knowledge by the consumer. This workshop unanimously supported the need for evidence based systems to underpin eating quality for lamb and beef in order to keep consumers purchasing products that are higher in price than the white meat competitors. Registrations were received from 80 people covering 17 countries (Australia, Brazil, Canada, China, Czech Republic, Denmark, France, Italy, Japan, Republic of Ireland, Poland, Portugal, South Africa, Spain, Thailand, United Kingdom, United States of America) creating a dynamic workshop atmosphere. In order to drive and focus the recommendations which were discussed at the end of the workshop, it was agreed to establish a working group of current collaborating countries that would be open with respect to new partners.

# INTRODUCTION

There are a number of beef and lamb grading systems employed around the world. These systems are intended to rank meat into a number of quality grades, although the term quality is often not well defined or even variable depending on the country (reviewed by Polkinghorne and Thompson, 2010). However, no practical system exists to grade eating quality at the consumer level except the Meat Standards Australia (MSA) system (reviewed by Polkinghorne et *al.,* 2008b), which has been tested in several countries (reviewed by Hocquette et *al.,* 2014b).

The MSA approach differs markedly from other systems currently employed. Firstly, it is based on consumer responses and secondly, for beef, it independently grades each cut rather than applying a common grade to the entire carcass. The system uses a Total Quality Management (TQM) System approach to grading. It includes information about all the events that have occurred up until the point when the steak was cooked and eaten. This includes the genetics, back grounding and finishing, pre-slaughter handling of the animal and post-slaughter treatment and processing of the carcass system (reviewed by Polkinghorne et *al.,* 2008b).

This paper includes all the oral presentations at the "International meeting on Beef and Lamb carcass grading to underpin consumer satisfaction" which was held in Paris on August 20-21, 2015 with speakers from all continents of the World describing research on the MSA system in their respective countries.

The aims of the meeting were to:
•encourage consumer-focused sensory research for beef and lamb with key collaborating international partners using common protocols.
•facilitate where appropriate MSA-like systems that focus on consumer satisfaction.
•work towards a global model (which may be called 3G for Global Guaranteed Grading) for sharing sensory data using the MSA protocols that can be used for scientific and for commercial purposes.
•explore models for funding future research collaboration.

# I. MEAT STANDARDS AUSTRALIA CUTS BASED GRADING − AN OVERVIEW OF USE IN AUSTRALIA

The first paper by John Thompson, David Pethick and Rod Polkinghorne presented the Meat Standards Australia (MSA) system as described in previous publications (Polkinghorne et *al.,* 2008b; Griffiths and Thompson, 2012). It is a cuts based beef grading system aimed at delivering an accurate description of eating quality to the consumer. The MSA grading model predicts the palatability of individual cuts based on sensory results from untrained consumer taste panels. MSA has identified those critical control points from the production, pre-slaughter, processing and value adding sectors of the beef supply chain that impact on palatability using large-scale consumer testing.

Key grading factors include:
*Bos indicus* content: *Bos indicus* content is assessed on a scale from 0 to 100%. As *Bos indicus* content increased palatability decreased, although the rate of decline varied with individual muscles. *Bos indicus* content is inputted from the vendor declaration, or measured using a combination of hump height and carcass weight.

Sex: Preliminary work suggests that when corrected for carcass grading parameters (such as rib fat, marbling, ossification) bulls have a lower eating quality score, depending on animal age. There are only small differences in eating quality between females and castrated males when corrected for other carcass grading parameters.

Hormonal growth promotants (HGPs): Muscles from animals implanted with steroidal growth promotants have lower MQ4 scores with the effect ranging from 0-10 points depending on the muscle. The scientific literature points to β-agonists having a similar or greater effect. Currently all HGPs are grouped together although work is currently underway to test for differences between HGP formulations.

Marbling and ribfat: As marbling score and rib fat are positively correlated, both parameters are used to assess the impact of marbling on the palatability of individual muscles. An increase in marbling score from 250 to 550 results in an increase of 8 palatability units for the striploin, with the magnitude of the adjustment varying with muscle. Ribfat is also used as a threshold effect and carcasses must have more than 3 mm to minimise variation in carcass chilling.

Ossification score/carcass weight/weaning status: The effect of ossification score on palatability interacts with carcass weight and varies according to muscle. The negative effect of an increased ossification scores can be minimised by increased carcass weight. In addition there is a milk-fed veal effect where muscles from young unweaned calves are more palatable across all muscles in the carcass.

Carcase hanging method: Hanging carcasses by either the obturator foramen or the sacral ligament results in increased palatability for the loin and hindlimb cuts. The tenderstretch effect resulted in a large increase in palatability at 5 days ageing but as tenderstretched cuts aged more slowly this effect was reduced in longer aged cuts

Ultimate pH and meat colour scores of the loin: Ultimate pH is used as a predictor up until 5.7, whereupon at higher pH it becomes a threshold effect and these carcasses are not eligible for grading. High pH meat can be tougher, have reduced shelf life, a dark colour and different cooking properties with respect to the degree of doneness. Meat colour is used as a threshold effect excluding those carcasses with meat colour scores greater than 3 being excluded.

Ageing: The rate of ageing varies for individual muscles and is estimated within hanging options. The impact of ageing on palatability decreases with ageing time being faster in Achilles hung carcasses. MSA graded beef cannot be sold to the consumer before 5 days ageing.

Muscle: The model predicts the palatability of 39 individual muscles with up to a 30 point range in eating quality score

Cooking method: Palatability for individual muscles is predicted for a specific cooking method such as grilling, roasting, stir fry and variations of thin slicing.

Cattle within the MSA system must come from registered producers and undergo best practice management and stress minimisation such as not mixing different mobs of cattle. At slaughter all carcasses are graded once ultimate pH is

obtained and then the grading data are used by the MSA model at the abattoir to predict the cut x cook outcome.

MSA currently grades in excess of 3.2 million carcasses in Australia. Compliance with threshold traits of ribfat, pH and meat colour is relatively constant at 93%. Over a seven year period an annual survey of retail, wholesale and over the hooks prices for MSA and non-MSA product showed that the premiums for MSA were distributed across the industry with ca. 50% to producers, 30% to wholesalers and 20% to retailers. Just using MSA as a threshold grade for 3 star or above the annual benefits are estimated to be of the order of $100 million pa. There is potential for this to increase if grades for 3, 4 and 5 star product are harvested and marketed accordingly.

# II. A VISION FOR INTERNATIONAL WORK UTILIZING COMMON SENSORY PROTOCOLS WITH UNTRAINED CONSUMERS

Rod Polkinghorne said "We have arrived at a very exciting time!" Rod Polkinghorne and his collaborators (Judy Philpott, John Thompson, Dave Pethick, Ray Watson, Robyn Warner, Jerzy Wierzbicki, Linda Farmer, Markus Miller and Jean-Francois Hocquette) have been asked to share their vision which is now known to be achievable and capable of being implemented as a plan to "reinvent" beef as a premium global consumer product.

In Australia we began utilizing untrained consumers to measure the impact of potential beef grading inputs in 1992. Initial work was extremely discouraging with traditional carcass grading systems proving to be ineffective in predicting consumer responses to a cooked beef meal. This led to a new approach based on two critical components: statistical analysis of consumer responses to define a satisfaction measure and then use of this measure to develop prediction approaches that could be applied within a grading system. The MQ4 statistic, derived from consumer responses, is now the measure used to evaluate experimental evidence, with the results in turn incorporated into a prediction model (Polkinghorne et.al, 2008a).

From the outset there were a number of challenging outcomes. A fundamental finding, though obvious in hindsight, was that the carcass was not a useful unit for description. Cuts differ significantly, hardly a revelation, but their relativity also differs widely as various grading inputs including marbling, tropical breed content, carcass suspension and hormone use have a differential effect across muscles. Post grading, ageing periods and cooking methods also have substantially different impacts on individual muscles (Polkinghorne and Breton, 2013). These basic facts logically lead to the need for a consumer focused grading scheme to describe individual cooked meal outcomes rather than the appearance of source carcasses. This insight and acceptance of its consequences are a direct result of utilizing consumers as the evaluation tool.

From very discouraging beginnings when we genuinely feared that it may not be possible to predict beef meal performance, experimental data and statistical application established, and progressively improved, an ability to deliver a guaranteed result via a prediction model for individual beef meals. This ability has progressed over time, improving accuracy and encompassing further cattle types, muscles, processing inputs and cooking methods (Polkinghorne and Thompson, 2010).

From the beginning, demographic effects were found to be minimal leading to growing confidence that a common approach may be possible across broad populations. This proved to be true within Australia and also in other countries as a number of collaborative and independent studies were conducted. Early work in South Korea and Northern Ireland was followed by studies in the USA, Japan and the Irish Republic. Later work in South Africa, France, Poland and New Zealand has added to the evidence that people are similar, although not identical, across cultures and demographics in regard to beef satisfaction.

The international work has established that untrained consumers can consistently provide highly relevant data from which beef can be evaluated and that, given sufficient data, prediction models can be used to deliver consistent product within nominated quality bands. Furthermore the evidence is strong that consumer willingness to pay for alternate quality levels is consistent with substantial discounting of unsatisfactory product and substantial premiums for higher quality (Lyford et.al., 2010), (Griffiths and Thompson, 2012).

A further fundamental issue derived from the data is that cut names are not effective quality indicators, arguably more confusing than helpful. The same can be said for many common beef marketing descriptions including breed, raising and ageing claims. While marketers will always seek to utilize images to build a brand it is possible to provide an underlying quality platform which ensures that eating quality promises are delivered. A simple retail presentation matrix of occasion or quality against meal type can deliver a much clearer consumer offer, not dissimilar to petrol or milk products, in turn reducing the uncertainty of selecting beef for a desired outcome (Polkinghorne et.al., 2008a). This is exciting news for retail description systems and beef branding, providing a genuine opportunity to "reinvent" the beef category and deliver a contemporary consumer product. This is part of the vision.

The vision can however be expanded by adopting a global collaborative approach with a result far beyond the sum of individual contributors. Consumer based research is not cheap despite delivering high value and large scale research studies exceed the budget available in most countries. Considerable efficiencies can be gained by collaboration, by utilizing common protocols and merging data through a data warehouse for research purposes. An observation from the many studies to date is that, while there is indeed an overlap, much data is complementary with production systems in different countries complementing each other if pooled. Taking cattle types and production systems as an example the Wagyu and Hanwoo cattle from Japan and Korea complement British and *Bos-Indicus* breed types typical in USA, Australia and South Africa and further compliment the large number of European breeds and dairy derived crosses common in Europe. Similarly bulls, cows, heifers and steers together with feeding systems form major but differentiated supply sources in different countries.

Prediction model development is heavily data dependent (Watson et.al., 2008b) and far more powerful and accurate

models can be derived from a global database. Carcass suspension, muscle ageing and cooking effects can be estimated more accurately with additional data and become more convincing when tested across a diverse consumer and carcass range. From experience we can categorically state that data derived from testing untrained consumers utilizing standard protocols can be used to develop useful predictions of cooked meal satisfaction. The restriction is always "n".

The vision is to deliver a fully contemporary consumer product through a simple, easily understood and accurate cooked meal outcome framework. An extended vision is to deliver this within a universal global description system that can predict satisfaction for any consumer population from any beef muscle from any carcass produced in any country.

It is technically possible and logical in a global community. Are we up to the challenge?

## III. OSSIFICATION SCORE AND SEX ARE MORE IMPORTANT THAN BREED AND AGE TO PREDICT BEEF EATING QUALITY

Sarah Bonny and co-workers (Pethick D.W., Legrand I., Wierzbicki J., Allen P., Farmer L., Polkinghorne R.J., Hocquette J.F. and Garner G.E.) demonstrated that ossification score and sex are more important than breed and age in the prediction and guarantee of beef eating quality in Europe

Eating quality is of vital importance to the beef industry. In Australia the producer funded organisation Meat and Livestock Australia (MLA) recognised this need and in the late 1990's developed an eating quality prediction system based on untrained consumer taste panels, called Meat Standards Australia (MSA). This system provides an eating quality guarantee for consumers and allows producers to be paid on a combination of yield and eating quality. In order for the European market to take advantage of an MSA-like quality prediction system, differences in production, processing and consumers have to be evaluated and implemented into a prediction model. For example, young bulls and mature cows are common sources of retail and restaurant beef in European production systems, but rare in Australia. Additionally, maturity related decreases in eating quality are estimated by animal age in Europe, and by ossification score, a measurement of bone maturity, in Australia. Presently France (Legrand et al., 2013), Poland, Ireland and Northern Ireland (Farmer et al., 2010) are collaborating with Australian researchers to set up a European wide database which has allowed us to examine many factors relating to eating quality. In particular the effects of sex and breed, the relationship of the European conformation and fat scores with eating quality, and the relative importance of age and ossification score have been examined.

A total of 760 carcasses, 18 different muscles and more than 15,500 individual consumers have so far been included in this database. Samples from these carcasses have been cooked using four different cooking methods, hung using two different carcass hanging methods and aged from between 5 to 35 days.

Meat preparation and consumer assessment of eating quality for the four cooking methods was performed according to the protocols for MSA testing described by (Watson et al., 2008a, Anonymous, 2008). Each muscle from each carcass was assessed by 10 individual untrained consumers. The highest and lowest two scores for each muscle were removed (clipped) and the average was calculated for the remaining six scores. These clipped mean values for tenderness, juiciness, flavour liking and overall liking were weighted and combined to create a single meat quality score (MQ4). The weightings were calculated using a discriminant analysis, as performed by Watson et al. (2008b) and are 0.3*tenderness 0.1*juiciness 0.3*flavour liking 0.3*overall liking.

Initially, a base model was established, with the following fixed effects and all their significant interactions, carcass hanging method, cooking method, muscle type, sex, country, and breed purpose. Post mortem ageing length in days was included as a covariate. Animal identification number within carcass source country, kill group (animals slaughtered on the same day at the same abattoir) and consumer country were included as random terms. This model was then used to separately evaluate the relative importance of the European carcass grade, sex, breed, age and ossification score.

First, the relationship between eating quality and the existing European carcass grading system, the European conformation and fat scores was tested. As this system was never designed to measure eating quality, it was not surprising to find that there was no relationship, aligning well with other work (Guzek et al., 2013). Therefore while the European carcass grade may adequately describe the appearance/meat yield of a carcass, this system cannot be relied upon to predict eating quality. Following this study, the effect of breed and sex on eating quality was investigated. As bulls are not eligible for grading in the current MSA model, they were classed as steers. Differences between breed types were able to be completely explained by the MSA model without the need for any additional adjustments. In contrast, the lower eating quality that was found for the bulls, when compared with steers and females, was not adequately explained by the MSA model. This demonstrates that bulls would need a separate adjustment in an eating quality prediction system. Animal age and ossification score both have a negative relationship with eating quality, however it was found that the relationship was stronger with ossification score for younger cattle, commonly used for premium beef production. As animals aged this relationship became weaker, and animal age was a more important determinant of eating quality, particularly after 7 years of age as for cull cows.

The next phase of analysis will be to evaluate how the demographics and country of origin influences eating quality scores (Lyford et al., 2010). In the long term the addition of data from other collaborating countries and further research will allow the development and testing of a prototype European eating quality prediction system to guarantee eating quality in the European market. Such a system would eventually facilitate feedback on eating quality from consumers to producers and provide a financial incentive for the production of consistent eating quality beef.

# IV. MODELING AND PREDICTION *VS.* STATISTICS WITH REFERENCE TO MSA

The MSA model is more than the sum of its parts. The talk by Garth Tarr and Ray Watson provided a brief overview of the development and current implementation of the MSA model which links real world eating quality with animal, abattoir and treatment variables (Polkinghorne *et al.,* 2008 ; Watson, Polkinghorne and Thompson, 2008a, 2008b). The consumer testing process (Watson *et al.,* 2008a) and data quality issues will be briefly reviewed before outlining the complexity of what a "full" MSA model would look like. It will be shown how fitting a "full" model is currently infeasible given the highly complex nature of the model and limitations inherent in existing data.

The development of the MSA model has taken many years of careful statistical analysis, but it also pragmatically incorporates scientific "truths" with regard to how certain biological processes affect eating quality. These "truths" are imposed as a set of assumptions resulting in a hybrid model that is firmly grounded in evidence but has developed through a bespoke process that is much more nuanced than any single statistical model.

The current hybrid approach will be with us for the foreseeable future. Any changes in the short term will mostly revolve around updating the parameters within the hybrid model based on analyses of existing or new data. In the longer term as more data are collected, curated and stored in an appropriate database, it may be the case that we can move towards a more transparent "full" model., However, this will need to be done in a careful and controlled manner with extensive sensitivity analyses. It is important to keep in mind that the MSA model is production level modelling and any major changes would need to yield significant improvements over the status quo while ensuring consistency with scientific "truth".

The crux of this talk is a warning about the application of pure statistical learning to highly complex data sets.

# V. AN OPPORTUNITY TOO GOOD TO MISS – EXPERIENCE FROM THE AUSTRALIAN INDUSTRY

Meat and Livestock Australia (MLA) Ltd (represented here by board member Peter Trefort,) is a producer owned company that strives to be the recognised leader in delivering world class research, development and marketing outcomes that benefit Australian cattle, sheep and goat producers. Working in collaboration with the Australian Government and the wider red meat industry, the mission is to deliver value to levy payers by investing in initiatives that contribute to producer profitability, sustainability and global competitiveness. There is a broad focus but the areas can be summarised around 5 key attributes of modern meat products (Pethick et *al.,* 2011). Naturally much of the investment focuses on (1) productivity (e.g. genetics, pastures, reproduction, disease) but consumer focused products must also offer (2) a healthy option, they must be (3) safe and the production systems must meet (4) societal expectations (e.g. animal welfare). However, we have realized that a non-negotiable 5th pillar is that the product must have a high organoleptic appeal (tender, flavoursome). Indeed the future of our red meat industry rests with satisfying consumers with consistent products every time. Beef and lamb will never be the lowest cost meat products at retail and so must offer an enjoyable meal experience.

Meat Standards Australia (MSA) was brought about by variable beef eating quality being a major concern in the 1990's during which time consumer discontent meant declining beef consumption (Polkinghorne *et al.,* 2008a). Associated work in lamb also highlighted unacceptable variation in tenderness and consumer satisfaction (Pethick et *al.*, 2006). MLA commissioned a research, development and extension program initially in beef and then for lamb and sheepmeats covering all areas from paddock to plate to identify and solve the issues. The MSA system, through rigorous scientific methodology, encouraged producers to change practices such as livestock management, genetics and best practice prior to slaughter. Processors took on new carcass grading parameters, focused on the consumer, optimized their processing conditions (pH decline, tenderstretch hanging) and finally embraced new systems for producer feedback of grading metrics so as our livestock producers could focus on improving the final meat product. Retailers have embraced ageing of the product and present consumers with the appropriate cut by cook methods. An area that is finally gaining traction is the presentation of beef cuts according to MSA grade. In the early period MSA grading was used as an in/out tool, however the system is designed especially to grade beef into good every day, better than every day and premium – failure to do so will create confusion for the consumer. The new research on MSA lamb intends to develop a cut x cook grading system similar to beef. As a result of changes due to the success of the research, development and extension thrust, MLA has identified an increase up to 3.22 million graded cattle and 3.47 million graded lamb carcasses in 2014/15. The metrics have shown a clear increase in the MSA score of beef and lamb cuts and for beef an average premium to producers of AUS 33c/kg carcass weight.

MLA is committed to exploring opportunities for international collaboration. We are a country that relies heavily on beef and lamb exports and any progress toward improving the global consumer appeal of beef and lamb worldwide is fully supported.

# VI. A UK RETAILER PERSPECTIVE: THE NEED TO MOVE BEYOND CARCASS GRADING

Beef and lamb sectors make a large contribution to the overall meat sector in UK and Europe. According to Duncan Sinclair (Waitrose Ltd, UK), there are many challenges in these sectors and in the future ruminant production systems must be capable of delivering positively on many fronts, producing safe, traceable, nutritious quality products for consumers, farming in a sensitive and environmentally friendly manner in a "climate changed world" (Scollan et *al.,*

2011), resource efficient and delivering to maintain and enhance our countryside and rural communities.

Consistently delivering on "quality" for consumers is very important to our business and for beef and lamb high eating quality characteristics (tenderness, juiciness, flavour) are a major element of "quality". In the UK and Europe, the EUROP grid method of carcass classification was implemented in 1981 under European Economic Community Regulations (EEC) No. 1208/81 and No. 2930/81. These were developed to facilitate the application of an EC wide scale for the classification of carcasses of adult bovine animals. This was to ensure the uniform classification of the carcasses of adult bovine animals in Europe and to make the definitions of conformation classes and fat classes more precise. The need arose for a common grading scale when member states of the European Economic Community began operating in the common beef market in 1968 (EEC) No. 805/68 and price reporting to the EC became mandatory.

In the UK, the Meat and Livestock Commission (MLC Services Ltd) is responsible for the classification of over 80%

of the cattle slaughtered in Britain. The EUROP grid consists of a 5 point scale in which each conformation and fat class is subdivided into low medium and high classes resulting in 15 classes. In the UK, the fat classes range from 1-5 with classes 4 and 5 having a high and low sub-class which results in a seven point scale for fatness. The price a farmer receives for an animal at slaughter is calculated by multiplying the carcass weight by the classification price for a particular category of animal (heifer, steer, bull, etc.).

Delivering consistency in eating quality is increasingly important to consumers and hence there is a need to be able to more objectively measure eating quality. The industry requires tools which may help it to move beyond carcass conformation and fat class assessment to those that can objectively measure both carcass yield and eating quality characteristics. Future grading systems which can link yield and eating quality would assist in creating a transparent value-based payment system that would also assist in encouraging improvements in production efficiency and reduced waste throughout the supply chain.

## VII. FRENCH INDUSTRY PERSPECTIVE ON BEEF AND LAMB EATING QUALITY GRADING

This summer (2015), milk and meat producers are demonstrating in France. François Frette (FNICGV) said: "Isn't it an opportunity to change French meat production?"

There are many reasons for this crisis. CAP (Common Agricultural Policy) reforms have made the market more open and prices more uncertain (Source: European Commission 2010). Each country will have to assert its assets. France suffers a lack of competitiveness, mostly because of its own constraints (Rapport d'information n° 784 (2012-2013) de Mme Sylvie GOY-CHAVENT). Every meat sector has lived through hard-times for 5 years now.

Perhaps, the time has come to put another meat on the market? Meat consumption has changed in France. More than one third of consumers are going to reduce their meat consumption (Hebel, 2014). They ask for a meat that gives them some "pleasure".

In December 2014, a new French legislation simplified the names of meat cuts in the self-service section of

supermarkets. Meat cuts names are now easier to understand. But this legal reform also classifies meat cuts by a three-level stars system. Now, a bovine fillet will be labelled with "3 stars" regardless of the animal it comes from, with no absolute guarantee of quality for consumers. French industry must now make another step towards this guarantee.

Finally, meat distribution is also changing in France. Supermarkets are investing in traditional meat departments, facilitating meat market segmentation based on quality. Meat ageing cabinets are blooming in butchers' shops and restaurants. Butchers are becoming stars. To be a carnivore is becoming a way of life. It seems that the ingredients are gathered in order to make quality meat an important segment of the French beef meat market.

There is no need for further quality grading for French lamb: 15% of the production uses official signs identifying quality and origin (INTERBEV 2014).

## VIII. THE POLISH INDUSTRY PERSPECTIVE ON BEEF QUALITY GRADING

Through the last 40 years the Polish beef industry has undergone many changes that have caused a substantial decline in demand to the lowest level of 1.6 kg per capita in 2013 (Małkowski, et *al., 2014*). The aim of the study presented by Jerzy Wierzbicki of the Polish Beef Association was to present changes which affected the Polish beef industry in recent years, in particular a fast spreading trend of assuring high quality of beef. It also contains: the transformation of ownership, the transition from compulsory (PKN, 1996) to voluntary carcasses and cuts specification and market incentives to implement EUROP classification (Komisja Europejska, 2008) (before and after EU accession).

An analysis was carried out of the consequences of opening access to the EU market for slaughterhouses and cutting plants and their ability to adapt to changed

requirements in terms of product specification. EU accession also influenced their approach to measuring parameters such as the pH or colour of the meat and this was analyzed in a separate case study. Demand changes and new consumer behavior have been noticed which resulted in building open quality assurance systems such as "Quality Meat Programme" as well as commercial brands: "Uczta Kulinarna", "Beef Quality Standards", "Wołowina z Pniew".

Our study briefly underlines new requirements concerning beef quality in the Polish market: stronger demand for aged beef and well-marbled beef. Two results of the ProOptiBeef project were presented: Polish consumers may pay more for beef if quality grade is guaranteed. A Polish prediction model, which is analogous to the MSA model, was also presented as a result of ProOptiBeef project.

# IX. GLOBAL TRADING OF BEEF USING MEAT STANDARDS AUSTRALIA

Michael Crowley from Meat & Livestock Australia described global trading of beef using the MSA system.

Global demand for beef has increased dramatically over several years and is set to continue to grow. An emerging middle class in developing countries, reduced supplies from major beef producing nations and population growth are combining to create all time beef demand highs. As global demand for beef increases with supplies in limited volume, prices rise as a result (Market Information Services, 2015). It is therefore imperative that as a global beef industry, we look at how we meet the needs of the global consumer. There is a clear preference for beef as a choice of protein. Australia is a high cost producer and as such cannot compete on price with intensively produced commodities such as pork and chicken. Consumers are however willing to pay more for beef if satisfied (Polkinghorne et *al.,* 2008b). In order to ensure beef remains part of the normal repertoire of the global consumer, we need to position beef as a quality product that is convenient, consistent, safe and healthy.

How do we do that?

In this paper I propose that the Australian beef industry will continue to evolve and become more integrated along the supply chain. Meat Standards Australia will underpin Australia's beef offering and in order not to reduce the earning potential of the beef supply chain, highly differentiated brands will deliver the eating quality message to the trade. Eating quality will be one of many key attributes of a brand that will be targeted at meeting the needs of a specific consumer. Brands, as the delivery tool of the eating quality message, will ensure Australian beef is no longer traded as a commodity. It will become something special, there will be emotional engagement and there will be greater opportunities to get closer to the consumer through program business capturing greater value.

For the supply chain to benefit from these close relationships with the consumer and to ensure the product performs that same way 365 days of the year, commercial signals will evolve.

The future lies in integrated information systems and objective carcass measurements that in turn lead to value based payments being made to producers. Through sophisticated feedback and benchmarking tools, producers can react to consumer driven market signals and make decisions on farm that increase the quality, productivity and profitability of the whole supply chain.

We are all in it together and with the right commercial signals, we will deliver better consumer based eating quality solutions that will return a more sustainable and profitable beef industry for all participants along the supply chain.

# X. THE PROSPECTS FOR GRADING LAMB CUTS BASED ON EATING QUALITY

Prof David Pethick and his collaborators (Alex Ball, Graham Gardner and Liselotte Pannier) described the Australian grading system for lamb cuts.

The Meat Standards Australia (MSA) grading scheme for underpinning the eating quality of lamb is currently a pathways system with guidelines for best practice feeding, handling and curfew management, slaughter protocols (pH decline), product ageing and retail presentation of lamb cuts (Pethick et *al.,* 2005). The system has now been adopted by industry with 3.5 million lambs graded annually, representing about 35% of the domestic slaughter. The Australian Sheep Industry Strategic Plan identified that the next phase of MSA for lamb and sheep meat would be the development of a cuts based grading scheme where by cuts could be graded into categories of unsatisfactory, good every day, better than every day and premium, similar to the MSA system for beef.

Meat & Livestock Australia and the Cooperative Research Centre for Sheep Industry Innovation have recently undertaken large scale studies using the MSA sensory protocols (based on over 7,000 untrained consumers) on 2 muscles (*m. longissimus lumborum* & *m. semimembranosis*) from over 2,000 lambs covering 223 sires from Terminal, Maternal and Merino sires. Much of this research has been published as a 2014 special edition in Meat Science (Pannier et *al.,* 2014a; Pannier et *al.,* 2014b; Mortimer et *al.,* 2014). This research has identified the following:

• Within the current MSA program of best practice management and processing there is still variation in consumer eating quality scores of up to 20 units in the loin.

• The level of intramuscular fat in the muscle of lamb has a positive influence on the sensory scores of grilled lamb cuts.

• There is a significant negative association between lean meat yield and eating quality but with measurement systems in place sustained genetic progress can be made on these traits to mitigate the negative response.

• At a phenotypic level it is possible through knowledge of breed type (or even better sire eating quality breeding value), carcass weight, a measure of lean meat yield and intramuscular fat, that an MSA model could account for up to 65% of the variance in eating quality of both loin and topside grills and that this model can segregate cuts into MSA grades.

• The same consumer research has shown that consumers are prepared to pay based on the grade achieved (Table 1).

**Table 1:** **Willingness to pay – price relative to 3\* (based on 1,858 consumers)**

|      | N     | Ungraded | 3*   | 4*   | 5*   |
|------|-------|----------|------|------|------|
| Mean | 1,858 | 49%      | 100% | 147% | 200% |

The key to development and implementation of an updated cuts based MSA grading model for lamb is direct measurements of carcass weight, lean meat yield and intramuscular fat undertaken at abattoir processing. Research in this area is discussed further in this issue under 'Objective carcass grading for yield and eating quality in Australia' (Gardner et *al.,* 2015).

# XI. OBJECTIVE CARCASE GRADING FOR LEAN MEAT YIELD AND EATING QUALITY IN AUSTRALIA

The next paper was presented by Graham Gardner and his collaborators (Sean Starling, Henrik Anderson, Thomas Lauridsen, Alen Alempijevic, Alex J. Ball and David W. Pethick).

In Australia lamb carcasses are purchased, processed and marketed based largely upon their weight. Increasing carcass weight aligns with maturity which is crudely associated with reduced lean meat yield (Anderson et *al.,* 2015) and increased eating quality (Pannier et *al.,* 2014). Yet within a weight range there is still marked variation in both of these traits, which represents a significant cost to industry. For lean meat yield, this cost is quite evident through the fat that is trimmed from carcasses and the variability in size of saleable cuts of meat at retail. Yet for eating quality the cost is hidden and reflected through a gradual loss in consumer confidence due to product variability (Pethick et *al.,* 2006).

This variability can be predicted using measurements taken from the entire carcass prior to fabrication into retail cuts. Therefore with carefully targeted sorting of carcasses based upon the cuts that will be fabricated from them, the amount of trimmed fat can be minimised, cut weight/dimensions standardised, and variability in eating quality reduced.

In Australia, the predictive tools required to achieve these outcomes have already been developed, including the MSA model which is discussed further in this issue under 'The prospects for grading lamb cuts based on eating quality' (Pethick et *al.,* 2015), as well as a cut weight and value prediction package called the carcass calculator (Hocking-Edwards et *al.,* 2015). These predictions of cut weight and eating quality can be used simultaneously to target the fabrication of the available carcasses to meet the real-time volumes of target markets based upon optimising total profit. Yet all of this hinges upon accurate and precise carcass measurements to enable the prediction of cut weights and eating quality.

On this basis, considerable Australian research effort has been invested into objective measurement technologies for lamb. These technologies must be accurate and precise, cost effective, operate at abattoir chain speed with the potential for automation, and be measured as soon after slaughter as possible. Most of these technologies are also likely to be relevant to the beef industry, however in lamb the requirements for speed and cost minimisation are greater due to the more rapid abattoir chain speeds and smaller return per head. To date a range of different technologies have been tested, with most progress occurring in the prediction of lean meat yield. Initially, considerable effort was invested into "probe-type" technologies that measure fat and eye muscle tissue depth at the 12th rib. Yet these failed due to considerable measurement error relative to the small changes in tissue depths which varied between 2-9 millimeters. Ultrasound was also tested at this measurement site, however it proved to be unreliable due to air bubbles captured at the surface of the carcass after hide removal. More recently, research has been initiated into a cost-effective vision image analysis system for predicting lean meat yield using 3-dimensional RGB cameras. Although vision image analysis systems have long been used to predict lean meat yield in Australia, they have relatively poor uptake within industry due to expensive cost structures and precision that is limited by older camera and analysis technologies. Most recently the development of a prototype dual energy x-ray absorptiometry (DEXA) system has shown good potential. This device resulted from the modification of an existing 2D X-ray system that provides images for robotic boning in lamb abattoirs (Scott Technology Ltd.). It demonstrated excellent precision ($R^2$, RMSE) for predicting fat (0.84, 1.64), lean (0.61, 1.99) and bone (0.70, 0.83) percent in a carcass, although it represents a relatively expensive alternative if the robotic boning system is not already in place.

Measurements taken to predict lamb eating quality have proven to be problematic. In particular, intramuscular fat has been shown to be an important determinant of eating quality (Pannier et *al.,* 2014), and therefore its measurement is the key priority. However in contrast to beef, this cannot be measured by a human grader as the cost per unit carcass is prohibitive in lamb. Electrical impedance between a series of probes inserted into the loin muscle of the carcass has been tested, however it lacked the precision to differentiate between intramuscular fat ranging across a relatively small range in lamb (2-8 percent). Therefore, technologies proven in other species are now being investigated, including near-infrared spectrometry, and hyperspectral imaging. The drawback of the hyperspectral imaging approach is that it requires an image taken of the cut surface of the loin. Near-infrared spectrometry has an advantage on this basis as it relies upon the insertion of a probe directly into the carcass.

This presentation will report on the development progress across all of these areas of technology, while also detailing the relevance for implementation within the supply chain.

# XII. EATING QUALITY GRADING - PERSPECTIVE FROM IRELAND AND AN UPDATE ON OBJECTIVE CARCASE GRADING IN EUROPE

Paul Allen from Teagasc described the eating quality grading systems in Ireland and perspectives from research on MSA.

The eating quality of beef is very important to consumers with tenderness being the most important attribute (Mannion et *al.,* 2000). It is affected by many on-farm and post-slaughter factors and can be variable at the point of sale. Yet the consumer cannot visually assess the eating quality of beef before cooking it. To provide the consumer with the possibility of choosing beef of consistent eating quality, Meat and Livestock Australia developed a model (the MSA grading model) to predict eating quality from the on-farm and post-slaughter factors that are known to affect it (Polkinghorne et *al.,* 2008b). This model is based on a large database of beef samples from different cuts, cooked in several ways and tasted by many consumers. The model predicts the Meat Quality Score (MQS), which is a weighted average of scores from 0 to 100 for tenderness, juiciness, flavour and overall acceptability. The samples are also given a star rating by the

consumers and an average cut-off point for each star category has been determined.

To see if the model could be used by the Irish beef industry it was tested on Irish beef and Irish consumers, using five different muscles either grilled or roasted. Similar Australian samples were also tasted by Irish consumers, having been scored by Australian consumers. It was therefore possible to determine how accurate the model predicted the scores for Irish beef and Irish consumers and to compare Irish and Australian consumers.

The model was at least as accurate at predicting consumer scores for Irish beef as when used on Australian beef and Australian consumers. The mean deviation of actual score from the score predicted by the model was less than 5, suggesting a small overall bias, but deviations for individual samples ranged from -22 to +27. A disturbing feature of the results was that striploin, rump and blade samples were almost equally distributed between the four quality categories, illustrating the need for an eating quality grading system for individual cuts.

A series of experiments was then devised to see how well the model accounted for some of the factors that are particularly relevant to the Irish beef industry. Low voltage electrical stimulation had no effect on the MQS for the three muscles tested (striploin, topside and outside round), whereas ageing for 28 days improved the MQS for all three muscles compared to ageing for 14 days. The model accounted for this effect in two muscles but not for the outside round. There was generally a good fit for model for the other factors tested such as high voltage electrical stimulation, hanging method, breed and sex. The MSA model could be used by the Irish beef industry to sort cuts into eating quality classes and reduce the

amount of variation in eating quality, but as of now it has not been adopted.

Currently, work is ongoing to improve the average eating quality of the Irish herd through genetics. Meat samples are being taken from the progeny of AI sires going through the Irish Cattle Breeding Federation (ICBF) testing station. These are subjected to objective measurements such as Warner Bratzler Shear Force (WBSF – tenderness) and Intramuscular fat (IMF – marbling) content and to sensory analysis by a trained panel. In-factory methods of predicting eating quality, such as Vis/NIRS spectroscopy are being tested on these carcasses. If they are sufficiently highly correlated with the objective and subjective eating quality traits they will be used as proxy measurements to build up a large database. When sufficient data have been collected eating quality traits will be included in the breeding values for AI bulls.

In 2003 the EC beef carcass grading regulation was changed to allow mechanical methods to be used in place of classifiers provided they were shown to be sufficiently accurate. Shortly after, Ireland became the first country to install Video Image Analysis (VIA) systems in all the major export factories where they have operated satisfactorily for over 10 years. Other EU countries have since adopted VIA systems in at least some of their factories. The industry in Ireland is interested in having accurate predictions of saleable yield and other criteria related to the realisable value of a carcass. While the VIA systems are capable of predicting yield variables there may be other technologies with the potential to achieve greater accuracy. The main barrier to the development and application of other technologies is that they will also have to predict EU conformation and fat cover with sufficient accuracy.

## XIII. BEEF CARCASS GRADING SYSTEM AND CONSUMERS' SENSORY PERCEPTION OF BEEF IN JAPAN

Professor Nishimura described the current grading system in Japan and the research which has been done in Japan about the MSA system.

The famous brand name Wagyu becomes very popular nowadays all over the world. "Wa" means Japan or sort of Japanese mind, and "gyu" means cattle. Actually, Wagyu include four types of Japanese cattle: Japanese Black, Japanese Brawn, Japanese Shorthorn, and Japanese Polled. Japanese Black is raised and fattened in all parts of Japan, and approximately 90% of Wagyu in Japan is of this breed. Japanese Black cattle and its crossbred cattle are produced in foreign countries such as Australia and the United States, they are also called Wagyu. In Japan, beef produced from Wagyu was 166,829 t (on the basis of primary cuts; 46% of total domestic beef production in Japan) and those from Holstein and crossbred were 112,581 t (31%) and 75,473 t (21%), respectively (Statistics of Agriculture, Forestry and Fisheries, 2012).

Domestic beef produced from Wagyu, Holstein and crossbred cattle in Japan are evaluated by accredited graders from the Japan Meat Grading Association (JMGA) in accordance with the beef carcass grading standards (Goto et al., 2014). The present grading system assigns both a yield grade (A, B, and C) and meat quality grade (1, 2, 3, 4, and 5). Yield score is determined as an estimated percentage of saleable product by the multiple regression equation, which

includes four carcass measurements, left side weight, rib eye area, rib thickness, and subcutaneous fat thickness on the 6th to 7th rib section. Beef yield percentage is calculated by using the following equation: Dressing percentage value = $67.37 + [0.130 \times$ cross-sectional area of *Longissimus thoracis* muscle at 6–7 thoracic vertebrae (cm2)] + [0.667 $\times$ thickness of ribs part including meat (cm)] – [0.025 $\times$ half carcass weight (kg)] – [0.896 $\times$ thickness subcutaneous fat (cm)]. We grade A as more than 72, B as 69 to 72, and C as less than 69. The quality grade is determined by way of 4 aspects, beef marbling, meat colour brightness, firmness and texture of meat, and colour, lustre and quality of fat. Beef marbling score is judged objectively based on beef marbling standard (BMS). Beef colour and brightness is judged by the combination of colour and brightness of lean meat. Beef colour is judged objectively based on the beef colour standard (BCS). The firmness and texture of beef are judged by way of naked eye observation. Fat colour is evaluated by Beef Fat Standard (BFS) prepared as seven continuous standards. The lustre and quality of fat are evaluated simultaneously by visual appraisal. The meat quality grade of the carcass is then assigned according to the lowest grade of these four items. Final yield and quality scores are indicated on carcasses by one class of the 15 combinations (A5 to C1). Wagyu are mainly graded A5-A3, while, Holstein steers are graded mainly B2 and C2. The Japanese grading system is good for selecting premium quality beef, but might not be suitable for evaluating everyday

beef such as Holstein beef. Breeds other than Japanese Black might be under evaluated than its real value to consumers. Beef marbling score has a significant weighting on the final quality grade and auction price. Furthermore, there is little information for consumers, because the JMGA grades are not usually displayed on retail cuts. However, recent trends show that the Japanese consumer is selecting leaner beef for everyday beef consumption. Consumer sensory testing would help to investigate these claims scientifically, as well as to explore the possibility of developing a Japanese beef grading system based on eating quality in the future.

In 2006, Rod Polkinghorne and his colleagues did sensory testing in Japan. The aims of this research is to evaluate the sensory categorization of beef by Japanese consumers, based on Meat Standards Australia methodology. Various cuts of beef, with a wide range of quality (from Australian and Japanese cattle) and three cooking methods (grill, yakiniku, shabu shabu), were evaluated by 1620 Japanese consumers in Tokyo and Osaka. Four muscles from 36 Japanese and 87 Australian carcasses were used in this study. Consumers rated each sample for four sensory attributes, then selected one of four grades, based on the quality of the beef within each cooking method. The distribution of the Japanese consumer

MQ4 scores showed a clear distinction between grades, with the majority of scores being included within the boundaries of each grade (Polkinghorne et *al.,* 2011). The MQ4 score allocated approximately 64% of the samples to their correct consumer grades. The MQ4 score showed potential to be used as a tool in developing and monitoring a consumer focused grading system that is able to predict Japanese consumer satisfaction of individual beef cuts prepared by different cooking methods. The proportion of samples assigned to each grade was similar for Japanese and Australian consumers for yakiniku and shabu shabu cooking methods, however Japanese consumers assigned lower scores to the grill samples (Polkinghorne et *al.,* 2014). In terms of the MQ4 boundary scores between grades, these were very similar for both Japanese and Australian consumers across all cooking methods. In terms of the weightings for the four sensory traits, juiciness was more important for Japanese consumers than Australian for grill and shabu shabu cooking methods. Flavour had the highest weighting for both consumer groups. This study showed that a beef description system based on the MQ4 score, with some adjustments to the weightings and cut-off values, could be useful in describing the eating quality of beef for the Japanese consumer.

## XIV. DEVELOPMENT OF THE MEAT STANDARDS AUSTRALIA (MSA) INDEX AND THE ROLE OF GENETICS

The objective of the study presented by Peter McGilchrist, Rod J. Polkinghorne, Alexander J. Ball and John M. Thompson was to produce a single number that depicts the eating quality of a beef carcass. The Meat Standards Australia (MSA) grading model accurately predicts the eating quality of 39 individual cuts in a beef carcass from commercial inputs available at grading (Watson et *al.,* 2008b). Each cut receives a meat quality score (MQ4) between 0 and 100, based on a prediction and combination of 4 traits; tenderness, juiciness, flavour and overall liking (Watson et *al.,* 2008b). The MQ4 score for 39 individual cuts is also predicted for up to 6 cooking methods for each muscle (Watson et *al.,* 2008b). The MSA model is complex due to the non-linear impact of different model inputs between cuts and the diversity of the Australian cattle demographics and production systems. The MSA system has also shown that no single indicator cut like a striploin can be used to truly reflect the eating quality of the carcass, which is why MSA predicts the eating quality of 39 cuts and not just 1.

The potential eating quality of a carcass is of interest to producers as they can use feedback to evaluate the improvement in eating quality due to various factors like: investment in new genetics; different suppliers of feeder cattle; difference between seasons or years and other production factors. However to date, carcass feedback to producers is in the form of individual measurements for carcass traits like carcass weight, ossification, MSA marbling score, rib fat, hump height or *Bos indicus* content, ultimate pH, gender, hormonal growth promotant, milk fed vealer and saleyard status. The impacts of all these factors on the eating quality of 39 different muscles in the body are not linear due to the complexity of muscle biology. Due to the non-linear nature of factors impacting eating quality, producers cannot assess individual carcass traits assessed by MSA graders to evaluate the eating quality of a carcass. Hence the MSA index was created, which is a single number calculated for each carcass.

The MSA index is an average of the MQ4 scores for the 39 cuts in the carcass for the most commercially utilised cooking method. Each of the 39 MQ4 scores has a fixed weighting for their proportion of the total cut weight of the 39 muscles. The proportion is fixed as Butterfield and May (1966) show that muscle distribution is largely a result of the functional stresses being placed on the muscles. All beef animals regardless of breed and whether they are raised in a feedlot, or on pasture, place similar functional stresses on their muscles by standing, walking and resting. Whilst different breeds (and also individuals within a breed) may differ widely in conformation, Butterfield and May (1966) suggest this has little impact on the functional stresses placed on individual muscles and hence the proportional muscle distribution within the carcass. The results from a bone-out of 40 cattle showed no variation between individual animals in muscle distribution as a proportion of the whole between high and low muscled cattle. However in cattle with a myostatin mutation, the proportional weights of some cuts did vary, but the proportion of the Australian herd carrying myostatin mutations is very low.

Across the Australian herd, the MSA index generally ranges between 30 and 80 and can be utilised to analyse eating quality over time within a production system, across production systems and to benchmark producers. It can also be used by producers to accurately measure the impact of production factors like hormonal growth promotants, marbling score or the percentage of *Bos indicus* on intrinsic eating quality of cuts delivered to consumers. The impact of selecting sires with higher genetic breeding values for marbling, growth, carcass weight and fatness on the MSA index is currently being evaluated across large data sets. This will be very useful information for producers to help evaluate the impact that sires will have on the eating quality of their progeny.

# XV. INCORPORATING FLAVOUR RESEARCH INTO CARCASSE GRADING FOR EATING QUALITY

Linda Farmer indicated that previous studies have shown that the Meat Standards Australia (MSA) grading system is excellent at predicting the eating quality of Northern Ireland's beef (Farmer et *al.,* 2010). Nevertheless, for NI consumers, the model was better at predicting tenderness than flavour and the consumer quality score was predicted better by flavour liking than by tenderness (Farmer et *al.,* 2009). Research on the MSA system in other countries (R Polkinghorne, personal communication) has shown that this latter is also true of consumers in other countries.

Flavour is the combined effect of odour and taste, caused by volatile compounds and water-soluble components, respectively. The odour compounds are generally formed during cooking by the reaction of 'flavour precursors' present in the raw meat. The formation of flavour arises through the known biochemical and chemical processes occurring post-slaughter (Figure 1). These various substances contributing to flavour are usually identified and quantified using chromatography and mass spectrometry methods. Many odour compounds are present at very low concentrations, requiring specialist techniques, and methods involving the analysis of more abundant 'marker compounds' have been developed. These techniques can provide useful insights into the factors affecting flavour, as determined by consumers (Farmer et *al.,* 2012).

**Figure 1:** **Summary of the mechanisms of formation of flavour in beef**
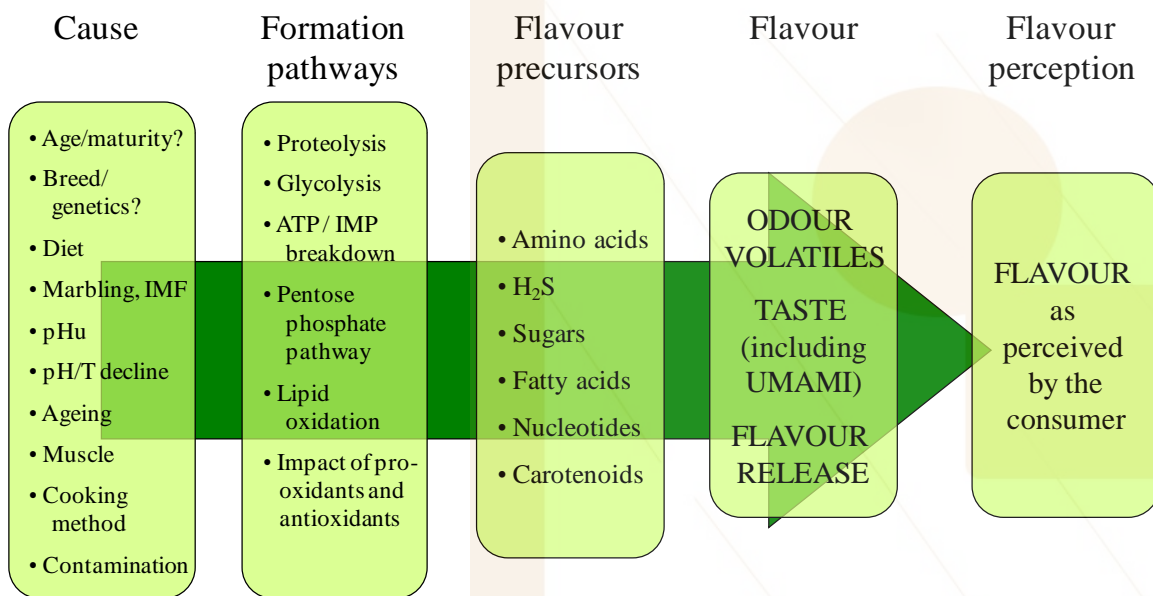


While analytical instruments are reducing in size and becoming ever more sophisticated, they are not yet suitable for analyses on-line in a meat plant. Therefore, the challenge is to use the understanding gained from instrumental analyses, combined with consumer and descriptive studies, to allow flavour quality to be incorporated into a grading system. Recent studies (Legako et *al.,* 2015; Legako et *al.,* unpublished data) have shown that the consumer perceptions of flavour arising from differences in muscle, intramuscular fat or ageing are reflected in differences in volatile odour compounds, taste compounds and precursors. Further research is needed to link meat biochemistry and chemistry with flavour formation and to allow flavour quality to be predicted and matched to consumer preferences.

# XVI. INTERNATIONAL BEEF EATING QUALITY LANGUAGE

The concept of an international beef eating quality language is no longer new and recent updates were described by Rod Polkinghorne and Jerzy Wierzbicki. Most descriptive beef languages used globally have probably always been thought to fill this role through describing carcass attributes, raising systems and cuts. In fact work over the past 20 years has established that the traditional carcass based systems, while grouping carcasses into groups of similar appearance and describing cutting lines, are relatively ineffective in describing actual consumer satisfaction with the resulting meal.

Attempts to overcome this deficiency have taken many forms including the Meat and Livestock Commission blueprint in the United Kingdom, PACCP Pathways in the USA and the initial Meat Standards Australia (MSA) pathways in Australia. The MSA system established a new approach in directly utilising untrained consumers as a measurement tool, moving over time from validation of production "pathways" to developing eating quality prediction models.

The MSA developed consumer testing and data collection protocols, supported by software routines, have been extensively utilised in Australia and in collaborative studies in South Korea, Northern Ireland, USA, Japan, the Republic of Ireland, South Africa and France. Further significant

independent studies utilising the protocols have been conducted in Northern Ireland, USA, New Zealand, Poland, the Republic of Ireland and France, with France and Poland also conducting collaborative studies. The individual data also include extensive linkages to other global language standards including EUROP and USDA. Consequently a considerable amount of consumer and consumer measured data exists in very similar format capable of being combined for analysis and potential application in describing and predicting beef sensory response across global consumer populations.

A primary aim should be to demystify beef at consumer level by facilitating the use of simple contemporary food product terms that clearly indicate an expected meal outcome rather than an elaborate set of often misleading cues that relate to source animals and cuts.

As beef is a globally traded product it is sensible to, as far as possible, develop and adopt a common language base. This can facilitate collaborative research, dramatically reduce the cost of developing consumer based prediction approaches and simplify product description in trading and retail environments.

The UNECE Specialized Section on Standardization of Meat, which currently administers a global beef language standard, has noted that further consultation is needed regarding development of a collaborative way to collect and record information on the development and keeping of protocols or procedures for consumer testing, potential meat grading inputs and data for research purposes. A working group led by Poland as lead rapporteur has further considered this issue (United Nations Economic Commission for Europe, 2015) and will report back in late September, 2015.

The focus of this is research collaboration which it is hoped will facilitate more efficient work across scientific and industry groups and an enhanced understanding of consumer populations and the interaction with livestock and production systems. Data analysis and tactical research collaboration will determine the extent to which consumer and cattle populations are similar or differ when corrected for typical grading inputs including gender, carcass weight, age, ossification and marbling. This in turn will inform the extent to which a common base may be applicable for the prediction of consumer satisfaction and the degree to which such predictions may need to be adjusted across consumer groups. It is also important that agreed standards to describe potential grading inputs be supported by formal standards and systems for training and monitoring their use.

It is hoped the principal of collaborative work facilitated by an agreed language standard will be readily accepted. The devil, as always, is likely to be in the detailed application with prior research funded by a range of industry and private entities and with differing degrees of support from a number of Government agencies. Consequently we need to begin considering models that can facilitate collaboration and potential ultimate commercial application.

We propose that a staged approach be considered utilising the following principles:

1. That a common cloud based database structure be developed with the format published and made available to interested parties.

2. That software routines be published in open code that facilitate and automate research trial design, data accumulation and the execution of consumer testing and related data collection. These routines should interact with the standard database structure.

3. That agreed ontology be developed and published to facilitate the consolidation of data from local databases, utilising local language and descriptive terms where necessary, to a common collaborative master global data cooperative.

4. That local groups retain ownership and control of their own country, organisation or company data to the extent desired through their local version of the standard database.

5. That data, or data fields, be approved for amalgamation in a collaborative global "data cooperative" / database. Confidential data such as company or producer names could be removed or blind coded within this process.

6. That approved data be uploaded through standard procedures to the global research data cooperative with ontological adjustment in the upload procedure.

7. That the proportion of valid records (to a minimum data standard) contributed by each partner be continually recorded.

8. That researchers be granted free access to the global data cooperative under a collaborative research structure with key researchers meeting through a steering committee to coordinate priorities and peer review results.

9. That the opportunity to develop consumer prediction models that share a common base and to clarify where local variations are warranted be pursued within the structure.

10. That a knowledge base of global consumers be progressively assembled through contributing studies to facilitate accurate prediction of sensory response within local populations and cooking styles.

11. That common terminology be adopted to describe consumer satisfaction facilitating trade communication and supporting beef recording, trading, reporting and commercial branding activity.

12. Should commercial application of prediction models developed from the global data cooperative be desired they could be delivered by an independent not for profit group and made available to all parties via web based processing at equal cost per carcass graded to all industry participants within a country. The GS1 commercial structure used for international product codes may be a useful model.

13. That revenue from any commercial application be applied firstly to cover the operational cost with a further proportion distributed to the research data contributors in proportion to their current share of the records held and contribution. This share would change over time as individual providers contributed additional research data and value.

The proposed structure is advanced for discussion and aims to provide a balance between the immense value of developing a global capacity to deliver consumer satisfaction through simple common description and the uneven contribution of research partners and other industry groups who do not or have not contributed to the research effort but have an interest in commercial application.

The collaborative research component must by definition proceed before any common commercial application occurs, or perhaps needs consideration, allowing time for alternative strategies or business models to be debated.

Development of an international eating quality language is an ambitious but very worthwhile endeavour of critical importance to the global beef industry. Delivered in full it is believed to be a fundamental game changer through firmly placing consumer satisfaction as the focus of beef description.

# XVII. PERSPECTIVES OF EATING QUALITY GRADING FOR BEEF AND LAMB: SCIENTIFIC AND INDUSTRY VIEWS IN CHINA

Professor Qing-Xiang Meng and his collaborators (Hai-Ling Luo, Yan-Ling Li, Li-Ping Zhao, Li-Ping Ren) described the perspectives of eating quality grading for beef and lamb in China.

As reported by the Statistical Data (Chinese Agricultural Yearbook, 2015), China had 68.39 million of inventory beef cattle and 6.73 million tons of beef output. Average beef produced was 141 kg per slaughter with 5.1 kg beef consumption per capita. Meanwhile, the inventory of sheep and goats was about 300 million with 4.28 million tons of both sheep and goat meat. Because of a strong demand for beef and lamb products by Chinese consumers, the market price of beef and lamb has been increasing in recent years. In order to meet such a demand of beef and lamb for the consumers, cattle, sheep and goat operations have tried to increase beef and lamb production by feeding more animals. In order to guarantee market supply and stabilize commodity prices, the Chinese government opened the channel for the importation of beef and lamb products from other countries, such as Australia, New Zealand, Canada, Argentina, Brazil, Uruguay, Chile and Costa Rica. However, there is another problem for smuggling of beef and lamb with an estimated amount of more than 3,000,000 tones illegally introduced to China from neighboring countries, such as Burma, India and Vietnam.

Although the national standards of carcass grading for beef cattle and sheep and goats (Beef Quality Grading, 2010; Lamb and Mutton Evaluation and Grading, 2002) were issued by Chinese central government, these standards were not applied well in practice. Some new progress has been made in the quality grading of beef and lamb in China. A laboratory for beef sensory quality evaluation has been established at China Agricultural University. Studies have been undertaken in this lab for samples of meat from local breed beef, Holstein calf meat and yak meat as well.

MSA-based techniques were also successfully tried in the lab using beef and lamb products with both hot-pot (Huoguo) and Tieban cooking ways. Based on the MSA procedure, Chinese beef and lamb could be graded for their eating quality that may be used for making decisions of their market price. Through collaboration on an international project led by Dr. Pethick of Murdoch University, Australia, we will compare sensory scores between Australian, Chinese and USA untrained consumers using lamb and yearling sheep meat. After that, beef products will be used for comparing their eating quality by the MSA system (Polkinghorne et *al.,* 2008b).

# XVIII. EUROBEEF, A EUROPEAN THEMATIC NETWORK ON IMPROVING OFFER AND DEMAND IN BEEF PRODUCTION IN EUROPE

Lastly, Koenraad Duhem, Linda Farmer, Isabelle Legrand, Christophe Denoyelle ; Jean-François Hocquette and their collaborators described the ambitions of the Eurobeef network in case of funding by the European Union.

The European Union is ranked third in the world for beef production with 7.7 million tons of carcasses. 40% of this production is produced by beef/suckling herds, which are principally located in France, Spain, United Kingdom, Ireland and Italy. European beef farm systems contribute significantly to beef production but also to an interesting land use, in the sense that areas utilized by suckler cows are mountains and Mediterranean areas or permanent grasslands that cannot be exploited for other types of food production. Cow-calf production occurs in rural areas and participates to a certain extent in maintaining economics and social life in the countryside, contributing to sustainability. Beef production is also well developed as a complementary activity in dairy farms.

Unlike its main competitors, Europe has a wide variety of beef farming systems. As a consequence, meat may originate from different categories of animals and beef meat is not a standardised product at the retailer stage. This diverse production makes the industry very complex.

The EU consumption of beef reached a high in 1985 with 25 kg, but from then steadily declined to 17 kg. Beef is an expensive meat and the quality offered at retail (tenderness, juiciness, flavour…) often doesn't meet expectations. Some countries like Australia have kept their beef consumption steady in recent years, partially due to quality programs (Griffiths and Thompson, 2012).

Beef consumption is not only driven by intrinsic quality (the characteristics of the product itself), but also by extrinsic qualities (animal health and welfare, food safety, nutritional value of beef, environmental impacts …) (reviewed by Hocquette et *al.,* 2014a). An assessment of beef supply chains found around Europe through standardised methods would allow the identification and development of the most sustainable strategies (United Nations Economic Commission for Europe, 2015; Watson et *al.,* 2008a, 2008b). Any discussion of these complex issues would require all stakeholders to take part.

Under the Societal Challenge 2 of the Horizon 2020 program, the topic ISIB-2-2014 proposes the development of thematic networks, aimed at closing the gap between research, innovation and practitioners. Eurobeef has been proposed as such a thematic network in the European value chain of beef production; it is led by "Institut de l'Elevage", (France), partnered by INRA (France), Agri-Food and Biosciences Institute (NI, UK), Polish Beef Association, Centro Ricerche Produzioni Animali (Italy), Teagasc (Ireland) and UECBV (EU).

The project is intended to enhance organisational innovation along the whole beef value chain. The purpose is to better address the offer and demand issue at several steps of the value chain to make the European beef industry more sustainable and competitive.

The objectives of EUROBEEF are to respond to the following questions:
"How can farmers, their organisations, slaughter-houses, meat processors and retailers all work together to supply the

European regional and International markets and consumers' meat demand, while improving sustainability of the beef industry?" The response lies in the organisation of a dialogue of all stakeholders. The project will focus on the consumer view and go 'upstream' along the supply chain to include production systems.

The Eurobeef Network will cover 15 regions in 8 countries. In each of the regions concerned, EUROBEEF will address 3 issues:

•"How can consumer's demand be addressed?" This issue is about the piece of meat ready to consume in the plate (not about the carcass quality or the animal characteristics including its breed)

•"How can producers and their organisations build up their offer with regard to the market's needs?" Here the issue concerns the best combinations of breeds/husbandry techniques to produce quality animals in each region according to market availabilities.

•"How can the whole beef chain be more sustainable in order to match with societal expectations?" This wider issue deals with citizens' concerns regarding social impacts, environmental services and economic viability of the beef chain.

The core themes will be:

•Networking (Work package 1)

•Regional Comparison of Beef Supply Chains (Work Package 2). Mapping the European supply chain and assessing the implications of the observed patterns.

•Eating Quality of Beef (Work Packages 3,4,5), comprising three parts: Determination of the industry real needs regarding eating quality and consistency, evaluation of existing scientific knowledge on eating quality and quality standards, identification of tools and mechanisms to meet the needs of the European beef industry to optimize eating quality

•Sustainability assessment of beef production (Work Package 6). Improving the economic and environmental performance of beef cattle farms by defining and disseminating of the most promising management tools to monitor technical, economic and environmental performance

•Development of a Stakeholder Driven Research agenda (Work Package 7). Identifying the research, development and innovation needs of the beef sector in the EU and selected regions

•Communication: the results will be communicated in the network and to a larger audience of interested stakeholders.

## OVERALL DISCUSSIONS AND CONCLUSIONS

A key feature of the MSA system is that the sensory response, or final eating quality assessment, is estimated as a weighted score of tenderness, juiciness, liking of flavour and overall liking using untrained consumers. In other words, the MSA system is focused on estimating the eating quality response of the population who purchase meat. Australia has a large data set of consumer responses to beef that has allowed the development and commercial application of the MSA muscle x cook prediction tool. Data sets using common protocols have now been developed in several collaborating countries and regions (France, Korea, Poland, Republic of Ireland, New Zealand, Northern Ireland, South Africa, United States of America) and most of this has occurred due to simple 'organic' collaboration between like minded scientists with some commercial input. Across the countries, the data has clearly showed enormous commonality in how consumers respond to beef in particular. Furthermore much of the data has been converted into peer reviewed journal papers meaning there is little if any residual intellectual property to protect. Finally, speakers from France, Poland, Republic of Ireland and Northern Ireland (and published work from Korea and South Africa) agreed that the base MSA model is an adequate tool for predicting the eating quality of beef for 'their' consumers. However extra precision would be possible if some adjustments were made for issues like (i) alternate production systems that are not included in the MSA prediction model (e.g. beef and dairy bulls, dairy cows) (ii) subtle consumer differences between countries and (iii) new cooking methods (e.g. hot pot, degree of doneness).

It was recognized that the value of a combined global database and cooperative development of eating quality standards and prediction routines far outweighed the sum of individual isolated databases due to the largely complementary nature of existing data and the benefit of cross linkages at animal and consumer level. Further benefits of collaborating in research work and merging data

under a data cooperative function were greatly improved efficiency and reduced cost for individual partners and the benefit of access to multiple research facilities and direct involvement of a larger pool of scientific expertise.

With this background the following recommendations have evolved:

1. The palatability web site be housed and managed by MSA (http://palatability.une.edu.au/drupal/user) with research partners encouraged to add content and stimulate dialogue.

2. The existing Australian MSA dataset format be adopted as a base for development of a more contemporary cloud based database structure (or content management system) with appropriate organisation, standardized ontology conversion and administration to provide a secure environment and facilitate merging of data from multiple partners within a data cooperative.

3. The MSA consumer testing and trial design software routines linked to the current database structure be utilized as a base for an open code software package that can be integrated with the new database structure. This should be developed to facilitate experimental design, and automate file and label creation for product collection, fabrication to consumer samples and allocation of muscles/meat portions/labels to consumer sessions by collaborating researchers.

4. That a consultant (Rod Polkinghorne) in collaboration with Meat & Livestock Australia coordinate and manage the data base development and trial design software routines. This is to include the transfer of existing data to individual country versions, and associated software routine development on behalf of the collaborating countries to ensure that existing data remains compatible and, where desired and approved by individual data contributors, be readily merged within a data cooperative. Cost recovery for this work to be negotiated.

5. That collaborating countries be offered the opportunity to upload 'like' consumer and related animal,

carcass and objective data into the data cooperative with a negotiated position on the use of both the uploaded and other cooperative data developed by the working group.

6. That the working group develop operational guidelines for research use of the data and extend this to a commercial model for the development of commercial 'MSA' like sensory prediction models.

7. The concept of Global Guaranteed Grading (3G), which has been presented in Milan, be embraced where shared Australian and international data sets be combined within a data cooperative to produce in the first instance country specific eating quality prediction models.

8. Meat & Livestock are open to the MSA prediction model being released by negotiation to collaborating countries using the 3G principal described above.

9. International collaboration on lamb eating quality using the MSA protocols is welcomed in a similar manner to beef.

10. Objective carcass grading for predictors of eating quality is a high priority, especially for lamb.

11. Ultimately systems need to evolve so producers are paid on the basis of eating quality of a muscle x yield of that muscle as planned in the Eurobeef network submission.

12. Of great importance is the development of smart tools for simple reporting across the value chain, especially to include producers.

In order to drive and focus the proposed recommendations, it was agreed to establish a working group of current collaborating countries that would be open with respect to new partners. The working group will meet 1-2 times yearly via teleconference or alike and strive to arrange the next workshop in association with the ICoMST 2017 conference in Cork, Ireland.

### References:

Anderson F., Williams A., Pannier L., Pethick D.W. and Gardner G.E. (2015). Sire Carcass breeding values affect body composition in lambs - 1. Effects on lean weight and its distribution within the carcass as measured by computed tomography. Meat Science, 108, 145-154.

Anonymous, (2008). Accessory Publication: MSA sensory testing protocols Australian Journal of Experimental Agriculture, 48, 1360-1367.

Butterfield R.M. and May N.D.S. (1966) 'Muscles of the ox.' (University of Queensland Print: Brisbane).

China Ministry of Agriculture (2002). Lamb and Mutton Evaluation and Grading. NY/T 630-2002, Beijing.

China Ministry of Agriculture (2010). Beef Quality Grading. NY/T 676-2010. Beijing.

European commission (2010). La politique agricole commune après 2013 – Débat public. http://ec.europa.eu/agriculture/cap-post-2013/debate/report/summary-report_fr.pdf.

Farmer L.J., Devlin D.J., Gault N.F.S., Gordon A.W., Moss B.W., Polkinghorne R.J., Thompson J.M., Tolland E.L.C., Tollerton I.J. and Watson R. (2010b). Adaptation of Meat Standards Australia Quality System for Northern Irish Beef. Advances in Animal Biosciences, 1, 127.

Farmer L.J., Devlin D.J., Gault N.F.S., Gordon A.W., Moss B.W., Polkinghorne R.J., Thompson J.M., Tolland E.L.C. and Tollerton I.J. (2009). Prediction of eating quality using the Meat Standards Australia system for Northern Ireland beef and consumers. In: International Congress on Meat Science and Technology, Copenhagen, 16-21 August 2009 2009. p PE 7.34.

Farmer L.J., Devlin D.J., Gault N.F.S., Gordon A.W., Moss B.W., Tolland E.L.C. and Tollerton I.J. (2010) Comparison of systems for assuring the eating quality of beef. Advances in Animal Biosciences, 1, 231-231.

Farmer L.J., Hagan T.D.J., Devlin Y., Gordon A.W. and Oltra O.R. (2012) Relationships between beef aroma compounds and other quality attributes. Paper presented at the International Congress on Meat Science and Technology Montreal, August 2012.

Gotoh T., Takahashi H., Nishimura T., Kuchida K., Mannen H., (2014). Meat produced by Japanese Black cattle and Wagyu. Animal Frontiers, 4, 46-54.

Griffiths G. and Thompson J.M. (2012). The aggregate economic benefits to the Australian beef industry from the adoption of Meat Standards Australia: updated to 2010/11. Australasian Agribusiness Review, 20, 11-38.

Guzek D., Glabska D., Pogorzelski G., Kozan K., Pietras J., Konarska M., Sakowska A., Glabski K., Pogorzelska E., Barszczewski J. and Wierzbicka A. (2013). Variation of meat quality parameters due to conformation and fat class in Limousin bulls slaughtered at 25 to 27 months of age. Australasian Journal of Animal Sciences, 26, 716-722.

Hebel P. (2014). Consommateur d'aujourd'hui et de demain. http://www.fnicgv.com/fichiers/20140610181022_1_CREDOC__Pascale_HEBEL__Evolution_du_consommateur.pdf.

Hocking-Edwards J. E., Smith C., Gardner G. E., Pethick D.W. and Ball A. J. (2015). The value of saleable meat yield to lamb processors. International Congress of Meat Science and Technology. Clermont-Ferrand.

Hocquette J.F., Botreau R., Legrand I., Polkinghorne R., Pethick D.W., Lherm M., Picard B., Doreau M. and Terlouw E.M.C. (2014). Win–win strategies for high beef quality, consumer satisfaction, and farm efficiency, low environmental impacts and improved animal welfare. Animal Production science, 54 (10), 1537-1548.

Hocquette J.F., Van Wezemael L., Chriki S., Legrand I., Verbeke W., Farmer L., Scollan N.D., Polkinghorne R.J., Rødbotten R., Allen P. and Pethick D.W. (2014). Modelling of beef sensory quality for a better prediction of palatability. Meat Science, 97, 316–322.

INTERBEV, L'essentiel de la filière viande ovine 2014. http://www.interbev.fr/wp-content/uploads/2014/10/essentiel-filiere-viande-ovine-francaise-2014.pdf.

Legako J.F., Brooks J.C., O'Quinn T.G., Hagan T.D.J., Polkinghorne R.J., Farmer L.J. and Miller M.F. (2015) Consumer palatability scores and volatile beef flavor compounds of five USDA quality grades and four muscles. Meat Science, 100, 291-300.

Legrand I., Hocquette J-F., Polkinghorne R.J. and Pethick D.W. (2013). Prediction of beef eating quality in France using the Meat Standards Australia system. Animal, 7, 524-529.

Lyford C., Thompson J., Polkinghorne R.J., Miller M., Nishimura T., Neath K., Allen P. and Belasco E. (2010). Is willingness to pay (WTP) for beef quality grades affected by consumer demographics and meat consumption preferences? Australasian Agribusiness Review, 18, 1-17.

Małkowski J., Zawadzka D. and i Pasińska D. (2014). Aktualny i przewidywany stan rynku wołowiny. Analizy Rynkowe, październik. pp. 23-35.

Mannion M., Cowan C. and Gannon M. (2000). Factors associated with perceived quality influencing beef consumption in Ireland. British Food Journal, 102, 195-210.

Market Information Services (2105), Meat & Livestock Australia. http://www.mla.com.au.

Mortimer S.I., van der Werf J.H.J., Jacob R.H., Hopkins D.L., Pannier L., Pearce, K.L., Gardner G.E., Warner R.D., Geesink, G.H., Hocking-Edwards J.E.H., Ponnampalam E.N., Ball A.J., Gilmour A.R. and Pethick D.W. (2014). Genetic parameters for meat quality traits of Australian lamb meat. Meat Science 96, 1016-1024.

Pannier L., Gardner G.E., Pearce K.L., McDonagh M., Ball A.J., Jacob R.H. and Pethick, D.W. (2014a). Associations of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb. Meat Science96, 1076-1087.

Pannier L., Pethick D.W., Geesink G.H., Ball A.J., Jacob R.H. and Gardner G.E. (2014b). Intramuscular fat in the longissimus muscle is reduced in lambs from sires selected for leanness. Meat Science, 96, 1068-1075.

Pannier L., Gardner G. E., Pearce K. L., McDonagh M., Ball A. J., Jacob R. H. and Pethick, D.W. (2014 a). Associations of sire estimated breeding values and objective meat quality measurements with sensory scores in Australian lamb. Meat Science, 96, 1076-1087.

Pethick D.W., Ball A.J., Banks R.G. and Hocquette J.F. (2011) Current and future issues facing red meat quality in a competitive market and how to manage continuous improvement. Animal Production Science, 51, 13-18.

Pethick D.W., Banks R.G., Hales J. and Ross I.R. (2006) Australian prime lamb – a vision for 2020. International Journal of Sheep and Wool Science, 54, 66-73.

Pethick D.W., D'Souza D.N., Anderson C.A. and Muir L.L. (eds) (2005) Eating quality of Australian Lamb and Sheep Meats – a special edition for Meat and Livestock Australia. Australian Journal of Experimental Agriculture, Volume 45, Number 5, 465-601.

PKN, 1996. PN-A-82001:1991/Az2: (1996) - wersja polska - Mięso w tuszach, półtuszach i ćwierćtuszach. Warszawa: Polski Komitet Normalizacji.

Polkinghorne R.J. and Breton J. (2013), Qualité des carcasses et des viandes bovines pour le consommateur, Viandes & Produits Carnés, VPC-2013-29-6-6.
http://www.viandesetproduitscarnes.fr/index.php?option=com_content&view=article&id=494:qualite-des-carcasses-et-des-viandes-bovines-pour-le-consommateur&catid=89&Itemid=466&lang=fr.

Polkinghorne R.J. and Thompson J.M. (2010). Meat standards and grading: A world view. Meat Science,86, 227–235.

Polkinghorne R.J., Nishimura T., Neath K.N. and Watson R.K. (2011). Japanese consumer categorization of beef into quality grades, based on Meat Standards Australia methodology. Animal Science Journal, 82, 325–333.

Polkinghorne R.J., Nishimura T., Neath K.N. and Watson R.K. (2014). A comparison of Japanese and Australian consumers' sensory perceptions of beef. Animal Science Journal, 85, 69–74.

Polkinghorne R.J., Philpott J., Gee A., Doljanin A. and Innes J. (2008a). Development of a commercial system to apply the Meat Standards Australia grading model to optimise the return on eating quality in a beef supply chain. Australian Journal of Experimental Agriculture, 48, 1451–1458.

Polkinghorne R.J., Thompson J.M., Watson R., Gee A. and Porter M. (2008b). Evolution of the Meat Standards Australia (MSA) beef grading system. Australian Journal of Experimental Agriculture, 48, 1351-1359.

Polkinghorne R. J. and Thompson J. M. (2010). Meat standards and grading: A world view. Meat Science, 86, 227–235.

Rapport d'information du Sénat n° 784 (2012-2013) de Mme Sylvie GOY-CHAVENT. http://www.senat.fr/rap/r12-784-1/r12-784-1.html.

Scollan N.D., Greenwood P.L., Newbold C.J., Yáñez Ruiz D.R., Shingfield K.J., Wallace R.J. and Hocquette J.F. (2011). Future research priorities for animal production in a changing world. Animal Production Science, 51, 1–5.

United Nations Economic Commission for Europe, 2015. Specialized section on standardization of meat. Eating quality – proposals by the working group.

Watson R., Gee A., Polkinghorne R.J. and Porter M. (2008a). Consumer assessment of eating quality – development of protocols for Meat Standards Australia (MSA) testing. Australian Journal of Experimental Agriculture, 48, 1360-1367.

Watson R., Polkinghorne R.J. and Thompson J.M. (2008b). Development of the Meat Standards Australia (MSA) prediction model for beef palatability. Australian Journal of Experimental Agriculture, 48, 1368-1379.