MAIN PAPER

The future trends for research on quality and safety of animal products

Jean-François Hocquette1, R. Ian Richardson3, Sophie Prache1, Françoise Medale2, Geraldine Duffy4, Nigel D. Scollan5

1 INRA. Centre de Recherches de Clermont-Ferrand/Theix, France
2 INRA. Station d’Hydrobiologie, France
3 Department of Clinical Veterinary Science. University of Bristol, England
4 The National Food Centre. Teagasc, Ashtown, Dublin, Ireland
5 Institute of Grassland and Environmental Research. Aberystwyth, Wales

Corresponding author: Dr. Jean-François Hocquette. INRA, Unité de Recherches sur les Herbivores, Centre de Recherches de Clermont-Ferrand/Theix, 63122 Saint-Genès Champanelle, France – Tel. +33 473 624253; Fax: +33 473 624639 – Email: hocquet@clermont.inra.fr

Paper received May 13, 2005; accepted July 1, 2005

ABSTRACT

Quality must now be considered as a convergence between consumers’ wishes and needs and the intrinsic and extrinsic quality attributes of food products. The increasing number of quality attributes which must be considered, increasing globalisation and the heterogeneity in consumption habits between countries are making this convergence progressively more difficult. In parallel, science is rapidly evolving (with the advent of genomics for instance), and a growing number of applications is thus expected for the improvement of food safety and quality. Among the meat and fish quality attributes, colour is very important because it determines, at least in part, consumer choice. The key targets to ensure a satisfactory colour are animal nutrition and management for fish, processing and product conditioning for meat. Tenderness and flavour continue to be important issues for the consumer because eating remains a pleasure. They both determine quality experience which itself influences repetitive purchase. Meat tenderness is a very complex problem which can be solved only by a holistic approach involving all the factors from conception, animal breeding and production, muscle biology and slaughter practice to carcass processing and meat preparation at the consumer end. Today, safety and healthiness are among the most important issues. Unfortunately, animal products can potentially be a source of biological and chemical contamination for consumers. The introduction of both control strategies along the food chain and the development of a food safety management system, from primary production to the domestic environment, are key issues that must be achieved. Despite a high dietary supply of saturated fats by dairy and meat products, it is imperative that professionals involved in animal research and in the associated industry convey the positive nutritional contributions of animal products to both consumers and health professionals. The latter include protein of high biological value, iron, zinc, healthy fatty acids including omega-3 polyunsaturated fatty acids (PUFA) and conjugated linoleic acid. Fish products are well known for their high content in PUFA. Meanwhile, new strategies in terms of antioxidant supply are required to limit PUFA and cholesterol oxidation, which has many detrimental effects including contributing to reduced sensory attributes. Traceability is another quality attribute used to implement food safety and quality. Traceability of an animal’s breed and identity, of geographical origin and of diet fed are increasingly important issues demanded by consumers. Safety and quality are thus important issues with increasing complexity, research has to adapt itself to meet this challenge.

Key words: Quality, Safety, Meat, Fish, Dairy products.
reduction in the amount of ruminant animal products consumed is recommended due to their high saturated lipid content which is deleterious for human health (Lucas et al., 2005; Valsta et al., 2005). Over the last 30 years, consumption has fallen naturally, though in more recent years any reductions are perhaps temporary in response to some safety crises such as BSE, dioxin issues, foot and mouth disease, etc.

So, while animal production was originally focused on quantity, it has now shifted towards delivering on quality which is high and consistent and improved safety. These are important issues in the European food industry. Quality used to be considered in relation to physical product quality (sensory, nutritional and technological traits, etc). They remain important issues which will be

RIASSUNTO
LE TENDENZE FUTURE DELLA RICERCA SU QUALITÀ E SICUREZZA DEGLI ALIMENTI DI ORIGINE ANIMALE

Oggi la qualità deve essere considerata come una convergenza tra i desideri e le necessità dei consumatori e i requisiti qualitativi intrinseci ed estrinseci dei prodotti alimentari. Tale convergenza è resa sempre più difficile a causa del numero crescente di requisiti qualitativi che deve essere considerato, della globalizzazione e dell’eterogeneità delle abitudini di consumo tra i vari Paesi. Parallelamente, la scienza si sta evolvendo rapidamente (grazie all’avvento della genomica, ad esempio) e si prevede quindi un numero crescente di applicazioni per garantire maggiore sicurezza e qualità degli alimenti. Tra i requisiti qualitativi della carne e del pesce il colore riveste grande importanza, poiché condiziona, almeno in parte, la scelta del consumatore. Le soluzioni principali per garantire un colore soddisfacente risiedono nell’alimentazione e nella gestione degli animali per quanto riguarda il pesce e nella preparazione e conservazione del prodotto per quanto concerne la carne. La tenerezza e il sapore continuano a rappresentare fattori importanti per il consumatore perché mangiare rimane pur sempre un piacere. Entrambi questi requisiti condizionano l’esperienza di qualità del consumatore e ne influenzano la tendenza a continuare ad acquistare un determinato prodotto. La tenerezza della carne rappresenta un problema estremamente complesso che può essere risolto soltanto adottando un approccio olistico che comprenda tutti i fattori che vanno dal concepimento alla riproduzione e allevamento degli animali, alla biologia del muscolo, alla tecnica di macellazione e al trattamento delle carcasse fino ad arrivare alla preparazione della carne da parte del consumatore finale. Oggi giorno la sicurezza e la salubrità rientrano tra i fattori più importanti in assoluto. Sfortunatamente, i prodotti di origine animale possono rappresentare una fonte potenziale di contaminazione biologica e chimica per i consumatori. L’introduzione di strategie di controllo lungo tutta la filiera alimentare e lo sviluppo di un sistema di gestione della sicurezza alimentare, dalla produzione primaria fino all’ambiente domestico rappresentano obiettivi fondamentali da raggiungere. Nonostante un elevato apporto di grassi saturi nella dieta quotidiana provenienti da prodotti caseari e dalla carne, è essenziale che i professionisti impegnati nella ricerca animale e attivi nell’industria del settore rendano noto sia ai consumatori che agli operatori sanitari il contributo nutrizionale positivo apportato dagli alimenti di origine animale. Questi infatti contengono proteine di elevato valore biologico, ferro, zinco, acidi grassi essenziali, compresi gli acidi grassi polinsaturi omega 3 (PUFA) e gli isomeri dell’acido linoleico coniugato (CLA). I prodotti a base di pesce sono già ben noti per il loro elevato contenuto di PUFA. Nuove strategie sono però necessarie per aumentare l’apporto di antiossidanti per limitare l’ossidazione dei PUFA e del colesterolo, compreso la perdita delle caratteristiche organolettiche. La tracciabilità è un altro requisito qualitativo utilizzato per attuare la politica di sicurezza e qualità degli alimenti. La tracciabilità della razza e dell’identità di un animale, dell’origine geografica e della sua alimentazione in allevamento sta diventando un requisito sempre più richiesto dai consumatori. Sicurezza e qualità sono pertanto fattori importanti caratterizzati da complessità sempre maggiore e la ricerca deve adattarsi per fare fronte a questa nuova sfida.

Parole chiave: Qualità, Sicurezza, Carne, Pesce, Prodotti caseari.

Introduction

At the beginning of human history, products of animal origin (harvested by hunting, fishing and milking) were considered as noble food contributing to growth, strength, health and longevity. As agriculture developed, the major objective was to satisfy the food needs of humans quantitatively. This objective was achieved in developed countries, and especially in the European Union, which is self-sufficient for most animal products. The development throughout the human history of the market economy, trades and exchanges within and between countries and continents has also permitted some countries to buy sufficient animal products from others to satisfy the quantitative demand of their own populations. Meanwhile, a reduction in the amount of ruminant animal products consumed is recommended due to their high saturated lipid content which is deleterious for human health (Lucas et al., 2005; Valsta et al., 2005). Over the last 30 years, consumption has fallen naturally, though in more recent years any reductions are perhaps temporary in response to some safety crises such as BSE, dioxin issues, foot and mouth disease, etc.

So, while animal production was originally focused on quantity, it has now shifted towards delivering on quality which is high and consistent and improved safety. These are important issues in the European food industry. Quality used to be considered in relation to physical product quality (sensory, nutritional and technological traits, etc). They remain important issues which will be
addressed in this paper, but quality also includes aspects related to production characteristics (e.g., environmental impact, wholesome) and economic performance of the overall food chain (e.g., minimal costs, service quality, etc).

It is also important to emphasise that not only consumers, but also international and national legislation place demands on quality and safety (probably due to the perceived demand of consumers by the political organisations). Last but not least, the increasing demand for quality and safety traits has induced a proportional increase in traceability which is considered to ensure quality and safety at the consumer end. Although this is not immediately apparent, traceability is now included in quality attributes.

Since the concept of quality is becoming more sophisticated, the first part of this paper will attempt to define this concept and to explain why the demand of quality and safety for food products of animal origin is increasing in the European and the World markets. This has also been discussed recently (Hocquette and Gigli, 2005). The following sections will present the major issues for important basic quality traits, namely (i) sensorial quality (colour, texture and tenderness, flavour and juiciness), (ii) nutritional value, (iii) safety and (iv) traceability. The more important food products of animal origin will be considered (dairy products, meat products and fish) although most of the given examples will be for meat products.

**Quality and safety concepts**

*Why the European characteristics of animal production systems has/will influence(d) quality and safety concepts*

The livestock and fishery systems in Europe have several characteristics which have modified and will further modify, the concepts of quality and safety of animal products. These characteristics mainly relate to the high degree of heterogeneity across the European Union and to difficulties of being included in the global world market. They are sometimes specific for either the meat or the dairy products sectors.

Heterogeneity appears firstly in the structure of agricultural holdings: 60% use less than 5 hectares in Greece, Italy and Portugal compared to 68 hectares on average in the UK; 53% are localised in less favoured areas or mountainous regions, some are mixed holdings (mixed cropping and/or mixed livestock) or specialised holdings with wide variations between European countries. In the case of meat, some countries are more than self-sufficient (350% for Ireland and Denmark) and others in deficit (54% for Greece). Heterogeneity also lies in the different European cultures: Mediterranean countries favour lamb; Scandinavian countries traditionally consume a lot of milk, while consumption of fish and aquatic products has steadily increased over the past decade in all the European countries (FAO data). Milk consumption has however decreased in Scandinavian countries probably due to the link between heart disease and milk consumption in humans. In the case of cattle, some countries (such as France, the UK and Ireland) are strongly oriented towards beef meat production and others (Denmark, Germany, Italy and The Netherlands) towards milk production. Ewe milk is mainly produced in Mediterranean countries, and goat milk mainly in France. This type of production is however important for rural life, especially in mountainous regions, dry areas and some southern European countries. In the case of pig production, contrasting trends have been observed in the different European countries: an increase in Spain despite limitation in feed resources, an increase in Denmark but a decrease in Germany despite concerns about environment issues in both countries, a decrease in the UK due to animal welfare concern and the foot and mouth disease crisis (Aumaitre and Rosati, 2004). Fish is supplied both by fisheries and by fish production. Products from fisheries have remained stable since the seventies while fish production is increasing (28% of world consumption, 13% in Europe) to meet the consumer demand.

The difficulties for the European food economy to be included more in the world market are linked to several factors. They include increasing labour costs and a decrease in labour forces on the farms, a strong deficit in the protein feed supply for animal nutrition, and some specific European legislations concerning animal welfare, environment and
safety issues. Among the latter, strong limitations on the use of feed additives (antibiotics, and any other growth promoters) have been recommended in the European Union in contrast to other countries. Some recommendations have also been given for the rearing conditions of laying hens. The reduction of protein level in the diets of monogastrics is also one of the most efficient solutions in the prevention of soil pollution by excess nitrogen and phosphorus (Aumaitre and Rosati, 2004). But the world market is important for the European economy because the EU is, for instance, among the largest exporters of pork and of dairy products. More generally, international trade issues are continually increasing. This is globalisation, which has brought with it, as side effects, a reduction in the international prices of agricultural products. Opening up international markets and obvious price differentials in different markets have a huge impact on quality attributes of products from animal origin. One major factor is that lifestyle and consumer expectations of food are tending to converge throughout the world. Consequently, players have more and more common tools and criteria to assess the quality and safety of animal products (Aumaitre, 1999), despite cultural, political and economical differences between countries across the world, and even across the European Union as discussed above. Divergences in legislation between countries, occurring concomitantly with developments in international markets, increase the complexity of the problem, as well as the continuous appearance of new products and the evolution of the food science throughout the world. Large differences in food preferences and lifestyle exist between countries. In Europe, for example, these differences in food preferences are important as it is the basis of cultural differences which most importantly helps to maintain the mosaic of farming and food production practices.

The definition of safety and quality

Many experts have attempted to define safety and quality. Safety is often included in the list of quality attributes and refers to the absence of adverse health effects due to the presence of biological and chemical contaminants in food products. Most available definitions of quality refer to consumers, e.g., quality has been defined as “product performance that results in consumer satisfaction and freedom from deficiencies, and which avoids consumer dissatisfaction”. Other definitions state that quality refers to product characteristics which “helps somebody and enjoys a good and sustainable market” or that “quality refers to the degree of standard of excellence, and/or fitness for purpose, and/or the consistency of attainment” of food properties. Quality has also been defined as characteristics of products “that bears on themselves ability to satisfy given needs” (Luning et al., 2002). From these definitions, safety is indeed included in the consumers' needs and therefore in the quality concept. Furthermore, one major difficulty is that the political and/or the commercial organisations have made their own interpretation of what quality means from these different but complementary definitions. An added difficulty is that consumers' needs and wishes differ between countries (including within Europe) as discussed above.

Whatever the definition, most of the experts have also made a distinction between intrinsic and extrinsic quality attributes. The first refers to the product itself and includes for instance, (i) safety and health aspects, (ii) sensory properties (e.g. texture and flavour) and shelf life, (iii) chemical and nutritional attributes and (iv) reliability and convenience. The latter refers to traits more or less associated with the product, namely (i) production system characteristics (from the animals to processing stages including animal welfare, environmental aspects, and social considerations for instance), and (ii) marketing variables (including price, brand name, distribution, origin, packaging, labelling, and traceability) (Luning et al., 2002; Grunert et al., 2004). We will mainly consider intrinsic quality attributes in this paper, despite obvious strong interactions between both.

Some experts have also made a distinction between quality expectation and quality experience. Consumers form a quality expectation when they buy a product, but they form a quality experience upon consumption. Quality expectation determines, at least in part, consumer choice behaviour, while quality experience is of vital importance.
importance for repetitive purchase. Quality expectation is assessed by quality cues which are related to intrinsic or extrinsic product characteristics. Quality experience depends on experience and credence quality attributes. The first are those that can be checked upon consumption (e.g. taste and texture), while credence attributes cannot be verified by the consumers (e.g. healthiness, animal welfare and environment concerns) (Luning et al., 2002). Unfortunately, the number of quality cues and attributes included in this concept is increasing gradually, as well as the interactions between them, complicating research in this area. However, one clear goal of approaching the issue from a scientific point of view is to develop objective measurements of the different quality cues ranging from the impact of animal genetics, husbandry and physiology to the final product characteristics (Figure 1), and especially to convert credence attributes (which cannot be measured) into quality attributes, which can be objectively assessed.

Due to this complexity, a Total Food Quality Model was proposed in an attempt to integrate a number of approaches related to quality at the consumer end (consumer perception, intention of purchase and decision-making and consumer satisfaction) including the intention to purchase a product again, which in turn depends mainly on the relationships between quality expectation and quality experience before and after purchase (Grunert et al., 2004). Because it is impossible to address all the parameters included in this model, only the most important ones among the intrinsic (colour, texture, flavour and juiciness and healthiness) and extrinsic (traceability) quality cues will be addressed in this paper. Attempts will be made in each section to explain why these cues are likely to be the most important ones. As a general example, focus group studies have shown that the strongest quality attributes for beef are taste (flavour), tenderness, juiciness, freshness, leanness, healthiness and nutrition. Whereas before purchase, eating quality and healthiness have the same weight in quality expectation, eating quality has a stronger weight in quality experience during consumption (Grunert et al., 2004). This emphasises the contradictory nature of consumers’ wishes.

Sensorial quality

Colour

In meat and fish, colour is among the first quality attributes taken into consideration by the consumer to assess quality at the time of purchase. It is thus of utmost importance, especially in the case of salmonid flesh for which the orange-red colour is highly expected by the consumer.

Hence, there are different situations when we compare for instance meat and fish.

In meat, colour depends on the content and chemical state of myoglobin, the principal pigment naturally present in meat. Depending on the oxidation state of the haem iron, different myoglobin forms can be found. In the muscle, myoglobin is reduced and thus exhibits a purple colour due to the absence of oxygen. In contrast, at the surface of the meat, myoglobin is in contact with the air and therefore oxygenated (MbO) and it exhibits a bright red colour. However, prolonged storage with air induces oxidation and formation of metmyoglobin resulting in a brown colour unacceptable to the consumer. The pH of meat affects beef colour. A high pH indeed leads to a dark colour due to first a low scatter of light and second a very high rate of oxygen consumption combined with a slow rate of inward diffusion of oxygen into the muscle. This allows for a very narrow band of MbO at the surface and with the greater translucence, light penetrates further into the meat and more is absorbed, making it appear darker. More of that reflected has the appearance of Mb than MbO. This is a serious problem for young bulls which can be stressed easily, meat pH being higher in stressed animals at slaughter due to low muscle glycogen levels. Furthermore, the supplementation of ruminants with selenium and more particularly vitamin E can strongly reduce the rate of myoglobin oxidation (Geay et al., 2001). Modified atmosphere packaging, containing high levels of oxygen to promote colour and carbon dioxide to inhibit bacterial growth, has extended the shelf life of retail meat cuts and allowed producers in many countries to distribute retail-ready packs over greater distances (Tewari et al., 1999). Whilst the high oxygen can eventually impair quality and safety (e.g. rancidity and discoloration of meat)
Figure 1. Quality must now be considered as a convergence of consumers’ expectations and needs with intrinsic and extrinsic quality attributes of food products depending on cultural habits. Today, consumers’ choice and purchase depend on the interaction between economic and social contexts, their perception of quality traits (through quality labels) and the true quality traits of animal products. The latter depends on animal genetics, husbandry and physiology, tissue characteristics and the process of muscle and milk transformation into meat and dairy products. Safety and traceability must be ensured along the whole food chain. Quality and safety are now becoming interdisciplinary approaches with the aim to satisfy consumers.
this is usually not until well beyond the use-by date of the pack. The use of natural antioxidants can overcome some of these problems.

In salmonid flesh, the orange-red colour comes from carotenoid pigments, which must be provided in feed, since fish are not capable of synthesizing these pigments. There are many potential sources of carotenoid pigments: yeast, algae, krill or industrial derivatives such as crab and shrimp offal but these sources result in highly variable pigmentation due to the strong variability in pigment content and bioavailability. The main carotenoid used in aquaculture is astaxanthin sometimes in association with canthaxanthin (depending on EC and local regulations). However supplementation with these synthetic molecules increases the cost of feed by 15 to 30%.

Pigment fixation in the muscle depends on factors such as concentration of the pigment in the diet, level of dietary lipid, digestibility of pigment sources, duration of the supply and the aptitude of the fish to deposit pigments (Choubert, 2001). Deposition of astaxanthin in the muscle increases with the amount of ingested astaxanthin up to a plateau. Consequently, the colour of trout and salmon muscle then tends towards a maximum that cannot be exceeded. Choubert and Storebakken (1989) found that the maximal retention of astaxanthin was 12.5% of the ingested dose in rainbow trout fed a dietary level of 25 mg per kg food. In the EU, the maximum recommended level is 100 mg of astaxanthin per kg of feed. In addition, since carotenoids are lipid-soluble compounds, their absorption is linked to that of lipids. Adding fat to the food favours pigmentation through an improvement of pigment digestibility. The effect of lipid sources on muscle pigmentation is still not clear. According to Choubert (2001), the concentration of astaxanthin in trout muscle would not be affected by the origin of the dietary fat (corn oil vs fish oil). As for meat, diet supplementation with antioxidants such as vitamin E and modified atmosphere packaging are tools to prevent pigment oxidation and changes in colour.

In conclusion, based on these two examples, depending on the animal physiology, the product characteristics and the consumer expectations, colour has to be controlled by different approaches including animal nutrition and management, processing and product conditioning. It is likely that the development of novel animal products due to innovative processing systems will induce new research in this area.

Texture and tenderness

Consumers ranked palatability and tenderness as the most important attributes of meat eating quality, and they can easily distinguish between tough and tender meat. The main source of consumer complaint is low and/or variable tenderness, and this is also the primary cause of failure to repurchase meat. This is particularly true for beef. Unfortunately, despite a great deal of research on the determinants of tenderness, little progress has been made, simply because the factors which affect tenderness are numerous and interact (Maltin et al., 2003). Therefore, present research on tenderness aims to (i) clearly identify the factors and the causes of variation in tenderness, and (ii) identify indicators of tenderness to be able to predict tenderness and to develop methods to improve tenderness.

Factors and causes of variation in tenderness

Large differences in tenderness exist when comparing different muscles from the same bovine animals (Veiseth and Koohmaraie, 2005; Mullen and Troy, 2005). However, less variation, although significant, is observed when comparing the same muscle from different cattle breeds (Hocquette et al., 2005a). From a biochemical point of view, the main factors which determine ultimate tenderness are the background toughness and the tenderization phase.

From existing knowledge, it is clear that variation in the background toughness results mainly from the connective tissue characteristics which exist at the time of slaughter and do not change during the storage period. The indicators which are most often studied are collagen content and solubility. The high variability in collagen content across bovine muscles (from 1% to 15% of dry weight), and especially at the perimysial level, is likely to explain the major differences in toughness between beef cuts. Thus, connective tissue is considered to play a dominant role in toughness where its content is high. Therefore, any factors...
related to the animal itself (e.g. genetic background, production system, physical activity or feeding) which has an impact on the collagen characteristics are widely studied. However, other factors (which remain to be extensively researched) are also important: e.g. thickness of perimysium, spatial distribution and composition of collagen, role of the different collagen isoforms, nature and role of the molecules which determine connective tissue organisation and/or which propagate tensional forces from muscle fibre sarcomeres to the connective tissue (McCormick, 1999; Purslow, 2005).

The tenderisation phase is characterised by a post-mortem proteolysis of muscle proteins. It occurs after the toughening phase caused by sarcomere shortening during rigor development. Different proteolytic systems have been shown to be responsible for the tenderisation process (Sentandreu et al., 2002), but the calpain proteolytic system (with its inhibitor calpastatin) is thought to be mainly responsible for this process (Veiseth and Koohmaraie, 2005). During the early post-mortem phase, glycolysis also occurs bringing about the decline in pH of the muscle, and the rate of this decline is known to regulate proteolysis. Optimum tenderness can be reached within a few hours in chicken, 4 to 6 days in pork and lamb and 10-15 days in bovine muscles. This is associated with the muscle type which is fast-glycolytic in poultry at one extreme and slow-oxidative in cattle at the other. However, within the same species, the relationship between muscle tenderness and muscle type is highly complex and therefore controversial (Maltin et al., 2003). But it was recently shown that slow-oxidative muscles of cattle tenderise as much as fast-glycolytic muscles whilst intermediate (fast-oxid-glycolytic) muscles are significantly tougher (Ouali et al., 2005). This is the reason why a negative correlation was found between tenderness and the proportion of fast-oxid-glycolytic fibers in muscles, although tenderness was also found to be negatively correlated with fibre diameter (Dransfield et al., 2003).

After slaughter, the extent of muscle contraction depends on the rate of the pH decline, residual ATP concentration and temperature of the carcass. Depending on the pH, muscle contraction may be high, when temperatures are low (<10°C) or high (>35°C) causing cold shortening or heat contraction respectively (Thompson, 2002; Savell et al., 2005).

During cooking, a sharp increase in toughness of meat occurs between 40 and 50°C, and then above 65°C. Intramuscular connective tissue contributes to the tension development below 50°C. But its contribution is thought to decrease at higher temperatures and longer cooking times (Purslow, 2005). Others have suggested that the elasticity of whole meat varies with temperature thereby affecting the stress which has to be applied during mastication (Tornberg, 2005). Therefore, the different biological factors described above will act differently depending on the cooking method, and hence cultural habits of consumers.

**Indicators of tenderness and methods to predict or improve tenderness**

It is important for the beef industry to predict beef tenderness in the early post-mortem period as soon as the carcass becomes available in the meat factory. The indicators or the technologies employed so far include biological indicators (pH, colour) or methods to assess the ageing process, such as electrical impedance and conductivity. Some other methods are emerging such as ultrasonics, image analysis, fluorescence and near infrared spectroscopy, or immunoassays to assess proteolysis. Physical methods are widely used, but the correlation between shear force and tenderness depends largely on the breed and the production system (Mullen and Troy, 2005; Dufour, 2005). For meat producers, it is also of interest for rearing or breeding purposes to predict the ability of live animals to produce tender beef. From a genetic point of view, a positive genetic correlation was found between marbling score and tenderness in the USA and Australia where beef toughness is assessed when cooked at high temperature (70°C). This relationship has driven most of the efforts dedicated to improving meat quality in these countries (Hocquette et al., 2005b). At the molecular level, variants of several genes associated with the proteolytic process (the calpain 1 gene and the calpastatin gene) or collagen synthesis (the lysyl oxidase gene) have been shown to be associated with variations in tenderness. However, thanks to the
genome sequencing project and the development of high-throughput genotyping methods, it is likely that more genetic markers will be discovered in the near future (Kühn et al., 2005). From a physiological point of view, it has been shown that tender beef has a lower proportion of fast-oxidative-glycolytic fibres, slower post-mortem glycolysis, lower connective tissue and higher fat contents, which is to be expected based on the existing knowledge described above (Dransfield et al., 2003). But only about one third maximum of the total variability in the final tenderness of beef could be explained by muscle characteristics (Renand et al., 2001). It is commonly agreed that functional genomics will help to identify new genes/proteins and hence muscle molecules which have a significant impact on tenderness (Eggen and Hocquette, 2004; Hocquette et al., 2005a). Some novel genes controlling muscle development (Sudre et al., 2003) or associated with muscle growth potential (Sudre et al., 2005) as well as proteins associated with muscle hypertrophy (Bouley et al., 2005) or tenderness (Bouley et al., 2004) have already been identified. A profile pattern of truly degraded protein would very likely be a more accurate tool to predict the final tenderness.

We have seen that the tenderization rate of beef is particularly slow. This is the reason why it is important to mature beef for a sufficient period (about 10-14 days) to ensure sufficient tenderization and hence a high tenderness. This is highly recommended in France for beef sold with a quality guarantee. Similarly, products within the Meat Standards Australia (MSA) grading scheme cannot be sold to consumers before 5 days post-slaughter, and aging to 21 days increases the consumer score (Pethick et al., 2005). Many leading retailers in the UK also specify a minimum ageing period for quality beef which must also have been electrically stimulated or hip suspended. This induces storage costs and related problems and this has therefore economic consequences for the beef industry. Another difficulty is that tenderization varies considerably between animals. As a result, it is difficult to ensure a consistent tenderness for consumers. Thus, predicting the final tenderness from information relative to the tenderization process is an active subject of research with the ultimate objective of marketing beef of a more constant tenderness. Some methods, such as electrical anisotropy (Lepetit et al., 2002), have the potential to predict meat ageing.

Several tenderness enhancing technologies have been described (Tarrant, 1998; Culioli, 1999). For instance, some research is focused on muscle stretching for improving tenderness (Sorheim et al., 2002). Now, the Tenderstretch method, or pelvic hanging, is widely used in some countries. Electrical stimulation is another method, which involves passing an electric current through the carcass of freshly slaughtered animals. This causes the muscles to contract increasing the rate of glycolysis resulting in an immediate fall in pH, an acceleration in the rate of proteolysis and an alteration in myofibrillar structure. It also prevents muscle from shortening excessively. But the challenge nowadays is to develop more effective electrical stimulation practices (Hwang et al., 2003). On a whole, interventions at the early post-mortem stage remains a key issue.

Cooking method also affects the main factors which have an impact on the eating quality of meat, especially beef tenderness. Thus, cooking method was included in the input factors which drive the palatability prediction model of the MSA grading scheme, which has identified the major Critical Control Points (CCPs) from the production, pre-slaughter, processing and transformation sectors of the beef supply chain. Grilling (25 mm thickness) low connective tissue cuts results in high palatability scores. Roasting low connective cuts is equivalent to grilling. On the contrary, roasting gave a higher palatability scores than grilling for the high connective tissue cuts. Stir frying (10 mm) and thin slicing (4 mm) give similar results to grilling for low connective tissue cuts, but higher scores for the high connective tissue cuts (Pethick et al., 2005). However, we must keep in mind that cooking methods depend largely on cultural habits and ways of life which differ between countries as discussed above.

In conclusion, meat tenderness is a complex function of production, processing and meat preparation. A guarantee for tenderness can only be given if all the factors affecting tenderness are controlled along the meat production chain.
Matching beef genotype, rearing system and processing system is a key challenge to ensure high and consistent tenderness at the consumer level. Modelling muscle characteristics for a beef product quality assurance scheme remains an important objective. The development of new further-processed more convenient-type beef products may change the priority of research in this area.

**Flavour and juiciness**

Tenderness is the most important eating quality attribute of meat in determining its acceptability, but when tenderness is increased, and variability decreased, then flavour and juiciness increase in relative importance (Love, 1994; Warkup et al., 1995). Meat is aged (conditioned) to improve tenderness and flavour but longer conditioning under some packaging conditions produces 'bland' flavours (Spanier et al., 1997). Ageing on the bone is thought to produce different flavours from ageing in vacuum pack, but bone-in meat aged in vacuum had higher beef flavour intensity than that aged on the carcass or boned out and aged in vacuum (Jeremiah and Gibson, 2003). However, in other studies, vacuum storage produced few significant differences (Campbell et al., 2001) and dry ageing produced consistent positive effects on flavour (Warren and Kastner, 1992).

Juiciness is more difficult to quantify and is sometimes combined with tenderness to produce the term 'suculence'. Speculation continues as to the role of fat, particularly marbling fat, in juiciness and flavour. It is the key criterion of the USDA Quality Grade for beef, but Dikeman (1987) concluded that there is only a small positive correlation with tenderness, juiciness and flavour scores and the range of fat levels required to produce significant sensory differences in juiciness or flavour are large compared to modern production practices. Recently, positive genetic correlations were found for juiciness and flavour. Fat and lean lines of lamb, scanned by X-ray computer tomography, differed significantly in muscle density, intramuscular fat and juiciness, as assessed by a trained sensory panel (Karamichou et al., 2005).

It is generally held that the flavour of meat resides in the water-soluble fraction, whereas species-specific flavours are located in the lipid soluble fraction (Mottram, 1998). However, diets such as forages or cereal, which can dramatically change the fatty acid composition of the meat (see following section), can also change the flavour (Elmore et al., 1999a; Elmore et al., 2004). Feeding linseed oil and/or fish oils to beef and lamb produced a higher muscle content of n-3 polyunsaturated fatty acids (PUFA) (18:3n-3; 20:5n-3; 22:6n-3) (Scollan et al., 2001; Cooper et al., 2004). With fish oil in particular, the meat produced was oxidatively more unstable with more abnormal, fishy and rancid flavour notes (Vatansever et al., 2000) and produced many more lipid degradation products upon cooking. Compounds such as n-alkanes, 2-alkenals, 1-alkenols and alkyfurans increased up to 4-fold and most of these compounds were derived from autoxidation of monounsaturated fatty acids and were promoted by increased levels of PUFAs (Elmore et al., 1999b). In a similar study comparing grass- and concentrate-finished animals, the biggest difference was that the concentrate-fed animals had higher concentrations of linoleic acid in their meat and on cooking produced seven compounds at over three times the level found in meat from grass-fed animals, which had much higher concentrations of α-linolenic acid and produced a higher amount of only one compound, 1-phytene (Elmore et al., 2004). Lorenz et al. (2002) quantified meat odour volatiles formed after pressure-cooking meat produced by feeding beef animals forage or concentrate. ‘Green’ odour from meat of grass-fed animals was connected with compounds (hexanals) derived from oleic (18:1cis-9) and α-linolenic acid (18:3n-3), and “soapy” (octanals) from linoleic acid (concentrate fed). Campo et al. (2003) used a trained sensory panel to study the flavour of the individual fatty acids 18:1, 18:2 and 18:3, alone or in combination with cysteine and/or ribose. Meaty aromas were much more pronounced when cysteine and ribose were present, i.e. interactions between Maillard reaction products and fatty acids. The three fatty acids produced different odour profiles and 18:3 in particular produced high scores for fishy and linseed/putty. When cysteine and ribose were present ‘grassy’ was more prevalent especially in the presence of FeSO₄ as pro-oxidant.

These studies could explain the differences
seen by sensory panels for forage- and feedlot-
(cereal) fed beef and lamb (Wood et al., 2003), but
they do not explain the differences for flavour pre-
ference seen in different countries. Whilst this may
be due to familiarity with a certain flavour (vide
infra) there are other explanations. In a US study,
Larick et al. (1987) observed that steers finished
on white clover (Trifolium pratense) had a higher
“grassy” flavour than those fed grass (Festuca
arundinacea) and range-fed animals produced
meat which was not only higher in PUFA but was
also oxidatively more unstable (Larick and Turner,
1990). The authors attributed these flavour diffe-
rences to both the increased content of PUFA, par-
icularly α-linolenic acid in the phospholipid frac-
tion, and its lower oxidative stability. Oxidation
products of fatty acids probably accounted for the
abnormal, unacceptable cooked flavours. Other
studies have found it more difficult to distinguis-
h flavour differences in grain - vs. concentrate-pro-
duced beef meat. Moloney et al. (2001) suggest
that this may be due to other factors than the fatty
acid composition, such as the antioxidant content.
In European studies it has been confirmed that
that feeding fresh, green forages not only promotes
the content of PUFA in meat, but also contributes
antioxidants such as α-tocopherol and β-carotene
to the meat, which stabilise the fatty acids and
make the meat more desirable (Richardson et al.,
2004; Gattellier et al., 2005).
Within more extensive ruminant production
systems, type of forage has been associated with
pastoral flavour in ruminant lean and fat (Young
et al., 2003). The effect of type of forage on flavour
is better documented for sheep. Lambs grazed on
white clover or alfalfa had more intense flavour
than those grazed grass pastures whilst lambs fin-
ished on grass pasture at a slow rate of growth
had more intense flavour than those finished on
pasture at a high rate of growth or on concentrates
(Duckett and Kuber, 2001; Roussett-Akrim et al.,
1997). Whilst the odour/flavour of lamb is due to a
wide range of compounds the characteristic
species flavour is caused by branched-chain fatty
acids (BCFA), resulting from propionate produced
in the rumen, and odour from skatole (3-methylindo-
dole), produced by degradation of tryptophan in
the rumen, particularly the faecal and barnyard
notes associated with those raised indoors (Young
et al., 2003). Culture and meat consumption habits
determine its acceptance with BCFAs being more
responsible for Japanese consumers disliking of
sheepmeat than skatole (Prescott et al., 2001).
Skatole is also found in beef, particularly animals
finished on grass or conserved forages, though its
role seems to be less important in beef than sheep.
Recent data suggests that skatole is not a negative
contributor to flavour as it is for example in pork
meat (Lane and Fraser, 1999; Whittington et al.,
2004). Skatole has been identified as the faecal taint
in milk from cows fed Lepidium spp. (Park, 1969).
It is of note that studies on milk and cheeses
(e.g. Saint-Nectaire-type in France) have shown
that changes from pasture to concentrate feeding
will produce paler, whiter, less well appreciated
butters and cheese. Differences in cheese favour
were noted between winter and summer produc-
tion, between high mountain and lowland pas-
tures and even from north and south facing slopes
(Coulon et al., 2004).

The role of breed in flavour development is
contentious. Breed effects on eating quality, par-
ticularly flavour, are usually small and where they
exist are related to differences in fatness, with fatter
animals generally tending to have higher
flavour intensity scores (Laborde et al., 2001;
Chambaz et al., 2003). It is often assumed that the
traditional beef breeds, such as Aberdeen Angus,
have the best flavour and dairy breeds the worst
although there is little scientific evidence for this.
In one study, no difference was found between
Holstein-Friesian steers and Welsh Blacks
(Vatansever et al., 2000), whilst in another, Koch et
al. (1976) found that Jersey and South Devon
crosses produced more tender and juicy meat than
that from traditional beef breeds. This is possibly
because in dairy breeds taken to the same level of
finish, intramuscular fat is higher. Martinez-
Cerezo et al. (2005) compared three Spanish
breeds (Rasa Aragonesa, a local meat breed,
Churra, a dairy breed and Spanish Merino, a spe-
cialised meat breed) at different slaughter weights
and after different periods of aging of the meat in
vacuum pack. Lamb odour and intensity
increased with slaughter weight, with the highest
score for Rasa Aragonesa. Off-flavour was highest
for Rasa Aragonesa and increased with ageing times. Juiciness was influenced by breed, age and conditioning, with the lightest Churra and heaviest Spanish Merino producing the juiciest meat.

In lambs, diet appears to have a greater effect than breed and differences in flavour, explained by higher concentration of 18:3 in animals fed grass and 18:2 in animals fed concentrates, appear to be more intensive in lamb. Cross-bred Suffolk’s finished on lowland grass or concentrates were compared with Soay, finished on lowland grass, and Welsh Mountain finished on upland flora (Fisher et al., 2000). The grass-fed animals showed typical fatty acid compositions with elevated 18:3n-3 and long chain polyunsaturated fatty acids (PUFA), but Soay had more than double the amount of 18:2n-6 than other grass-fed breeds and the same as the Suffolks fed concentrates, despite being less fat overall. Flavour characteristics were similar for lamb chops from Welsh Mountain and Suffolks fed grass, which differed from Soay and Suffolks fed concentrates. The latter had low scores for flavour and high scores for abnormal flavour, metallic, bitter, stale and rancid. Soay also had a high score for livery, sometimes scored highly for beef, and may be related to its leanness, darker colour and higher myoglobin content.

Flavour is not only a desirable attribute of meat, but its particular nuances must be familiar to the consumer. The UK exports carcasses from small breeds of lamb to Spain where carcasses are often obtained from early-weaned milking breeds, but these UK carcasses will be older, grass-finished and of stronger flavour. Whilst British and Spanish panels described Welsh and Spanish lamb meat to the same order of magnitude for texture and strength of flavour, the panels showed preference for familiar flavours. The Spanish panel preferred Spanish lamb and the English panel, English lamb (Sanudo et al., 1998). A similar conclusion was drawn when Japanese and New Zealand consumers tested New Zealand lamb (Prescott et al., 2001). Results are much clearer than those found for beef. If members of the EU are to trade in meats on the world market; then not only must the quality of such products in terms of texture, juiciness and flavour, be of a high standard, but flavour, in particular, from their production systems must be familiar or acceptable to the flavour preferences of consumers in the target market.

Nutritional value

Healthiness of human beings depends on the balance between dietary intake and quantitative and qualitative needs of individuals. Obviously, healthiness is linked to the quantitative amount of ingested food products and their individual nutritional value. This is the reason why some food products are suggested to be used in moderation only despite their high sensory value or low price for instance. This is also the reason why many countries (such as the USA, Italy, Scandinavian countries, Germany in association with Austria and Switzerland, the United Kingdom, France, the European Union, etc) have produced nutritional references to assess the nutritional quality of current dietary intakes of populations, to determine their adequacy for physiological requirements, depending on age, physiological status, physical activity, etc, or to modify existing diets and food products and even to conceive novel diets of food products to satisfy these requirements.

Nutritional quality of food per se is related to its nutrient content, their bioavailability and their ability to meet the human requirements. For instance, fish flesh has a high nutritional value because it contains highly digestible protein (17 – 22 g/100 g wet weight) with a well balanced amino acid profile, it is also rich in free amino acids (1.3 to 3.8 g/100 g) and low in collagen (3 to 10 g/100 g compared to 16 to 28 g/100 g in beef meat) and supplies a variety of minerals, vitamins and essential fatty acids (Médale et al., 2003). Traditionally, meat and milk have also been considered to be highly nutritious and valued foods. The importance of meat as a source of high-value protein is well accepted. For instance, all muscles have a similar amino acid profile (except those rich in connective tissue) which is not far from the human’s requirement (Culioli et al., 2003). Traditionally, meat and milk have also been considered to be highly nutritious and valued foods. The importance of meat as a source of high-value protein is well accepted. For instance, all muscles have a similar amino acid profile (except those rich in connective tissue) which is not far from the human’s requirement (Culioli et al., 2003). Traditionally, the milk proteins are of high nutritional quality due to their favourable composition in essential amino acids (Lucas et al., 2005). This is of utmost importance because the major portion of dietary proteins comes from animal products (65%
in France in 1995, half by meat and meat products, 35% by dairy products and 8% by fish and sea products). Furthermore, the digestibility of these proteins is high compared to plant proteins. Additionally, meat, fish and milk are recognised as important sources of micronutrients (including for example calcium, immunoglobulins, bioactive peptides, sphingolipids, vitamins A, B6, B12, C, D, E, iron, zinc and selenium).

However, a number of negative factors (such as high fat and saturated fat content, associations between red meat and cancer and non-nutritional issues such as animal health scares, BSE, foot and mouth disease) have played down the many positive nutritional attributes of meat and milk. In particular, health concerns have been targeted at the fat content and fatty acid composition of meat and milk. Fat in these raw food materials provides essential fatty acids and vitamins to the consumer and for example, in meat, fat plays an important role in the sensory perception of juiciness, flavour and texture (Wood et al., 2003). However, there is a perception among consumers that meat (in particular red meat) and milk are foods with a high fat content rich in saturated fatty acids (SFA) which is considered to contribute towards certain human diseases. Finally, while the protein level and amino acid profile of fish and meat are nearly constant, the micronutrients content, lipid level and fatty acid composition are greatly affected by feed composition and rearing factors of the animals. This emphasises the responsibility of agricultural practice in providing animal products of high or low nutritional value.

In addition, consideration must be given to the target consumer base when considering routes for exploiting research about nutritional value of food. The concept of “functional” foods has increased in recent years. The term functional foods is a generic term used to describe foods or food components that have beneficial effects on human health above that expected on the basis of nutritive value (Milner 1999). Such products are targeted at disease prevention and are aimed at healthy people. Omega-3 and/or CLA enriched products would make a valuable consideration in this respect and indeed in some countries the dairy industry has been progressive in developing such products. The problem with this approach is that it will only target a limited consumer base and largely those who can afford to pay for such products. However, in terms of health maintenance and disease prevention in the wider consumer base, it is more appropriate to consider application of this research to improving the healthiness of ruminant products in general.

Recent guidelines from the World Health Organisation and the Food and Agriculture Organisation emphasise the importance of maintaining a balanced diet in helping to reduce the incidence of non-communicable diseases such as obesity, type-2 diabetes, cancer and cardiovascular disease (WHO, 2003). For fat it is recommended that total fat, SFA, n-6 polyunsaturated fatty acids (PUFA), n-3 PUFA and trans fatty acids should contribute < 15-30, < 10, < 5-8, < 1-2 and < 1 % of total energy intake, respectively. Within these targets reductions in the intake of SFA (which are known to raise total and low-density lipoprotein cholesterol) and increases in the intake of unsaturated fats (in particular the omega-3 PUFA which are known to be beneficial to in human health and disease prevention; Simopoulos, 2001; Leaf et al., 2003) are important issues.

The total fat content of raw meat and milk typically ranges between 1-8 g/100 g food and is influenced by a variety of factors including for example animal breed, diet, age. However, the fat content of meat and dairy products ranges considerably from typically 1-5% in raw muscles depending on the species (chicken, pigs, cattle) (Culioli et al., 2003), 10% in low fat sausages, 20-35% in most cheese varieties (Lucas et al., 2005) to 40-50% in salami. Ruminant fat typically contains a high proportion of SFA (40-60 %; largely as a consequence of microbial biohydrogenation within the rumen) and monounsaturated fatty acids (MUFA; 30-50%) and small amounts of PUFA (5%). Oleic acid (18:1n-9) is the most prominent MUFA, with the remainder of the MUFA consisting of a high proportion of SFA (40-60 %; largely as a consequence of microbial biohydrogenation within the rumen) and monounsaturated fatty acids (MUFA; 30-50%) and small amounts of PUFA (5%). Oleic acid (18:1n-9) is the most prominent MUFA, with the remainder of the MUFA occurring mainly as cis and trans isomers of 18:1. Linoleic (18:2n-6) and α-linolenic acids (18:3n-3) are the main PUFA. Generally, the PUFA and MUFA are regarded as beneficial for human health and there is even recent evidence of positive effects of 18:1 trans-11 (Clift et al., 2003), though other work suggests negative effects (Clifton et al., 2004). The predominant SFA are
14:0, 16:0 and 18:0. As mentioned above, there are concerns about the effects of SFA on plasma cholesterol, though 18:0 is regarded as neutral in this regard. Myristic acid (14:0) is regarded as more potent than palmitic acid (16:0) in raising plasma lipids. Meat and milk products from ruminants are also the main dietary sources of conjugated linoleic acid (Ritzenthaler et al., 2001), which have being identified as processing a range of health promoting biological properties including anticarcinogenic activity of the dominant CLA in milk and meat, the cis-9, trans-11 isomer. Poultry and pork contain higher levels of unsaturated fatty acids and PUFA than ruminant products (Wood et al., 2003).

In most European countries, the consumption of higher levels of total SFA and fat intake is associated with meat and milk products (Valsta et al., 2003). This has contributed towards a more negative image for these products. However, meat contains significant amounts of beneficial n-3 PUFA, particularly α-linolenic acid (18:3n-3) but also the long chain PUFA, eicosapentaenoic acid (EPA; 20:5n-3) and, docosahexaenoic acid (DHA; 22:6n-3). This is the reason why a great deal of research has been conducted to manipulate the fatty acid composition of meat. Higher amounts of EPA and DHA are commonly found in fish and sea products.

In fish, numerous studies have demonstrated that the fatty acid profile of the diet has a strong impact on the fatty acid profile of the lipid deposited in muscle. However the variation in flesh fatty acid content is typically less pronounced than that of diet (Bell et al., 2003; Régost et al., 2003a). As aquaculture consumes a large proportion of the fish oil available on the market, alternatives to fish oils in fish diets have received considerable attention in recent years, but the fatty acid composition of vegetable oils differs considerably from that of marine fish oils. Substitution of fish oil by vegetable oils in the feed dilutes EPA and DHA levels in fish flesh and increases the content in 18:2n-6 with consequences on taste, healthy values and consumer acceptance. A promising feeding strategy to reduce the use of fish oil for aquaculture without compromising the fatty acid profile of fish flesh is the return to a fish oil diet some weeks prior to slaughter (Bell et al., 2003; Régost et al., 2003a; Régost et al., 2003b). According to an ongoing study performed in the scope of the European research project RAFOA (Corraze et al., personal communication), feeding rainbow trout, previously fed for 9 months on a 100% vegetable oil (rapeseed or linseed oil), on a fish oil diet for 3 months restored 80 % of DHA and EPA but wash out of 18:2n-6 was less efficient. Further research is needed to find the right balance in order to produce fish with the desired fatty acids profile.

Despite the great interest of fish products, meat and milk are, however, a significant source of n-3 PUFA for many people since consumption of oily fish is low (British Nutrition Foundation, 1999). Research has focused much attention on methods of enhancing the nutritional value of milk and meat by further increasing n-3 PUFA and CLA (Lock and Bauman, 2004; Scollan et al., 2005; Wood et al., 2003). The main approach employed in these studies is based on modifying the animal diet by enhancing the intake of MUFA and/or PUFA provided as (1) fresh and ensiled forages (i.e. grass), (2) oils and oilseeds (i.e. sunflower, linseed), (3) fish oil and marine algae. In ruminants, because dietary lipids are extensively modified in the rumen, this research is contributing towards an increased understanding of the relationships between diet, rumen fermentation, lipid metabolism and incorporation of beneficial fats into lipid in muscle and milk. The fatty acid composition of meat and milk products have also been modified during processing by adding vegetable oils leading to improvement in nutritional value (Valsta et al., 2005). Both these approaches help to improve the nutritional value of meat and milk and it is important that efforts continue to seek consumer acceptable approaches for further improvements. This work has contributed towards an increased awareness that these foods do contain micro-components which may confer beneficial effects on health maintenance and disease prevention.

Among the lipid soluble vitamins, tocopherols are of major interest because their main function is to protect tissues unsaturated fatty acids against oxidation by blocking the free radicals reaction chain. Oxidation of fish lipids is a major problem of flesh quality due to its high content of PUFA which are very sensitive to oxidation: it can...
decrease the nutritional value of the product by lowering the PUFA content, producing off-flavour compounds and modifying texture and colour by oxidizing pigments. Several studies conducted in different fish species demonstrated that deposition of lipid-soluble vitamins such as vitamin E in the muscle was dependant on the dietary supply (Frigg et al., 1990; Bai and Gatlin, 1993; Sigurgisladottir et al., 1994). Fish muscle enriched in vitamin E by increasing dietary tocopherol level has an improved oxidative stability during storage (Frigg et al., 1990; Bai and Gatlin, 1993; Baker, 2001). The main source of aroma in fish being the compounds formed by the oxidation of PUFAs, increasing the concentration in vitamin E in the feed leads to a reduction in the “fishy” aroma of fish fed high fat diets (Chaiyapechara et al., 2003). Similarly, lipid oxidation is also a problem during storage of meat or milk fats. For meat, lipid oxidation induces unpleasant tastes and odours and is associated with changes in colour, and with the potential formation of toxic compounds. For milk, spontaneous oxidised flavours develop when fats are oxidised. Fat oxidation is reduced by the presence of endogenous antioxidative enzymes present in milk and meat, and also by antioxidants (such as lactoferrin, vitamins C and E and carotenoids in milk, or vitamin E and histidine-containing dipeptides (i.e. carnosine and anserine) in meat). New strategies in terms of antioxidant supply should be developed especially when animal products are enriched in PUFA (Durand et al., 2005).

Safety

The importance of safety as a food attribute has increased significantly in recent years and the integrity of the food chain is now a priority for the agri-food sector. Microbial infections related to foods of animal origin, alone impose a substantial public health and economic burden on society. In addition, there are concerns about the long term effects on public health from exposure to chemical residues though the food supply and despite current controls related to removal of spinal cord and associated tissue there remains fears about exposure to prion material. This section will focus on safety issues related to microbial contaminants only.

Primary production

It is well documented that many potentially harmful pathogens (Salmonella, Verocytotoxigenic E.coli in particular E. coli O157:H7, Listeria monocytogenes, Campylobacter, Cryptosporidium parvum and others) can be carried by animals and shed in their faeces. In the environment, not only in faecal material but also in the underlying soil and grass, many pathogens survive for extended periods ranging from several weeks to many months. This provides an important transmission route for pathogens within herds, farms, the fresh food chain, water courses and the wider environment. Some farm management practices have been shown to affect the general carriage and spread of pathogens. In particular, the provision of clean (non-contaminated) feed and water and reduction in stock, housing and grouping densities will reduce the prevalence of pathogens within herds. Manipulation of diet pre-slaughter can alter the gut flora and can affect rates of faecal shedding (Van Baale et al., 2004). Alternative future strategies to reduce the prevalence of pathogens in food animals could involve immunisation with a view to preventing colonisation and carriage (Potter et al., 2004) or the incorporation of probiotics into animal feed (Schamberger et al., 2004). Undesirable faecal shedding of pathogens by all animals is increased by transport stress and is a particular problem if animals are transported long distances in confined spaces or held in lairage for prolonged periods.

Salmonella is the second most common cause of bacterial food borne illness and pigs are recognised as an important vector. Recognising this, many EU countries have national control programmes for Salmonella in pig herds based on establishing Salmonella status of herds. An ELISA method is used to tests for antibodies to Salmonella in the meat juice at slaughter and results in a herd categorisation status (1-3) based on the percentage of the herd which test positive. A positive test indicates that the pig has been exposed to Salmonella at some point within the last two months and provides the starting point for further investigations and either specific measures are taken at slaughter or specialist advice is given to farmers about measures to control Salmonella on-farm.
Slaughter

Pathogens maybe present in the gut and faeces of food animals presented for slaughter. During the slaughter evisceration process, these enteric organisms may be transferred to carcasses from the intestines, stomach contents, oral cavity or oesophagus. The risk of faecal contamination on the carcass at this stage of slaughter can be reduced by specific procedures including "rodding" (a technique used to separate the oesophagus from the trachea and diaphragm). Bagging and tying of the bung can also help prevent contamination of the carcass. In addition, gut micro-organisms in the faeces can contaminate the hide (cattle) or fleece (sheep) and it is generally accepted that the amount of faecal material adherent to animals delivered to abattoirs significantly influences the levels of microbial contamination on derived carcasses. Removal of hides should be carried out in a manner that avoids contact between the hide and the carcass. This can be achieved by a number of measures including the use of hide pulling equipment and using clean equipment (immersion of knives in water at 82°C) for the dehiding operation.

Because of the risk of transmission of E. coli O157:H7 from cattle faeces and hides, many EU countries have implemented "clean cattle policies", which aim to reduce the level of contamination on carcasses and derived raw meat products. The level of faecal material on the animal hide is judged by visual ante-mortem inspection. Subsequent strategies for the processing of dirty animals may include the rejection of animals with excessively dirty hides, washing of the animals, hide trimming or clipping, slaughter of dirty animals at the end of the kill period or reducing the speed of the slaughter line.

Intervention steps used to decontaminate carcasses include cold (10-15°C), warm (15-40°C) or hot (75-85°C) water washing, organic acid sprays (acetic, lactic), steam pasteurisation or combinations of these procedures. While organic acids are widely used in the USA, they are not permitted under EU regulations for beef carcass decontamination.

Meat products

The comminution of whole raw meats to produce burgers, steak tartar etc., distributes the initial surface contamination throughout the derived product. Commonly used additives for raw meat such as 3% sodium lactate, have no significant effect on the survival of E. coli O157:H7. Therefore the primary control measure remains adequate cooking of the product or stringent hygiene in the case of streak tartar. Fermented meat products are normally rendered microbiologically safe by a combination of factors including pH reduction, end products of fermentation and a range of other additives. E. coli O157:H7 have a greater ability than other enteric organisms to survive the low pH of such products and pose a particular risk. Concerns in relation to the survival of E. coli O157:H7 have led to the recommendation that the processes for such ready to eat meats should achieve a log_{10}5.0 cfu/g decline in numbers of this pathogen. It is difficult to manipulate the intrinsic factors in the fermentation process to achieve this target and additional hurdles in the process such as the inclusion of a heat treatment step are most successful (Riordan et al., 2000).

Dairy products

Many cases of microbial infections have been linked to the consumption of raw milk and derived products. Pasteurised milk and dairy products have been implicated in human infections but only where inadequate pasteurisation or post process contamination was reported. In hard cheeses, the additional process hurdles including the low water activity and pH as a result of the curing process, and the differences in the competing microflora reduces the potential for survival or growth of pathogens in this product compared to high moisture soft and semi-soft cheeses. Listeria monocytogenes and E. coli O157:H7 in particular pose a risk in soft unpasteurised cheeses (Sanan et al., 2004) and immunocompromised people are advice not to consume such products.

Regulatory issues

Following the publication of the White Paper on food safety in 2000 the EC carried out a major review of the hygiene directives. The numerous directives developed ad hoc since 1964 intermingled different disciplines, including hygiene, ani-
mal health and official controls. The existence of different hygiene regimes for products of animal origin and other food have led to a detailed and complex regulatory situation. Discussions and negotiations on new legislation, generally referred to as the Hygiene Package (H1 to H5) have been ongoing for a number of years and are now being finalised. This new hygiene legislation, applicable as of January 1st 2006 will be more streamlined. Hygiene 1 sets out the rules applicable to all food businesses from farm to sale to the consumer and places primary responsibility for the safety of food on the food producer. Hygiene 2 details specific hygiene rules for food of animal origin. Hygiene 3 details the official controls for products of animal origin and H4 sets down animal health rules for food animals. Hygiene 5 repeals the 17 existing directives while leaving the implementing decisions in force. Issues within these new directives which will significantly impact on the food sector include HACCP being legally mandated for all food business and changes to microbiological criteria for fresh foods including a new requirement to test for *Salmonella* on fresh meat species.

It is and will remain for the foreseeable future a challenge for global, EU and national policy makers, the regulatory authorities and the food industry to reduce the burden of microbial food borne illness from both known contaminants and those which are emergent or may emerge in the future. It is now well recognised that the best way to address this challenge is to design food safety management systems based on the principles of risk analysis linking an acceptable public health risk to food safety objectives and set microbial criteria for the food producer to achieve.

**Traceability**

Traceability is an important component of quality policy in agribusiness. It is defined by the international standard ISO 8402 as ‘the ability to trace the history, application or location of an entity by means of recorded identifications’. This definition covers both the origin of the entity, i.e. traceability back to the origin, and the mode of production of this entity, i.e. traceability of the processes. Traceability back to the origin refers to an animal’s identity, breed and geographical origin, which are often important considerations for quality labels. Traceability of process refers to production systems, including feeding diets, processing and conservation processes and any adulteration of products. Traceability was initially mandatory only within the general framework of the certification of protected denomination of origin (PDO) status, and was used to differentiate niche market products. However, since the BSE crisis, it has also been used to implement food safety. There is currently an increasing consumer demand for information and guarantees concerning the mode of production of animals, and particularly animal feeding diets. Bodies operating product certification systems also require control tools, to be able to guarantee objectively that specification commitments have been fully met. Being able to trace the feed given to animals is therefore a major challenge for scientists, monitoring and commercial entities and farmers. This section deals mainly with traceability of feeding diet, and also gives some insight into traceability of geographical origin, but see San Cristobal-Gaudy et al. (1999) for traceability of animal’s identity and Rouzaud et al. (2000) for traceability of animal’s breed.

**Potential tracers and approaches**

Efforts have recently been made to develop analytical tools to quantify specific compounds in the product, or the animal tissues and fluids that can act as tracers of the animal’s feeding diet. Four approaches have been investigated to provide information on the feed given to herbivores: (i) plant biomarkers, coming directly from the diet, (ii) metabolic markers derived from animal metabolism, (iii) physical markers, and (iv) global approaches. Plant biomarkers such as carotenoids and terpenes, animal metabolites such as 2,3-octanedione, skatole, fatty acids and ratios of oxygen-, carbon- and nitrogen-stable isotope, are potential tracers in meat and milk or animal tissues, of animal feeding diets. Phenolic compounds also recently proved their usefulness in successfully discriminating milks obtained from cows fed different diets (Besle et al., 2005) and an experimental evaluation of these compounds for meat is warranted. Terpenes, phenolic compounds and
ratios of stable isotope are also potential tracers of the geographical origin of milk and meat. Full details of the corresponding analytical methods can be found in Prache et al. (2003a; 2003b) for carotenoid pigments, in Besle et al. (2005) for phenolic compounds, in Priolo et al. (2004) and Cornu et al. (2005) for volatile compounds (terpenes, 2,3-octanedione and skatole), in Piasenter et al. (2003) and Renou et al. (2004a; 2004b) for the isotopic composition of the water and fat of tissues and products and finally in Loor et al. (2005) and Aurousseau et al. (2004) for the fatty acid composition of dairy products and of the meat.

Global approaches, especially near infra-red spectroscopy (Cozzolino et al., 2002) and functional genomics (Cassar-Malek et al., 2005) are just emerging and need further experimental evaluation.

Some leading examples and results in meat and dairy products

These techniques have already allowed the discrimination of products obtained in contrasting feeding conditions. In dairy cows, a research project of the INRA Research Centre of Clermont-Ferrand/Theix has been developing analytical techniques to distinguish animal feeding diets in milk and cheese (Martin et al., 2005). Terpene profiles from dairy products (milk and cheese) proved effective in identifying the presence of diverse grassland types in the feed. Beta-carotene content or measurement of the reflectance spectrum of milk and cheese can distinguish ‘maize silage’ or ‘hay and concentrate’ products from ‘grass silage’ or ‘grazed grass’ products. Milk fatty acid composition gave valuable information to single out the concentrate-rich diets from the others. Nevertheless, those individual compounds offer only a partial solution in distinguishing one diet from another. In a trial where cows were fed with six different diets (rich in concentrates 65% of the diet-, based on maize silage, ryegrass silage, ryegrass hay, native mountain hay and native mountain grazed pasture), the best results were obtained by combining analyses of terpenes compounds and fatty acids, which allowed successful categorization of 100% of the milk.

In lamb meat, we have undertaken at the INRA Research Centre of Clermont-Ferrand/Theix a project to find tracers for grass-feeding in lamb (Prache et al., 2005). We compared lambs fed either exclusively grass at pasture or a diet containing 85% concentrate and 15% hay indoors (besides maternal milk for both groups). The feeding level of stall-fed lambs was adjusted to achieve similar growth patterns in both treatments until slaughter. In these studies, carotenoids in the blood and in the perirenal fat, terpenes and 2,3-octanedione in the fat, and fatty acid composition of the meat all made it possible to distinguish between grass-fed and stall-fed animals. Grass-fed lambs had 5 to 6 times more carotenoids in their blood, 2.4 to 4.1 times more lutein in their perirenal fat (Prache and Theriez, 1999; Priolo et al., 2002; Prache et al., 2003a; Prache et al., 2003b) and 25 times more 2,3-octanedione in their fat than stall-fed lambs (Priolo et al., 2004). The (n-6)/(n-3) ratio in total lipids was tripled in concentrate-fed lambs compared with the grass-fed lambs (Aurousseau et al., 2004).

In beef cattle, the French production system ‘Beuf Fin Gras Du Mezenc’, which qualifies for PDO status, is committed to keeping the concentrate consumption below a set limit (700 g/100 kg liveweight per day). It has recently been demonstrated that the spectral characterization of the faeces using NIRS can be used successfully to control this specification commitment (Noziere et al., 2005). Six heifers were fed 2, 4 or 6 kg concentrate/day (+ hay so that total feed per day was 9 kg) in a latin-square design. After a two-week adaptation period, samples of faeces were taken every 6 h over a 48 h period to account for maximal variability, and scanned in a NIRS instrument in a reflectance mode. Principal component analysis of optical information showed differences in faeces resulting from the different diets, that permitted satisfactorily authentication that the specification commitment has been fully met.

In conclusion, these examples indicate that it is possible to determine the diet which herbivores have received using analytical methods that quantify direct or indirect tracers in the product or the animal tissues. Results also show that the combined use of different tracers and tissues may be useful. These methods were however developed using a relatively small number of animals and
they are currently being validated with a much larger number of animals. A validation procedure is essential because between-animal variability can be high, and the ability to accumulate potential tracers may include a genetic component. Further research is also directed at elucidating the sources of variation of the animal’s response and the quantification of their effects, studying the latency of appearance and persistence of tracers in the case of modification of animal diet (Prache et al., 2003a; Prache et al., 2003b; Noziere et al., 2004), and addressing the potential sources of bias and fraud.

Conclusions

Since consumers’ expectations are the basis of the quality definition, food quality is more and more a social concept, although biological sciences are essential to characterise animal products, and technical sciences to improve quality attributes (Figure 1). Fundamental research is also important to understand the underlying biological and physical mechanisms and to suggest new techniques with a quality improvement.

Eating quality is an important determinant of food choice. If the product does not look attractive, does not smell good or does not taste good, the consumer does not purchase it despite its nutritional and health value. Therefore, sensory quality remains a research priority. Generally, the question of sensory quality (for instance colour and tenderness for meat) must now be studied by systemic approaches due to the complexity of the problem. Research must continue to focus on methods of improving the nutritional value of fish, meat and milk and associated products. This work helps to provide novel approaches which may contribute to product differentiation in the market place, helping to add value across the food chain. Consumer communication is also essential to correct consumer and medical myths and to increase awareness of new information on the enhanced properties of a wholesome food.

The importance food safety has been considerably increased during the last decade due, at least in part, to recent crises such as BSE and foot and mouth disease. In reality, the incidence of these problems in terms of human health is very low, whereas contamination by pathogens (such as E. coli O157:H7, Listeria or Salmonella) and by chemicals is the main source of safety problems. Traceability is another quality attribute with increasing importance. Consumers request more detailed information from "the farm to the fork" in order to be able to choose the best products which suit individual needs and expectations.

To summarise, quality and safety issues are increasingly complex problems to solve. We are now in a situation where nutrition has evolved from the prevention of inadequacy (due to the decline in nutritional deficiency) to the issue of health promotion (decreasing of the risk of diseases such as cancer, vascular diseases or diabetes which are on the rise in our society), while eating remains not only a need but also a pleasure. Therefore, current research should be more interdisciplinary (including social, economical and nutritional sciences) to meet the new challenges of society. Important points to consider are the amount of food eaten by individuals, the different typologies of consumers and the dietary diversity associated with a sound way of life, which form the basis for healthiness.

REFERENCES

AUMAÎTRE, A., 1999. Quality and safety of animal products. Livest. Prod. Sci. 59:113-124.
AUMAÎTRE, L., ROSATI, A. 2004. Development of livestock system in Europe. In: A. Rosati, A. Tewolde and C. Mosoni (eds.) WAAP Book of the year 2003, A review on developments and research in livestock systems. Wageningen Academic Publishers, Wageningen, The Netherlands, pp 47-60.
AUROUSSEAU, B., BAUCHART, D., CALICHON, E., MICOL, D., PRIOLLO, A., 2004. Effect of grass or concentrate feeding systems and rate of growth on triglyceride and phospholipid and their fatty acids in the M. longissimus thoracis of lambs. Meat Sci. 66:531-541.
BAI, S.C., GATLIN, D.M., 1993. Dietary vitamin E concentration and duration of feeding affect tissue alpha-tocopherol concentrations of channel catfish (Ictalurus punctatus). Aquaculture 113:129-135.
BAKER, R.T.M., 2001. The effect of certain micronutrients on fish flesh quality. Chpt. 16 In: S.C. Kestin and P.D. Warriss (eds.) Farmed Fish Quality. Blackwells Science, Oxford, UK, pp 180-191.
BELL, J.G., MCGHEE, F., CAMPBELL, P.J., SARGENT, J.R., 2003. Rapeseed oil as an alternative to marine...
fish oil in diets of post-smolt Atlantic salmon (Salmo salar): changes in flesh fatty acid composition and effectiveness of subsequent fish oil "wash out". Aquaculture 218:515-528.

Bouley, J.M., La Maison, J.L., Dujob B., Pradel, P., Fraisse, D., Viella, D., Martin, B., 2005. Flavonoids and other phenolics in milk as a putative tool for traceability of dairy production systems. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 345-350.

BOULEY, J., MEUNIER, B., CULIOLI, J., PICARD, B., 2004. Analyse protéomique du muscle de Bovin appliquée à la recherche de marqueurs de la tendreté de la viande. Rec. Rech. Ruminants 11:87-89.

BOULEY, J., MEUNIER, B., CHAMON, C., DESMET, S., HOQUETTE, J.F., PICARD, B., 2005. Proteomic analysis of bovine skeletal muscle hypertrophy. Proteomics 5:490-500.

BRITISH NUTRITION FOUNDATION, 1999. Meat in the Diet. London: British Nutrition Foundation.

CAMPBELL, R.E., HUNY, M.C., LEVES, P., CHAMBERS, E. 2001. Dry-aging effects on the palatability of beef longissimus muscle. J. Food Sci. 66:196-199.

CAMPO, M.M., NUT, G.R., WOOD, J.D., ELMORE, S.J., MOTTRAM, D.S., ENSER, M. 2003. Modelling the effect of fatty acids on odour development of cooked meat in vitro: part I - sensory perception. Meat Sci. 63:367-375

CASSAR-MALEK, I., BERNARD, C., JURIE, C., BARNOLA, J., GENTES, G., DOZIAS, D., MICOL, D., HOQUETTE, J.F., 2005. Pasture-based beef production systems may influence muscle characteristics and gene expression. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 385-390.

CHAYAPRUCHA, S., CASTEN, M.T., HARDY, R.W., DONG, F.M., 2003. Fish performance, fillet characteristics and health assessment index of rainbow trout fed various carotenoid concentrations. Aquaculture 218:715-738.

CHAMBREZ, A., SCHEIDER, M.R.L., KREUZER, M., DUFAY, P.A., 2003. Meat quality of Angus, Simmental, Charolais and Limousin steers compared at the same intramuscular fat content. Meat Sci. 63:491-500.

CHOUBERT, G., 2001. Carotenoids and pigmentation. Chpt. 11. In: J. Guillaume, S. Kaushik, P. Bergot and R. Métailer (eds.) Nutrition and Feeding of Fish and Crustaceans, Springer Praxis, Chichester, UK, pp 183-196.

CHOUBERT, G., STORERAKKEN, T. 1989. Dose response to astaxanthin and canthaxanthin pigmentation of rainbow trout fed various carotenoid concentrations. Aquaculture 81:69-77.

CLIFTON, P.M., KOGH J.B., NOAKES, M., 2004. Trans fatty acids in adipose tissue and the food supply are associated with myocardial infarction. J. Nutr. 134:874-879.

COOPER, S.L., SINCLAIR, L.A., WILKINSON, R.G., HALETT, K.G., ENSER, M., WOOD, J.D., 2004. Manipulation of the polyunsaturated fatty acid composition of muscle and adipose tissue in lamb. J. Anim. Sci. 82:1461-1470.

CORI, R.A., BARRANO, D.M., BAUMAN, D.E., IP, C., 2003. cis-9, trans-11 CLA derived endogenously from trans-11 18:1 reduces cancer risk in rats. J. Nutr. 133:2893-2900.

CORN, A., KONDOYAN, N., MARTIN, B., VERDIER-METZ, L., PRADEL, P., BRIERIQUE, J.L., COULON, J.B., 2005. Terpene profiles in Cantal and Saint-Nectaire type cheeses made from raw or pasteurised milk. J. Sci. Food Agric., in press.

COULON, J.B., DELACROIX-BUCHET, A., MARTIN, B., PIRISI, A., 2004. Relationship between management and sensory characteristics of cheeses: a review. Lait 84:221-241.

COZZOLINO, D., DE MATTOS, D., VAZ MARTINS, D., 2002. Visible/near infrared reflectance spectroscopy for predicting composition and tracing system of production of beef muscle. Anim. Sci. 74:477-484.

CULIOLI, J., 1999. La qualité de la viande bovine: aspects biologiques et technologiques de la gestion de la tendreté. Bull. Acad. Vét. de France 72:25-46.

CULIOLI, J., BÉRI, C., MOUROT, J., 2003. Muscle foods: consumption, composition and quality. Sci. Aliments 23:13-34.

DIEKEMAN, M.E., 1987. Fat reduction in animals and the effects of palatability and consumer acceptance of meat products. Proc. Reciprocal Meat Conf. 40:93-102.

DRAINSFIELD, E., FRANK, J.M., BAUCHART, D., ABOUELKARAM, S., LEPETIT, J., CULIOLI, J., JURIE, C., PICARD, B., 2003. Meat quality and composition of three muscles from French cul culls and young bulls. Anim. Sci. 76:387-399.

DUCRETT, S.R., KUBER, P.S., 2001. Genetic and nutritional effects on lamb flavour. J. Anim. Sci. 79(E. suppl.):E249-E259.

DUPUER, E., 2005. Determination of structure and textural quality of dairy and meat products using fluorescence and infrared spectroscopies coupled with chemometrics. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 191-202.

DURAND, D., SCIULIWSKI, V., GRUFFAT, D., CHILLIARD, Y., BAUCHARD, D., 2005. High-fat rations and lipid peroxidation in ruminants: consequences on the health of animals and quality of their products. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 137-150.
EGGEN, A., HOQUETTE, J.F., 2004. Genomic approaches to economic trait loci and tissue expression profiling; application to muscle biochemistry and beef quality. Meat Sci. 66:1-9.

ELMORE, J.S., COOPER, S.L., ENSER, M., MOTTRAM, D.S., SINCLAIR, L.A., WILKINSON, R.G., WOOD, J.D., 1999a. Dietary manipulation of fatty acid composition in lamb meat and its effect on the volatile aroma compounds of grilled lamb. Meat Sci. 69:233-242.

ELMORE, J.S., MOTTRAM, D.S., ENSER, M., WOOD, J.D. 1999b. Effect of the polyunsaturated fatty acid composition of beef muscle on the profile of aroma volatiles. J. Agr. Food Chem. 47:1619-1625.

ELMORE, J.S., WAREN, H.E., MOTTRAM, D.S., SCOLLAN, N.D., ENSER, M., RICHARDSON, R.I., WOOD, J.D., 2004. A comparison of the aroma volatiles and fatty acid compositions of grilled beef muscle from Aberdeen Angus and Holstein-Friesian steers fed diets based on silage or concentrates. Meat Sci. 68:27-33.

FISHER, A.V., ENSER, M., RICHARDSON, R.I., WOOD, J.D., NUTE, G.R., KURT, E., SINCLAIR, L.A., WILKINSON, R.G., 2000. Fatty acid composition and eating quality of lamb types derived from four diverse production systems. Meat Sci. 55:141-147.

FRIGG, M., PRAHUCKI, A.L., RUDHEL, E.U. 1990. Effect of dietary vitamin E levels on oxidative stability of trout fillets. Aquaculture 84:145-158.

GATTELLIER, P., MERCIER, Y., JUNN, H., RENNER, M., 2005. Effect of finishing mode (pasture- or mixed-diet) on lipid composition, colour stability and lipid oxidation in meat from Charolais cattle. Meat Sci. 69:175-186.

GEAY, A., HOQUETTE, J.F., CULLIOLI, J., 2001. Effect of nutritional factors on biochemical, structural and metabolic characteristics of muscles in ruminants; consequences on dietary value and sensorial qualities of meat. Reprod. Nutr. Dev. 41:1-26. Erratum, 41:377.

GRUNERT, K.G., BREDAHL, L., BRUNSO, K., 2004. Consumer perception of meat quality and the market potential for product development in the meat sector-a review. Meat Sci. 66:259-272.

HOQUETTE, J.F., CASSAR-MALEK, I., LISTERAT, A., PICARD, B., 2005a. Genomic approaches to economic trait loci and tissue expression profiling; application to muscle biochemistry and beef quality. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 65-79.

HOQUETTE, J.F., GIGLI, S., 2005. The challenge of finishing mode (pasture- or mixed-diet) on lipid composition, colour stability and lipid oxidation in meat from Charolais cattle. Meat Sci. 69:233-242.

HOQUETTE, J.F., GIGLI, S., 2005. The challenge of finishing mode (pasture- or mixed-diet) on lipid composition, colour stability and lipid oxidation in meat from Charolais cattle. Meat Sci. 69:233-242.

HOQUETTE, J.F., RENAND, G., LEVEZIEL, H., PICARD, B., CASSAR-MALEK, I. 2005b. Genetic effects on beef meat quality. In: J. Wood (ed.), The Science Beef Quality, 8th Annual Langford Food Industry Conference, Proc. Brit. Soc. Anim. Sci. pp 13-19.

HWANG, I.H., DEVINE, C.E., HOPKINS, D.L., 2003. The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. Meat Sci. 65:677-691.

JEREMIAH, L.E., GIBSON, L.J., 2003. The effects of post-mortem product handling and ageing on beef palatability. Food Res. Int. 36:513-520.

KARAMICHOU, E., RICHARDSON, R.I., NUTE, G.R., McLEAN, K.A., BISHOP, S.C., 2005. Genetic Analyses of Carcass Composition, as Assessed by X-ray Computer Tomography, and Meat Quality Traits in Scottish Blackface Sheep (submitted to Anim. Sci.)

KOCABAY, M., DEREK, M.E., ALLEN, D.M., MAY, M., CROUSE, J.D., CAMPION, D.R., 1976. Characteristics of biological types of cattle. III. Carcass composition, quality and palatability. J. Anim. Sci. 43:48-62.

KÜHN, CH., LEVEZIEL, H., RENAND, G., GOLDHAMMER, T., SCHWERIN, M., WILLIAMS, J., 2005. Genetic markers for beef quality. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 23-32.

LABORDE, F.L., MANDIEL, I.B., TOSH, J.J., WILTON, J.W., BUCHANAN-SMITH, J.G., 2001. Breed effects on growth performance, carcass characteristics, fatty acid composition and palatability attributes in steers. J. Anim. Sci. 79:355-365.

LANE, G.A., FRASER, K., 1999. A comparison of phenol and indole flavour compounds in fat, and of phenols in urine of cattle fed pasture or grain. New Zeal. J. Agr. Res. 4:289-296.

LARICHEK D.K., TURNER, B.E., 1990. Flavor characteristics of forage- and grain-fed beef as influenced by phospholipids and fatty acid compositional differences. J. Food Sci. 55:312-317.

LARICHEK D.K. HEDRICK, H.B., BAILEY, M.E., WILLIAMS, J.E., HANCOCK, D.L., GARNER, G.B., MORROW, R.E., 1987. Flavor constituents of beef as influenced by forage and grain feeding. J. Food Sci. 52:245-351.

LEAF, A., XIAO, Y.F., KANG, J.X., BILLIAMS, A.G., 2003. Prevention of sudden cardiac death by n-3 polyunsaturated fatty acids. Pharmacol. Therapeut. 98:355-377.

LEPEH, J., SALÉ, P., FAVIER, R., DALLE, R., 2002. Electrical impedance and tenderisation in bovine meat. Meat Sci. 60:51-62.

LOCK, A.L., BAUMAN, D.E., 2004. Modifying milk fat composition of dairy cows to enhance fatty acids beneficial to human health. Lipids 39:1197-1206.

LOOR, J.J., REHAAN, A., OLLIER, A., DOREAU, M., CHILLIARD, Y., 2005. Relationship among trans and conjugated fatty acids and bovine milk fat yield due to dietary concentrate and linseed oil. J. Dairy Sci. 88:726-740.

LORENZ, S., BUETTNER, A., ENDER, K., NÜRNBERG, G.,
PAPSTEIN, H.-J., SCHIEBERLE, P., NURNBERG, K., 2002. Influence of keeping system on the fatty acid composition in the longissimus dorsi muscle of bulls and odours formed after pressure-cooking. Eur. Food Res. Technol. 214:112-118.

LOVE, J., 1994. Product acceptability evaluation. In: A.M. Pearson and T.R. Dutson (eds.) Quality attributes and their measurement in meat, poultry and fish products, Glasgow, Blackie Academic and Professional, pp 337-358.

MCCORMICK, R.J., 1999. Extracellular modifications to LUNING, P.A., MARCELIS, W.J., Jongen, W.M.F., 2002. MOLONEY, A.P., KEANE, M.G., DUNNE, P.G., MOONEY, MILNER, J.A., 1999. Functional foods and health promotion. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 163-178.

LUNING, P.A., MARCELIS, W.J., Jongen, W.M.F., 2002. Food quality management. A techno-managerial approach. Wageningen Pers., Wageningen, The Netherlands.

MALTIN, C., BALCERZAK, D., TILLEY, R., DELRAY, M., 2003. Determinants of meat quality: tenderness. Proc. Nutr. Soc. 62:337-347.

MARTINEZ-CEREZO, S., SANUDO, C., MEDEL, I., OLLETA, J.L., 2005. Breed, slaughter weight and ageing effects on sensory characteristics of lamb. Meat Sci. 69:571-578.

McCORMICK, R.J., 1999. Extracellular modifications to muscle collagen: Implications for meat quality. Poultry Sci. 78:785-791.

MEDALE, F., LEPEYRE, F., CORRAZE, G., 2003. Qualité nutritionelle et diététique des poissons : constituants de la chair et facteurs de variations. Cah. Nutr. Diét. 38:37-44.

MLNER, J.A., 1999. Functional foods and health promotion. J. Nutr. 129:1395S-1397S.

MOLONEY, A.P., KEANE, M.G., DUNNE, P.G., MOONEY, D.T., TROT, D.J., 2001. Delayed concentrate feeding in a grass silage/concentrate beef finishing system: effects on fat colour and meat quality. Proc. 47th Inter. Conf. Meat Sci. Technol., Krakow, Poland, pp 188-189.

MOTTRAM, D.S., 1998. Flavour formation in meat and meat products: a review. Food Chem. 62:415-424.

MULLEN, A.M., TROT, D.J., 2005. Current and emerging technologies for the prediction of meat quality. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 179-190.

NOZIERE, P., ANDUEZA, D., MEUNIER, B., MICOL, D., 2005. Mise au point d’un dispositif de contrôle sur l’animal de la quantité de concentré ingérée par des bovins en finition. Renc. Rech. Rumin., 12: in press.

Ouali, A., SENTENDREU, M.A., AUBRY, L., BOUDJELLAL, A., TASSY, C., GRESINK, G.H., FARIAS-MAFFET, G., 2005. Meat toughness as affected by muscle type. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 391-395.

PARK, R.J., 1969. Weed taints in dairy products. I. Lepidium taint. J. Dairy Res. 36:31-35.

PETTHICK, D.W., FERGUSSON, D.M., GARDNER, G.E., HOCQUETTE, J.F., THOMPSON, J.M., WARNER, R., 2005. Muscle metabolism in relation to genotypic and environmental influences on consumer defined quality of red meat. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 95-110.

PIASENTIER, E., VALUSSO, R., CAMIN, F., VERSINI, G., 2003. Stable isotope ratio analysis for authentication of lamb meat. Meat Sci. 64:239-247.

POTTER, A.A., KLAISHINSKY, S., LI, Y., FREY, E., TOWNSEND, H., ROGAN, D., ERICKSON, G., HINKLEY, S., KLOPPESTEN, T., MOXLEY, R.A., SMITH, D.R., FINLAY, B.B., 2004. Decreased shedding of Escherichia coli O157:H7 by cattle following vaccination with type III secreted proteins. Vaccine 22:3-4:362-9.

PRACHE, S., CORNU, A., BERDAIGUE, J.L., PRIOLA, A., 2005. Traceability of animal feeding diet in the meat and milk of small ruminants: a review. Small Ruminant Res., in press.

PRADEL, P., ROCK, E., CHILLIARD, Y., PETIT, M., 2004. Evolution des teneurs du plasma et du lait de vache en beta-carotène et autres composés d’intérêt nutritionnel lors d’un changement de régime (ensilage d’herbe puis foin). Renc. Rech. Rumin., 11:63-66.

PRESCOTT, J., YOUNG, O., O’NEILL, L., 2001. The impact of variations in flavoured compounds on meat acceptability: a comparison of Japanese and New Zealand breeds. Food Quality Management. A technico-managerial approach. Wageningen Pers., Wageningen, The Netherlands.
Zealand customers. Food Qual. Prefer. 12:257-264.

Priolo, A., Cornu, A., Prach, S., Kroghmann, M., Kondjoyan, N., Micol, D., Berdagüe, J.L., 2004. Fat volatile tracers of grass feeding in sheep: Influence of measurement site and shrinkage time after slaughter. J. Anim. Sci. 80:886-891.

Purslow, P.P., 2005. Intramuscular connective tissue and its role in meat quality - a review. Meat Sci. 70:435-447.

Régost, C., Arzel, J., Robin, J., Rosenlund, G., Kaushik, S.J., 2003a. Total replacement of fish oil by soybean or linseed oil with a return to fish oil in turbot (Psetta maxima). 1. Growth performance, flesh fatty acid profile and lipid metabolism. Aquaculture 217:465-482.

Régost, C., Arzel, J., Cardinal, M., Rosenlund, G., Kaushik, S.J., 2003b. Total replacement of fish oil by soybean or linseed oil with a return to fish oil in turbot (Psetta maxima). 2. Flesh quality properties. Aquaculture 220:737-747.

Renand, G., Picard, B., Touraille, C., Berge, P., Lepetit, P., 2001. Joint variability of meat quality traits and muscle characteristics of young Charolais beef cattle. Meat Sci. 59:49-60.

Renou, J.P., Devonce, G., Gachon, P., Bonnepoy, J.C., Coulon, J.B., Garèl, J.P., Verité, R., Ritz, P., 2004a. Characterization of animal products according to geographic origin and feeding diet using nuclear magnetic resonance and isotope ratio mass spectrometry: cow milk. Food Chem. 85:63-66.

Renou, J.P., Bielicki, G., Devonce, G., Gachon, P., Micol, D., Ritz, P., 2004b. Characterization of animal products according to geographic origin and feeding diet using nuclear magnetic resonance and isotope ratio mass spectrometry. Part II: Beef meat. Food Chem. 86:251-256.

Richardson, R.I., Nute, G.R., Wood, J.D., Scollan, N.D., Warren, H.E., 2004. Effects of breed, diet and age on shelf life, muscle vitamin E and eating quality of beef. Proc. Brit. Soc. Anim. Sci., pp 84.

Riddan, D.C., Duffy, G., Sheridan, J.J., Whiting, R.C., Blair, I.S., McDowell, D.A., 2000. Effects of acid adaptation, product pH, and heating on survival of Escherichia coli O157:H7 in pepperoni. Appl Environ Microbiol. 66:1726-9.

Ritzenthaler, K.L., McGuire, M.K., Falen, R., Schultz, T.D., Dasgupta, N., McGuire, M.A., 2001. Estimation of conjugated linoleic acid intake by written dietary assessment methodologies underestimates actual intake evaluated by food duplicate methodology. J. Nutr. 131:1548-1554.

Roussel-Akrim, S., Young, O.A., Berdagüé, J.L., 1997. Dietary growth effects on panel assessment of sheep meat odour and flavour. Meat Sci. 45:169-181.

Rouzaud, F., Martin, J., Gallet, P.F., Delourme, D., Goulemot-Legre, V., Amigues, Y., Menissier, F., Leveziel, H., Julien, R., Oulmouden, A., 2000. A first genotyping assay of French cattle breeds based on a new allele of the extension gene encoding the melanocortin-1 receptor (Mc1r). Genet. Sel. Evol. 32:511-520.

San Cristobal-Gaudy, M., Renand, G., Amigues, Y., Boscher, M.Y., Leveziel, H., Bibé, B., 1999. Validation d’une procédure de traçabilité des viandes bovines par marquage moléculaire. Rec. Rech. Rumin., 6:273.

Sanada, M., Coroller, L., Cerf, O., 2004. Risk assessment of listeriosis linked to the consumption of two soft cheeses made from raw milk: Camembert of Normandy and Brie of Meaux. Risk Anal. 24:389-99.

Sanudo, C., Nute, G.R., Campo, M.M., Maria, G., Baker, A., Sierra, I., Enser, M.E., Wood, J.D., 1998. Assessment of commercial lamb quality by British and Spanish Taste panels. Meat Sci. 48:91-100.

Savell, J.W., Mueller, S.L., Baird, B.E., 2005. The chilling of carcasses—a review. Meat Sci. 70:449-459.

Schamberger, G.P., Phillips, R.L., Jacobs, J.L., Diez-Gonzalez, F., 2004. Reduction of Escherichia coli O157:H7 populations in cattle by addition of colicin E7-producing E. coli to feed. Appl. Environ Microbiol. 70:6053-60.

Scollan, N.D., Choi, N.J., Kurt, E., Fisher, A.V., Enser, M., Wood, J.D. 2001. Manipulating the fatty acid composition of muscle and adipose tissue in beef cattle. Brit. J. Nutr. 85:115-124.

Scollan, N.D., Richardson, I., De Smet, S., Moloney, A.P., Doreau, M., Bauchart, D., Nuernberg, K. 2005. Enhancing the content of beneficial fatty acids in beef and consequence for beef quality. In: J.F. Hoquette and S. Gigi (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 151-162.

Sentendreu, M.A., Coulis, G., Ouali, A., 2002. Role of muscle endopeptidases and their inhibitors in meat tenderness. Trends Food Sci. Tech. 13:398-419.

Sigurjonsadottir, S., Parrish, C.C., Ackman, R.G., Lall, S.P., 1994. Tocopherol deposition in the muscle of Atlantic salmon (Salmo salar). J. Food Sci. 59:256-259.

Simopoulos, A.P., 2001. n-3 fatty acids and human health: defining strategies for public policy. Lipids 36:S83-S89.

Soehnem, O., Hildrum, K.I., 2002. Muscle stretching techniques for improving meat tenderness. Trends Food Sci. Tech. 13:127-135.

Spanier, A.M., Flores, M., McMillin, K.W., Bidner, T.D., 1997. The effect of postmortem ageing on flavour in Brangus cattle. Correlation of treatment, sensory, instrumental and chemical descrip-
tors. Food Chem. 59:531-538.

Sudre, K., Cassar-Malek, I., Listrat, A., Ueda, Y., Leroux, C., Jurie, C., Auffray, C., Renand, R., Martin, P., Hocquette, J.F., 2005. Biochemical and transcriptomic analyses of two bovine skeletal muscles in Charolais bulls divergently selected for muscle growth. Meat Sci. 70:267-277.

Sudre, K., Leroux, C., Petit, E., Cassar-Malek, I., Petit, E., Listrat, A., Auffray, C., Picard, B., Martin, P., Hocquette, J.F., 2003. Transcriptome analysis of two bovine muscles during ontogenesis. J. Biochem. 133:745-756.

Tarrant, P.V., 1998. Some recent advances and future priorities in research for the meat industry. Meat Sci. 49 (Suppl. 1):S1-S16.

Tewari, G., Jayas, D.S., Holley, R.A., 1999. Centralized packaging of retail meat cuts: A review. J. Food Protect. 62:418-425.

Thompson, J.M., 2002. Managing meat Tenderness. Meat Sci. 60:365-369.

Tornberg, E., 2005. Effects of heat on meat proteins: Implications on structure and quality of meat products. A review. Meat Sci. in press.

Valeta, L.M., Tapakanen, H., Mannisto, S., 2005. Meat fats in nutrition – a review. Meat Sci. 70:525-530.

Van Baale, M.J., Sarogant, J.M., Gnad, D.P., DeBey, B.M., Lechtenberg, K.F., Nagaraja, T.G. 2004. Effect of forage or grain diets with or without monensin on ruminal persistence and fecal Escherichia coli O157:H7 in cattle. Appl Environ Microbiol. 70:5336-5342.

Vatsanssver, L., Kurt, E., Ensor, M., Nute, G.R., Scollan, N.D., Wood, J.D., Richardson, R.I., 2000. Shelf life and eating quality of beef from cattle of different breeds given diets differing in n-3 polyunsaturated fatty acid composition. Anim. Sci. 71:471-482.

Veiseth, E., Koohmaraie, M., 2005. Beef tenderness: significance of the calpain proteolytic system. In: J.F. Hocquette and S. Gigli (eds.), Indicators of milk and beef quality, EAAP Publ. 112, Wageningen Academic Publishers, Wageningen, The Netherlands, pp 111-126.

Wakkup, C., Marie, S., Harrington, G., 1995. Consumer perceptions of texture; the most important quality attribute of meat? In: A. Ouali, I. Demeyer and F.J.M Smulders (eds.) Expression of tissue proteinases and regulation of protein degradation as related to meat quality, ECCEAMST 1995 CIP-Gegevens Koninklijke Bibliotheek Den Haag, The Netherlands, pp 225-238.

Warren, K.E., Kantner, C.L., 1992. A comparison of dry-aged and vacuum-aged beef strip loins. J. Muscle Foods 3:151-157.

Whittington, F.M., Nute, G.R., Scollan, N.D., Richardson, R.I., Wood, J.D. 2004. Effect of diet and breed on skatole deposition in cattle slaught-