The relationship between consumer perception of quality and the food industry's drive to satisfy consumer needs is complex and involves many different components. Science and innovation play a major role in equipping the industry to respond to consumer concerns and expectations. This paper examines the main elements of consumer perception of meat with focus on the red meat sector. Emphasis is placed on perception at point of sale particularly the intrinsic quality cues of colour, packaging and degree of visual fat. The state of the art developments in increasing consumers' perception at this point are discussed. Experienced quality cues such as tenderness and flavour are well known as being of immense importance to consumers at point of consumption. The latest technological developments to enhance the quality experienced by consumers are discussed. The use of pre-rigor restraining techniques offers the industry a method for changing its conventional procedures of processing beef for instance. Background cues of safety, nutrition, animal welfare and sustainability are also discussed. Finally opportunities and challenges facing the industry are outlined. It is concluded that the meat industry needs to invest in and embrace an innovation agenda in order to be sustainable. It must utilise emerging scientific knowledge and take a more proactive role in setting out a research agenda.

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1. Introduction

Consumer perception of meat and meat products is a critical issue for the meat industry because it directly impacts its profitability. Many studies have concluded that consumer perception is both complex, dynamic and difficult to define. The role of science and technology in enabling the meat industry to improve consumer perception is often the focus of much research. Many valuable scientific contributions which have been widely taken up by the industry have indeed improved the consumer perception of meat and meat products particularly in terms of safety, quality and product stability. However the industry faces other challenges in terms of consumer perception especially in the areas of health (nutrition), animal welfare and convenience. Can the application of science and technology augment consumer perception of meat and meat products in today's context?

This paper reviews the scientific literature in an attempt to ascertain what the perception of consumers towards meat are, how science can improve them and to what extent trends, gaps and opportunities exist for commercial exploitation.

1.1. Consumer perception

It is well documented that consumers cannot be categorised based on one type of behaviour. Both their behaviour and their context interact, i.e. consumer behaviour is shaped by their needs and what is available to meet their needs. However behaviour is strongly influenced by the psychological factor perception. Korzen and Lassen (2010) describe how perceptions of meat qualities vary between contexts. In relation to meat the authors describe two contexts, the “everyday context” (relating to buying, preparing and eating) and the “production context” (relating to primary production, slaughtering and meat processing). Perception is defined as the act of apprehending by means of the senses and/or the mind. Hence, perception not only relates to basic senses such as visual, flavour and taste attributes, but also to formed learning or experiences. Some of our non-cognitive learning mechanisms such as conditioning and imitation are predominant in the early formation of food habits. Therefore, perception incorporates complex aspects of consumer behaviour such as learning, motivational and contextual factors. Various models and theories have been developed and are discussed by Koster and Mojet (2007). Consumer perceptions are not fixed and may change. How and in what direction consumer perceptions change is difficult to predict because of the complex dynamic which drives the change.

Consumer perceptions therefore are dynamic, and there are often differences between what consumers perceive and their behaviour. Models have been developed to predict consumer behaviour based on perceptions, some of which do not take context into account. With regard to food, the viability of the industry depends on consumers demanding and paying for products. In order for consumers to willingly purchase and consume a particular food type, their perceptions must be positive towards it. In the context of food and particularly meat, it is normally understood that consumer perception of meat relates to its quality in a broad sense.

Food quality like perception is difficult to define: invariably dynamic and difficult to measure. In the past “Food Quality” was more related to safety, sensory and shelf-life aspects of food products. More recently it is associated with nutrition, well-being and health. The basic definition of quality, as associated with food, relates to food as fit for human consumption or in its ability to satisfy stated or implied needs. Despite its difficulties, what is certain is that it is a critical factor in a highly competitive meat industry. It must be constantly measured, at all times maintained, opportunistically enhanced and always evaluated in terms of consumer expectations and needs. Various models of food quality have been proposed (Grunert, Larsen, Madson, & Baadsgaard, 1996; Peri, 2006).

The models that have been proposed to date distinguish between the product as a food (safety, nutrition, sensory, and ethical) and the product as an object of trade (certification, traceability, convenience, and price) (Peri, 2006), or as a product before purchase (costs, extrinsic quality cues, and intrinsic quality cues) and as a product after purchase (meat preparation, experienced quality, and sensory characteristics) (Grunert et al., 1996). Steenkamp (1990) proposed that perceived quality has three dimensions, preference, in terms of evaluative judgement, the interaction between the subject and the object i.e. it is comparative in terms of other products, and lastly consumption in terms of being valued by the consumer.

In all models “quality cues” i.e. information stimuli that can be ascertained by the consumer prior to consumption are taken into account. Quality cues contribute to the function of beliefs and therefore purchase choice. Grunert, Breidahl, and Brunso (2004) detail the Total Food Quality Model with respect to meat and describes the various intrinsic and extrinsic quality cues perceived by the consumer.

Intrinsic quality cues are those which are physically part of the product itself (e.g. marbling, colour) while extrinsic cues are not physically part of the product (price, origin).

Since consumers base their purchase choices on the perceived quality cues, it is essential that the meat industry fully understand (a) what these cues are, and which are the most important, (b) what (if anything) can the meat industry (producers, processors and retailers) do in order to maintain or enhance these cues in existing or new products and (c) how through using best scientific knowledge and technology can the industry enhance such perceptions. These are difficult questions to address but ones which the authors suggest could impact in a positive and economical way to the competitiveness of the industry while addressing consumer needs and wants.

1.2. Quality cues and attributes

Much research has been carried out to understand and identify the major intrinsic and extrinsic quality cues in relation to meat (Acebrón & Dopico, 2000) (Table 1).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Meat quality cues and attributes.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point of sale</strong></td>
<td>• Meat colour</td>
</tr>
<tr>
<td></td>
<td>• Packaged meat colour</td>
</tr>
<tr>
<td></td>
<td>• Visible drip</td>
</tr>
<tr>
<td></td>
<td>• Visible fat</td>
</tr>
<tr>
<td><strong>Point of consumption</strong></td>
<td>• Tenderness</td>
</tr>
<tr>
<td></td>
<td>• Flavour</td>
</tr>
<tr>
<td></td>
<td>• Juiciness</td>
</tr>
<tr>
<td></td>
<td>• Succulence</td>
</tr>
<tr>
<td><strong>Major background cues</strong></td>
<td>• Safety</td>
</tr>
<tr>
<td></td>
<td>• Nutrition</td>
</tr>
<tr>
<td></td>
<td>• Sustainability</td>
</tr>
<tr>
<td></td>
<td>• Ethics</td>
</tr>
</tbody>
</table>
Of a greater importance is the relative importance placed by the consumer on these quality cues. Generally extrinsic quality cues include price, product presentation, origin and brand. Important intrinsic quality cues for meat include the physiological characteristics of the product such as colour, visible fat and tenderness. Some but not all of these quality attributes can be evaluated by the consumer at the point of purchase. These and others contribute to the consumers’ “expected quality”. In the case of meat expected quality increases with consumers perceived likeness of appearance, as well as freshness but decreases with for example the amount of visible fat present in meat (Steenkamp & Van Trijp, 1996).

Expected quality judgment is measured at the point of purchase while experienced quality is measured on the basis of being fit for purpose at the point of consumption. It is important for the meat industry to fully understand the major cues associated with expected quality and those associated with experienced quality. Overall perceived quality by the consumer is a measure which is based on both of these aspects.

Grunert (1997) reported that the extrinsic and intrinsic quality cues infer specific quality attributes and that these are quite similar across a number of countries. The consumer therefore forms the decision to purchase meat on the basis of a large number of cues (price, label, brand, appearance, and type of cut) which in turn signposts the quality of the meat in terms of attributes (tenderness, flavour, freshness, and nutrition).

Despite our knowledge on the type and importance of meat quality attributes, consumers still have difficulty in accurately predicting experienced quality by perception at the point of purchase (Grunert et al., 2004) (Table 2). This is a major challenge for the meat industry. Very few industries produce relatively expensive products while failing to provide to the consumer reasonable data allowing them to reliably predict important quality traits at the point of sale. Since the most important quality attributes are known, the industry must ensure that they produce meat that at least meets the expectations of consumers.

Much research has been carried out in both the enhancement of the quality attributes of meat as well as their measurement (Thompson, 2002). While the former has met with a great deal of success the latter has had only limited success in terms of uptake and c knowledge and uptake by industry.

In the mind of the average consumer about to purchase meat, colour becomes synonymous with fresh red meat quality (Renere & Labas, 1987). The colour of fresh red meat is of the utmost importance in meat marketing since it is the first quality attribute seen by the consumer who uses it as an indication of freshness and wholesomeness. At the point of sale, colour and colour stability are the most important attributes of meat quality and various commercial approaches have been used to meet consumer expectation; that an attractive bright red colour is compatible with long shelf-life and good eating quality (Hood & Mead, 1993). In reality, the colour of fresh meat is not well correlated with the eating quality, however, the consumer still demands beef to be a bright cherry-red colour (Taylor, 1996), lamb a brick red colour and pork and chicken an even pink colour. Carpenter, Cornforth, and Whittier (2001) showed that consumer preference for beef colour was sufficient to influence their likelihood to purchase, but was not enough to bias taste scores. It is likely that once a decision to purchase beef is made in the market, whether the beef is the red of fresh bloomed beef, the brown of discounted beef or the purple of vacuum packaged beef, consumer eating satisfaction at home will depend only on the beef quality attributes of tenderness, juiciness and flavour. Nevertheless, the presentation of fresh red meats with appropriate colour at retail level is of the utmost importance as consumers will discriminate negatively against meat that does not appear to match expectations or that is discoloured. Discoloured meat cannot be sold unless it is significantly discounted or minced (Liu, Lanari, & Schaefer, 1995; Sherbeck et al., 1995). Smith, Belk, Sofos, Tatum, and Williams (2000) estimated that

### Table 2

Consumer cues at point of sale: Scientific knowledge and uptake by industry.

<table>
<thead>
<tr>
<th>Point of sale</th>
<th>Scientific knowledge</th>
<th>Uptake by industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Meat colour</td>
<td>• Meat colour chemistry+++</td>
<td>• Adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Instrumentation and measurement+++</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Pre- and post-slaughter factors+++</td>
<td></td>
</tr>
<tr>
<td>• Packaged meat colour</td>
<td>• Material science+++</td>
<td>• Adopted for best practice+++</td>
</tr>
<tr>
<td>• Visible drip</td>
<td>• Meat chemistry+++</td>
<td>• Moderately adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Packaging technologies+++</td>
<td></td>
</tr>
</tbody>
</table>
| • Visible fat | • Pre- and post-slaughter factors+++ | | +++ extensive, ++ moderate, + limited.

### Table 3

Consumer cues at point of consumption: Scientific knowledge and uptake by industry.

<table>
<thead>
<tr>
<th>Point of consumption</th>
<th>Scientific knowledge</th>
<th>Uptake by industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tenderness</td>
<td>• Muscle biochemistry+++</td>
<td>• Moderately adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Instrumentation and measurement+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Pre- and post-slaughter factors+++</td>
<td></td>
</tr>
<tr>
<td>• Flavour</td>
<td>• Flavour chemistry+</td>
<td>• Poorly adopted for best practice+</td>
</tr>
<tr>
<td></td>
<td>• Pre- and post-slaughter factors+</td>
<td></td>
</tr>
<tr>
<td>• Juiciness</td>
<td>• Meat chemistry+++</td>
<td>• Poorly adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Post-slaughter factors+</td>
<td></td>
</tr>
</tbody>
</table>
| • Succulence | • Pre-slaughter production factors+ | | +++ extensive, ++ moderate, + limited.

### Table 4

Major background cues: Scientific knowledge and uptake by industry.

<table>
<thead>
<tr>
<th>Major background cues</th>
<th>Scientific knowledge</th>
<th>Uptake by industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Safety</td>
<td>• Zoonotic pathogens+++</td>
<td>• Moderately adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Chemical contaminants+++</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Traceability+</td>
<td></td>
</tr>
<tr>
<td>• Nutrition</td>
<td>• Nutritional composition+++</td>
<td>• Poorly adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Health implications+</td>
<td></td>
</tr>
<tr>
<td>• Sustainability</td>
<td>• Greenhouse gas emissions+++</td>
<td>• Poorly adopted for best practice+++</td>
</tr>
<tr>
<td></td>
<td>• Energy+</td>
<td></td>
</tr>
</tbody>
</table>
| • Ethics | • Animal welfare+++ | | +++ extensive, ++ moderate, + limited.
|               | • Biotechnology+ | |
15% of retail sales in the USA were discounted and that this accounted for an annual revenue loss of one billion dollars.

Meat colour is dependent on the concentration and chemical state of the meat pigments, primarily myoglobin and haemoglobin, and on the physical characteristics of meat, such as its light scattering and absorbing properties (Kropf, 1993). The myoglobin concentration of muscle varies between and within species and is affected by factors such as age, exercise, diet of the animal, as well as genetic and environmental factors (Livingston & Brown, 1981).

Myoglobin can exist in one of three forms: deoxymyoglobin, oxymyoglobin or metmyoglobin. Interconversion of the three pigment states is possible and the dominant pigment form depends on localised conditions (Kropf, 1993). Deoxymyoglobin, frequently referred to as myoglobin or reduced myoglobin, contains iron in the ferrous (Fe²⁺) state and is characterised by the absence of a ligand at the sixth coordinate position of the haem group. It is purplish-red in colour and is responsible for the colour of meat immediately after cutting into a deep muscle, or of meat stored under a vacuum (Renerre, 1990). Oxymyoglobin, a cherry-red form of the pigment, forms very quickly after exposure of deoxymyoglobin to oxygen. The pigment must be in the ferrous state for oxygenation to occur and oxygen occupies the sixth binding site of the ferrous haem iron (Livingston & Brown, 1981). In red meats oxymyoglobin imparts the colour that consumers associate with freshness (Faustman & Cassens, 1990).

The colour of red meats is relatively short-lived and both deoxymyoglobin and oxymyoglobin readily oxidise to metmyoglobin, in which the haem iron has been oxidised to the ferric (Fe³⁺) state and water occupies the sixth coordinate position. Metmyoglobin is incapable of binding oxygen and is thus physiologically inactive (Faustman & Cassens, 1990). Metmyoglobin gives meat a brown colour which consumers associate with a lack of freshness and unacceptability (Hood & Riordan, 1973).

A number of factors contribute to discoloration in meat during storage and the rate of metmyoglobin accumulation is related to intrinsic factors such as muscle pH, muscle fibre type and the age, breed, sex and diet of animals, as well as extrinsic factors such as preslaughter treatment of animals and hot-boning, electrical stimulation and chilling of carcasses. Additionally, during retail display environmental factors such as temperature, oxygen availability, type of lighting, microbial growth and packaging storage atmosphere all influence the shelf-life and potential retail sale of meat.

2.2. Colour of packaged meat

Of all the approaches used by industry to deliver market-ready muscle-based food products that meet consumer requirements, the application of packaging is paramount. As previously described, the colour of meat is a fragile characteristic, particularly in fresh meat and yet is one of the most critical properties that needs to be presented to consumers correctly and in an appropriate manner. In the case of fresh red meat, two important visual clues that determine perceived quality are colour and packaging (Issanchou, 1996). Both factors, meat colour and packaging, constitute the overall visual product entity that the consumer will evaluate at the product–consumer interface just prior to the point of purchase or product rejection. Therefore, the selection of appropriate packaging materials for meat packaging is of paramount importance for fresh red meat presentation to the consumer, yet little research has been carried out to determine what other packaging properties might enhance the persona of the packaged product and its interaction with the consumer; for example, tactile properties, odour delivery, etc.

There are four categories of preservative packaging that can be used with raw muscle foods and these consist of vacuum packs, high oxygen modified atmosphere packs, low oxygen modified atmosphere packs and controlled atmosphere packs (CAP) (Gill & Gill, 2005). However, based on specific consumer meat colour demands, fresh red meats are predominately presented by meat packers in two basic formats, namely: placed on trays and over-wrapped with an oxygen permeable film or more commonly placed within a contained gaseous modified atmosphere using tray and lidding formats which are impermeable to moisture and gases. Over the past number of years, much research has focused on the influence of modified atmosphere packaging (MAP) on meat quality attributes and the purchasing preferences of consumers (Carpenter et al., 2001; Jayasingh, Cornforth, Brendnand, Carpenter, & Whittier, 2002).

Discoloration in retail packaged meats during display conditions may occur as a combined function of muscle pigment oxidation (oxymyoglobin to metmyoglobin) and lipid oxidation in membrane phospholipids (Sherbeck et al., 1995). MAP is one of the principle methods of maintaining and prolonging fresh meat colour as high oxygen concentrations within retail packs promotes the development of oxymyoglobin. However, in tandem with this process is the development of oxidative instability through muscle lipid degradation; consequently leading to the development of undesirable flavors (Estevez & Cava, 2004; Rhee & Ziprin, 1987). The breakdown products of lipid oxidation have been associated with the development of off-flavors and off-odours and more significantly, in the loss of fresh meat colour (Faustman, Chan, Lynch, & Joo, 1996).

2.3. Packaging materials used for commercial packaging of meat

Plastic-based films are the materials of choice for the majority of meat products presented at retail level. Most meat packaging films are thermoplastic and are extruded from the molten stage through dies. They can be stretched (oriented) to thinner gauges (thicknesses) before cooling and this may impart the ability to shrink when heated (Taylor, 1996).

If the properties required of a packaging material cannot be satisfied by a single film, several films with individual desirable properties may be combined to give a satisfactory laminate. Laminates can be constructed by laminating (sticking) two or more polymeric films together. This can be achieved by joining together previously extruded plastic films using tie layers (adhesives). Polymers may be co-extruded together to form a single material by delivering individual molten resins by separate extruders to a combined round or flat plate die which maintains their separation in discrete but welded polymeric layers. Composite plastics can also be used for meat packing and these are produced by coating a film with another polymer. In this case a layer of molten plastic resin or a dissolved or dispersed polymer is applied onto a preformed film (Humphreys, 1996). Polyvinylidene chloride and ethyl vinyl alcohol are commonly used in one or a number of these ways to produce materials with very good gas and moisture properties (Taylor, 1996).

In meat packaging, film choice is largely determined by moisture and gas permeability. Most of the films used are moisture barriers, in order to avoid weight loss from the meat. Gas permeability is much more variable and is specific to individual polymers. For over-wrapped retail cuts of fresh meat, where retention of bright red colour is desired, elasticated pack materials with the capacity to elongate and with high oxygen transmission rates are used. However, for cuts of meat held under MAP conditions at retail level and where an extended colour storage life is the primary concern, pack formats consisting of tray and lidding materials will have low gas transmission rates in order to prevent ingress of air or egress of the functional gas mix.

Thermoforming is now the most common method of modified atmosphere packaging of meat and meat products. Trays are produced from a bottom web of plastic, evacuated and then flushed with the gas mixture before they are sealed with a top web of film. Typically trays are manufactured from unplasticised polyvinyl chloride or PS and the lidding materials from PET and PS combinations, which may also include a PVD or EVOH (Ethylene Vinyl Alcohol) component to improve gas barrier properties and a polyolefin to effect a pack seal.
2.4. Drip loss from packaged meat

One of the main quality attributes of fresh meat is its water-holding capacity because it influences consumer acceptance and the final weight of the product (Den Hertog-Meischke et al., 1997). The loss of exudates from muscle tissue is unavoidable but requires attention in order to minimize its presence around fresh meat products where possible due to the negative impact that it has on consumer attitude to fresh meat product purchase and quality perception. Any system prolonging the shelf-life of packed chilled meat will be subject to accumulation of exudates or drip. Drip loss is thought to originate from the spaces between fibre bundles and the perimysial network and additionally, the spaces between muscle fibres and the endomysial network (Offer & Cousins, 1992). These spaces appear during rigor development. Factors, which may affect drip losses, include: rigor temperature and membrane integrity (Honikel, 1998; Honikel, Kim, Hamm, & Roncales, 1986), pre-slaughter stress, processing factors and packaging (Payne et al., 1997). Exudate losses are exacerbated by cutting meat into smaller portions. Losses of approximately 5% of the primal cut weight can be expected at the packing plant. The amount of drip in cut meat is also largely dependent on sample thickness, surface to volume ratio, orientation of cut surface with respect to muscle fibre axis and prevalence of large blood vessels (Farouk, Price, & Salih, 1990).

Taylor, Down, and Shaw (1990) found that drip losses were lower for vacuum skin packaged samples than modified atmosphere packaged samples. Conversely, Payne, Durham, Scott, and Devine (1998) investigated drip loss in beef under conventional vacuum packaging systems and non-vacuum packaging systems and found that drip loss can be reduced without the application of a vacuum. The accumulation of juice from processed meat products is also a cause for concern in vacuum packs. Vacuum skin packs have an advantage over vacuum packs for processed meats in that there is no excess of film around the product, leaving virtually no space for product juice to collect (Mondry, 1996).

Condensation of moisture on the surface of the meat and the package may be prevented by carrying out packaging operations in an environment having a dew point temperature below the subject temperature (Rizvi, 1996). As stated previously, the packaging material as well as the fresh meat product must function together in terms of presenting a uniform and acceptable appearance, and presentation of the overall product in an acceptable manner is of paramount importance in terms of achieving adequate product sales. Visual distortion or product masking is undesirable in terms of presentation to the consumer and consequently, accumulation of condensation (or fogging) on the inside of the container lid must be avoided by minimising temperature fluctuations in the display. Additionally, anti-fog properties in fresh meat packaging film are provided by lowering the surface tension of the film through incorporation of wetting agents into the film formulation or by coating the surface with a wetting agent. Trays used for MAP of meat are often designed with patterned bases to disperse the drip which may accumulate on storage. In most cases, smart packaging elements in the form of extra absorbent pads are also included. More recently, smart technologies which provide tray materials with the capacity to absorb drip loss from fresh meat are being developed. These contain a layer of multi-absorbent material which resides in the base of the tray but above which lies a false perforated floor allowing the drip to migrate from the product to the base of the tray. Little by way of commercial uptake by the meat industry has occurred at this point.

2.5. Marbling and fat colour in fresh meat

The importance of fresh meat colour as a quality determinant should be seen in the context of overall appearance as perceptions of quality related to colour can be altered by other visual factors such as the presence and extent of marbling (Varnam & Sutherland, 1995). Marbling is the visible fat present in the interfascicular spaces of a muscle and the architecture of the muscle influences the pattern of fat deposition such that looseness of the fascicular organization generally parallels the quantity of interfascicular lipid present (Kauffman & Marsh, 1987). The intramuscular fat producing a marbling effect has been shown to affect flavour, juiciness, tenderness and visual characteristics of meat with increasing marbling in meat being linked to increased palatability (Miller, 2002). However, improvements in palatability with increasing fat percentage are not equal across all fat levels and fat levels exceeding 7.3% has been identified as too high by health-conscious consumers, consequently, meat with a fat content between 3 and 7.3% is generally considered acceptable (Miller, 2002).

Fat content preference however is market specific. Additionally, the colour of fatty tissues can vary from white to yellowish-orange and variation is due primarily to the type of feed consumed by the animal (forage versus concentrates) and the biological ability of the animal to convert fat-soluble compounds (such as carotene: yellow) to other forms (such as vitamin A: almost colourless). The yellow colour does not affect the palatability of the cooked product, but is considered objectionable by most consumers because fat is usually white or off-white, a yellow appearance often suggesting (incorrectly) that the tissue necessarily originated from an old, malnourished or unhealthy animal (Kauffman & Marsh, 1987).

The quantity of intramuscular fat or the degree of marbling is affected by many factors, namely: animal breed, slaughter weight (Candek-Potokar, Zlender, Lefaucheur, & Bonneau, 1999; Johnson et al., 1969; Keane, 1993), feeding strategy (Blanchard et al., 1999) and growth rate (Keane, 1993; Therkildsen et al., 2002). Consequently, as all of these factors pertain to animal production, meat processors need to understand how these factors can be manipulated at farm or production level so that visually acceptable meat can be tailored to suit niche market requirements.

Table 2 summarizes in general terms our current scientific knowledge and understanding of consumers cues at the point of sale and an indicative level of take up of this knowledge by the meat industry.

3. Eating quality

3.1. Enhancing the eating quality of meat

In order to produce meat of consistently high eating quality a thorough understanding of the important factors which influence quality is imperative. The meat industry is not regarded as a science-driven sector investing substantially in research and development. In fact it has a poor record of scientific capability compared to other sectors such as pharmaceuticals, information technology, or even its equivalent food sector, the dairy industry. The greatest amount of investment in meat research is through public funding agencies (national and international).

Results from focused research into meat eating quality revealed that tenderness, juiciness, flavour and overall palatability remain the most sought after attributes by consumers. Tenderness is deemed most important (Miller, Carr, Ramsey, Crockett, & Hoover, 2001). Furthermore, consumers are willing to pay more for guaranteed tenderness on one hand but up to 20% of steaks sold to consumers are tough (Miller, 2002).

It is generally accepted that the main determinants of meat tenderness are the extent of proteolysis on key structural proteins and the degree of shortening of the muscle fibres. Most evidence points to the calpains as the main proteomes involved in post-mortem tenderisation (Dransfield, 1993). Although their precise actions remain uncertain it is thought that calpains act by degrading strategic and structural proteins of the cyto-skeletal network such as titin, nebulin and desmin.
Shortened muscle fibres produce tough meat. This can occur when early post-mortem variables of pH, temperature and time interact in such a manner as to induce cold-shortening. Pre-rigor muscle shortens on exposure to temperatures below about 10 °C. The faster the temperature declines the slower the rate of glycolysis and therefore the greater the degree of shortening. Cold-shortening occurs as calcium is uncontrollably released into the sarcoplasm which in turn is due to the decrease in temperature and pH resulting in reduced ability of the sarcoplasmic reticulum and mitochondria to retain calcium.

The increase in concentration of free calcium in the presence of sufficient ATP results in increased shortening of the sarcomeres (Locker, 1985). Shortening causes the thick filaments to penetrate the z-discs and may interact with actin filaments in adjacent sarcomeres. This can result, in extreme cases, of the formation of a continuum of myosin throughout the myofibril (Marsh & Carse, 1974).

This dense structure is responsible for the increased toughness experienced by consumers of cold-shortened beef.

In relation to beef carcasses it follows that if pH, temperature and time post-mortem (i.e. the biochemical dynamics) of the early post-mortem period are critical in determining the tenderness/toughness of meat then meat throughout a carcass will experience a variety of biochemical profiles resulting in meat of highly variable eating quality. The rate of pH fall varies from animal to animal (O’Halloran, Troy, & Buckley, 1997) and the temperature varies considerably throughout a chill, a carcass and a muscle and hence their interaction is quite variable.

Meat science has contributed to providing scientific data that has been employed effectively by the meat industry to reduce the risk of cold-shortening. From understanding of the early post-mortem period specific recommendations have been implemented by meat processors.

### 3.2. Chilling rates

Chilling rates of beef carcasses to a limited extent can influence the rate of pH fall and thereby contribute to cold-shortening. The well known 10/10 rule i.e. no part of the carcass should fall below 10 °C within 10 h of slaughter (Troy, 1995) is implemented in many meat processing operations.

Various temperature and chilling regimes have been suggested (Savell et al., 2005) to avoid or reduce cold-shortening. Retailer specifications can go as high as maintaining carcass temperature above 12 °C for 12 h post-slaughter.

### 3.3. Hanging methods

Another method to reduce the degree of cold-shortening or increase the degree of stretching of sarcomeres is by altering the normal hanging method of carcasses. Conventionally hanging carcasses (by Achilles suspension from the Achilles tendon) induces some stretching of hind quarter muscles (Ahnstrom, Effalt, Hansson, & Lundstrom, 2006).

However, hanging carcasses by the pelvis (or the obturator foramen) is a much more effective method to increase the tenderness and to decrease the variability in eating quality of the commercially important primary meat cuts (Hostetler et al., 1970). Pelvic suspension (or tenderstretch) induces a stretching effect on key muscles preventing the sarcomeres from shortening and in some cases actually stretching the distances between z lines. This reduces the density of overlap between the filaments. Troy (1996) found that there were 15%, 30%, 33% and 30% average increases in sarcomere length from pelvic suspended carcasses of m. longissimus dorsi, semimembranosus, biceps femoris and the gluteus medius respectively. Sensory analysis showed that panelists consistently rated all muscles from pelvic suspended carcasses as more tender (average 20%).

Alteration of muscle shape, as a result of pelvic suspension was not considered a limiting factor.

Tenderness differences between steaks from conventionally hung compared to pelvic suspension carcasses was noted in those carcasses chilled faster (Sarheim et al., 2001) suggesting that less cold-shortening occurred in the latter.

The psoas major muscle is slightly toughened in pelvic suspended carcasses because of its particular position in the carcass. In Ireland and the UK pelvic suspension forms part of numerous retailer specifications often in combination with a slow chilling regime or in combination with electrical stimulation. The industry cites some drawbacks however including the requirement for more chiller space, demands for greater labour input and the distortion in shape of some muscles.

### 3.4. Electrical stimulation

The application of an electrical current to the carcass after the death of an animal is widely known as electrical stimulation (ES). ES has a long history of development dating back to the 1950s (see Chrystall & Divine, 1985). The primary reason for the use of ES in the meat industry is to allow rapid chilling of carcasses without the risk of cold-shortening. It also influences other aspects of meat quality. Many forms of ES applications are available varying in magnitude of voltage, current, frequency of pulses, and waveforms (Simmons et al., 2008).

Briefly the use of ES induces severe muscular contractions throughout a carcass. The resulting increased energy expenditure of the muscles due to contractions results in a rapid decline in pH. Consequently rigor develops early post-mortem thereby reducing the risk of cold-shortening should the carcass encounter rapid chilling (Troy, 1995). Generally, meat from ES carcasses is more tender than those of non-ES treated carcasses when placed in environmental conditions that would promote this quality defect. ES has also been reported to increase post-mortem temperatures in carcasses, increase the drip loss and water-holding capacity of meat and increase the brightness values of the red colour of beef (Eikelenboom & Smulders, 1985). Apart from its use in the avoidance of cold-shortening, three other mechanisms of tenderisation associated with ES are reported. Firstly, the disruption of the lysosomal sac with subsequent release of proteolytic cathepsins at low pH/high temperature environment (Dutson, Smith, & Carpenter, 1980). Secondly, the physical disruption of the muscle fibres brought about by severe contractions of the muscles (Sorinmade, Cross, Ono, & Wergin, 1982), especially in the case of high voltage stimulation (HVES see later) and, thirdly, a reduction in collagen cross-linking (Judge, Reeves, & Aberle, 1980). If these three mechanisms were induced by ES then major and consistent benefits in meat tenderisation would be inevitable. This is not the case and some reports suggest that ES induces a toughening effect (Pommier, Poste, & Butler, 1987) or in the absence of cold-shortening, accelerates the tenderisation process through increased initial activity of calpain brought about by inducing a higher temperature during rigor but then creating denaturing conditions which will reduce the effect (Dransfield, 1993; Simmons et al., 2008).

The reason for the many complaints is possibly due to the variability of the process of electrical stimulation (voltage, frequency, etc.), the type of carcass used, the subsequent chilling conditions and the location of the muscle sample within the carcass.

The meat industry often differentiates between two types of ES namely high voltage (HVES, 300–1000 V) and low voltage (LVES, 50–120 V) stimulation.

HVES is more expensive and requires greater safety precautions to be implemented. Apart from these drawbacks its HVES benefits over and above those of LVES are not immediately apparent from the literature. The rate and extent of pH decline is similar (Eikelenboom & Smulders, 1985; Koh, Bidner, McMillin, & Hill, 1987) for both HVES and LVES. Simmons et al. (2008) has suggested that HVES produces a
greater rate of pH decline and one which is more consistent and less variable than LVES treatments. A greater difference between pH decline was noted in terms of time of application (3 min versus 40 min after slaughter) rather than type of stimulation (high versus low) (Hwang & Thompson, 2001).

Furthmore, a faster, earlier decline in pH can cause detrimental effects on meat quality through the earlier reduction in activity in u-calpain combined with a relatively high calpastatin level resulting in tougher meat (Hwang & Thompson, 2001). Another risk due to “excessive stimulation” is the formation of a pale, soft and exudative (PSE) like meat which can occur through a very rapid pH fall early post-mortem when the carcass temperature is high. This condition has a profound effect on meat tenderness (due to heat-shortening), water-holding capacity (due to protein denaturation) and colour and stability (due to protein denaturation and the increase in free water resulting in increased reflectance) as well as lower oxygen consumption (Simmons et al., 2008). These detrimental effects can be minimised or eliminated by reducing the chilling temperature (Strydom, Frylinck, & Smith, 2005). ES (high or low voltage) hence should be seen as one component of a complex system or environment under which muscle is converted to meat. While it can reduce ageing times and increase the consistency of tenderness it can also contribute to the production of poor quality meat especially where cold-shortening is not a risk. A clearer understanding of the optimum pH/temperature environment throughout the carcass would aid greater precision in its application. Great care needs to be taken in avoiding over-stimulating beef carcasses. (O’Halloran et al. 1997) demonstrated that there is a great variability in the rate of pH decline in the first 24 h post-mortem between animals and the application of ES may not be required in some cases.

There is still an ongoing debate about the effectiveness of ES especially where high temperature and low pH conditions prevail in deep muscles over 24 h post-mortem. This problem can exist for ES and non-ES muscles and is problematic for beef processors.

3.5. Muscle restraint

Hot-boning is a process which was developed in response to commercial demands to lower energy usage and chiller space requirements (West, 1983). It can be described as the removal of muscle or muscle systems from the carcass prior to chilling (normally within 90 min post-slaughter). Benefits include reduced carcass weight loss, reduced drip loss, lower energy use, reduced chill requirements, reduced labour costs and increased functionality of proteins for use in further processed products (Pisula & Tyburcy, 1998). Despite such benefits, hot boning has not been adopted by the meat industry on a widespread basis. Certainly retrofitting of facilities, training of staff, hygiene considerations and a more careful synchronisation of the chilling, boning and processing operations would require modifications and investments. However one of the primary reasons for its poor uptake is the potential of hot boned muscles to shorten in the absence of skeletal restraint and produce very tough beef.

Recently, research has focused on restraining techniques of hot boned individual muscles to prevent shortening. This is not unlike targeting muscles and ensuring that they are prevented from shortening. The results generally show an increase in sarcomere lengths, decrease in shear force and an increase in tenderness (Sørheim & Hildrum, 2002).

Prevention of hot boned muscle shortening can utilise mechanical devices such as clamps to fix or stretch the muscle. Although cumbersome and time-consuming, the results are effective (Sørheim & Hildrum, 2002). A more practical approach however seems to be wrapping or tightly binding muscles in film (Devine et al., 1999) or using an elastic film (Meixner & Karnitzschky, 2001; Troy, 2006).

The latter is not used to any great extent on a commercial basis. However the Pi-Vac Elasto-Pack system (Meixner & Karnitzschky, 2001) allows the prevention of shortening of hot boned muscles through the stretching of extremely elasticated film into which the hot boned muscles/cuts are inserted and releasing the stretched film so that it binds extremely tightly all around the muscle. In this way, the low oxygen permeable film returns to its original dimension expelling most of the oxygen and preventing any diametrical expansion. This allows the immediate chilling of the muscles as low as 2 °C without any tendency to induce cold-shortening (Troy et al., in press). In fact the results showed that not only was tenderness increased and more consistent but also drip loss was decreased. Preliminary results further indicate that shelf-life may also be extended using a combination of hot-boning, Pi-Vac, lower temperature chilling (<2 °C) and normal ageing. Further studies are required to allow the industry to implement the TenderBound system. If effective in ensuring quality as described above as well as decreasing energy costs it has the potential to dramatically change the conventional methods of beef processing.

3.6. Flavour, juiciness and succulence

Flavour, juiciness and succulence are along with tenderness, important factors in meat palatability. Although very important to the consumers’ “experienced quality” during consumption it is difficult for the meat industry to influence these attributes during the processing of beef carcasses. Most alterations to these attributes occur during the pre-slaughter period or during further processing stages such as when muscle pieces are being cooked.

The flavour of raw meat is bland, slightly metallic and serum like. It is only upon cooking that a series of thermally induced complex reactions take place between the many different non-volatile compounds of the lean and fatty tissues (Calkins & Hodgen, 2007; Motttram, 1998).

Through a series of interactions and degradation of these components (peptides, amino acids, sugars, metabolites, nucleotides, lipids and components of lipid oxidation) the flavour of cooked meat is developed. Over one thousand volatile components of these reactions have been identified. Because the flavour of cooked meat depends on its water soluble components and lipids the distinct flavour differences between species (beef, pork, and lamb) is not surprising. The deposition of fatty acids is different between species resulting in different flavour components on cooking. Other pre-slaughter factors which effect cooked meat flavour are age, sex, stress level, amount and type of fat, as well as animal feed/diet. These differences all derive from the level and type of precursors in the muscle of the animal prior to slaughter. Flavour differences due to these parameters are not always clear, presumably due to the complex nature of flavour chemistry development. Calkins and Hodgen (2007) described contradictory findings for example in work on flavour precursors of grass fed versus concentrate fed animals where differences were described (Melton, 1990) and where no differences were identified (Muir, Deaker, & Brown, 2003).

Many other workers have studied the effects of feed on beef flavour (see Calkins & Hodgen, 2007). The majority of these report differences (if found) mainly due to difference levels of lipid depo- sition and fatty acid composition.

In many countries the degree of intramuscular fat (or marbling) determines the quality grade of carcasses. The role of marbling in meat palatability has been debated in the literature for many years. Intramuscular fat can vary from 0.5% to 8.0% but under normal production systems in Ireland averages around 3% (Maher et al., 2004). In the Meat Standards Australia (MSA) data base of over 55,000 beef samples tested by consumers Thompson (2002) concluded that the contribution of marbling to palatability was not high. In an earlier
study by Dikeman (1987) it was concluded that marbling accounted for only 10–15% of the variance in palatability.

Jeremiah (1996) reported a low relationship between palatability and marbling as found by a semi-trained laboratory panel as well as consumers.

Variation in flavour characteristics between muscles has often exercised the minds of researchers and the meat industry. Muscle flavour differences have been reported in many studies (see Calkins & Hodgen, 2007; Jeremiah, Gibson, Aalhus, & Dugan, 2003). Generally the differences in flavour intensity are small. Results from the study of Jeremiah et al. (2003) showed that sensory panelists scored “beef intensity” over a range of only 10% (one panel unit of ten) after tasting 33 different beef muscles. Slightly higher differences were shown in flavour intensity between major beef muscles in Carmack, Kastner, Dikeman, Schwenke, and Garcia Zepeda (1995) where the hindquarter muscles especially the biceps femoris showed the strongest flavour intensity.

Both Jeremiah et al. (2003) and Carmack et al. (1995) concluded that juiciness as measured by panelists was higher in the forequarter and loin muscles than the hindquarter muscles.

3.7. Post-mortem ageing

The biochemical events following the slaughter of animals contribute to the production of flavour precursors. Energy phosphates are depleted, proteolysis occurs through the disruption of lysosomal sacs releasing cathepsins as well as increased activity of the calcium dependant calpains. These and many other reactions contribute to the development of flavour precursors during conditioning. Jeremiah et al. (2003) reported that beef can be aged for up to four weeks without influencing significantly the overall quality of beef flavour. An inappropriate “livery” aromatic and aftertaste became more intense when beef was stored beyond 28 days.

Dry ageing is a process that can produce specific flavour characteristics. It is a high value product but has increased associated costs due to the greater weight loss during storage compared with normal meat ageing. Smith (2007) reported that dry aged cuts would need to command between 16.3 and 18.8% greater retail price than wet aged beef. Weight losses during the dry ageing process are in the order of up to 20% (De Geer et al., 2009).

Dry aged beef is normally stored at 0–4 °C uncovered for 3–5 weeks under a relative humidity of between 75 and 80% under controlled air flow. Because dry aged beef undergoes a greater degree of moisture loss there is a concomitant concentration of flavour precursors. This should result in a greater degree of beef flavour intensity. In a study by Warren and Kastner (1992) beefy flavour and brown/roasted flavour increased in intensity in dry aged beef.

Specific volatile flavour components in dry aged beef were detected in a greater proportion compared to wet aged beef (King, Matthews, Rule, & Field, 1995). Heptane for instance was suggested as deriving from auto-oxidation of oleate acid and may be associated with dry aged beef (King et al., 1995). The interaction of dry aged beef with air, and its more concentrated level of flavour precursors could contribute to a larger extent in the differences between volatile flavour components in dry and wet aged beef. However results from sensory and palatability studies differ in magnitude between wet and dry aged samples. For example, Warren and Kastner (1992) showed large differences in beef flavour profiles while other workers (Sitz et al., 2006) reported little differences in flavour or acceptability between wet and dry aged beef.

Presently dry aged beef is seen as a high value product sold in many expensive restaurants with a unique selling point. Table 3 summarizes in general terms our current scientific knowledge and understanding of consumers cues at the point of consumption and an indicative level of take up of this knowledge by the meat industry. There is a potential for the industry to adopt more of the available knowledge in practice. Furthermore there is still a knowledge gap in the area of measuring consumer cues on-line in meat plants.

4. Background cues (Table 4)

4.1. Safety

The importance of meat and poultry as vehicles of zoonotic pathogens is considerable in terms of the resultant public health and economic burden. Within the meat chain, Hazard Analysis Critical Control point (HACCP) provides the basis for the food safety management system. The seven essential steps for a HACCP plan are outlined by Codex Alimentarius Commission (Codex, 1991) and should cover all stages of the food chain from production, to catering and retail. In terms of hazards, it is well documented that many potentially harmful pathogens (Salmonella, Verocytotoxigenic E. coli in particular E. coli 0157:H7, Listeria monocytogenes, and Campylobacter) can be carried by animals and shed in their faeces and then directly or indirectly infect humans via the food or water chain. Pathogens can survive in faeces for extended periods ranging from several weeks to many months, providing an important transmission route for pathogens within herds, farms, the fresh food chain, water courses and the wider environment (Duffy, 2003). Control measures taken can range from good farming practices and general hygiene based measures to targeted approaches, specifically designed to reduce or eliminate carriage and shedding of key pathogenic bacteria by food animals or poultry. Treating animals with a range of biocontrol agents including probiotics, bacteriophage and bacteriocins have been shown to be capable of reducing pathogen carriage and shedding (Duffy, 2009). Vaccines are an alternative strategy, to preventing pathogen colonisation and carriage in food animals, (Potter et al., 2004) and are already used in the poultry sector. 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.

Pathogens in the gut and faeces of food animals presented for slaughter may be transferred to carcasses during slaughter and dressing operations. The risk of faecal contamination on the carcass from the gut contents 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. Recent risk assessments have however shown that hide (cattle) and fleece (sheep) are the most significant source of pathogen contamination on carcasses (Duffy, Cummins, Nally, O’Brien, & Butler, 2007). Because of the risk of transmission of E. coli O157:H7 from hides, many EU countries have implemented “clean cattle policies”. 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 organic acids but while widely used in the USA, they are not permitted under EU regulations. Research is ongoing to develop suitable hide decontamination methods.

The mixing of whole raw meats to produce burgers, sausages, steak tartar, etc., distributes the initial surface contamination throughout the derived product and increases the safety risk in such products. The primary control measure for such products remains adequate cooking of the product or stringent hygiene in the case of streak tartar, which is ready to eat. Research efforts are now directed at developing suitable biocontrols and physical treatments such as...
high pressure to control/eliminate pathogens from processed meats. The negative impact of such controls on sensory quality of the meat is often an issue and research in this area is ongoing. Fermented meat products, which are generally ready to eat, are reliant on a combination of factors including pH reduction, salt, end products of fermentation, and additives such as sodium nitrite to render them microbiologically safe, however *E. coli* O157:H7 poses a particular risk in these products due their ability to survive at low pH. Concerns in relation to the risk posed by *E. coli* O157:H7 have led to the recommendation that the processes for such ready-to-eat meats should achieve a log<sub>10</sub>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 have been most successful (Riordan et al., 2000).

It is, and will remain for the foreseeable future, a challenge for the meat sector, policy makers, and the regulatory authorities to reduce the burden of microbial meat borne illness. 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 performance objectives and microbial criteria for the food producer to achieve. One very important aspect of such food safety management systems, particularly where control has been lost at the point of manufacture, is through the effective use and operation of traceability systems.

Regulation EC (European Commission) no. 178/2002, defines traceability as the: ability to trace and follow a food, feed, food producing animal or substance intended to be, or expected to be incorporated into a food or feed, through all stages of production, processing and distribution (European Commission, 2002). Consequently, traceability involves managing the successive links between batches and logistic units throughout the entire supply chain (Ruiz-Garcia, Steinberger, & Rothmund, 2010). Regulatory agencies around the globe have now insisted upon the implementation and application of traceability systems for food stuffs in general, but particularly for meat products owing to the fact that the meat chain starts at production level through to the consumer with transport of product movement being particularly important at numerous points between.

In order for traceability systems to operate effectively and efficiently, the free and steady collection, processing and movement of information or data pertaining to food production and distribution must be known so as to avoid system breakdown. As the meat industry comes to terms with their demanded role within the traceability system, the requirement for the industry will be to come to terms with the operation of sophisticated data handling systems like those offered through the use of radio frequency identification (RFID) and wireless sensor networks (WSN) in order to satisfy regulatory requirements and alleviate consumer concerns.

5. The nutritional contribution of meat to the diet

The food that we consume today is scrutinized more now than it has ever been in the past in a whole variety of ways, such as: product composition, labeling concerns, clean labels, health claims, product ‘naturalness’, safety concerns, issues pertaining to the environment and sustainability. Like other products, meat is suffering from a negative image due to its presumed high fat content and the consequent linkage made to its consumption with specific health issues pertaining to cancer, heart disease and obesity (Demeyer, Honikel, & De Smet, 2008). However, this narrow view overlooks the fact that some of the most important micronutrients are best available from meat e.g., iron, selenium, vitamins A, B12 and folic acid, either because they do not exist in plant-derived food or because they have poor bioavailability (Biesalski & Nohr, 2009). Furthermore, meat is rich in proteins and poor in carbohydrates and thus, contributes to a low glycemic index, which is assumed to have positive effects with regard to obesity and the development of diabetes and cancer (Biesalski & Nohr, 2009). Consequently, meat can be viewed as having a double mirror image with respect to composition and nutrition, a negative image and a positive image; sadly with most emphasis being placed on the negative due to common misconceptions about meat and ignorance with respect to product quality and composition.

While meat is a complex and nutritionally important component in the diet, its composition varies with respect to numerous factors, including: species from which muscle is derived, muscle type, age of the animal, gender of the animal, animal growth rate and maturation, diet, genetic defects and disease status, medication and hormone usage, holding and rearing conditions as they pertain to temperature and relative humidity and general husbandry practices (Doyle, 1980; Doyle & Spaulding, 1978; Lynch & Kerry, 2000). While all of these factors play an important role in determining meat composition and can in most cases be manipulated to alter the nutritional profile of such products, diet is the factor which can most easily be manipulated and which has one of the most profound effects on meat composition, especially in meat derived from monogastric animals. Monounsaturated and polyunsaturated fatty acid composition can be altered in pig and poultry diets while conjugated linoleic acid, which is associated with positive health effects, can be altered through manipulation of forage diets in ruminants. Additionally, micronutrients like vitamin E, selenium and iron can be increased in meat through dietary supplementation.

While manipulation of meat composition is possible through dietary intervention, care must be taken to address consumer concerns in adopting such an approach as there has been a steady and growing consumer resistance to the incorporation of additives in muscle foods, whether raw or fully processed. This is particularly so for additives which are of synthetic origin, even when they have a nutritional or health advantage (Lynch & Kerry, 2000).

5.1. Beef consumption and sustainability

There is a growing availability of information regarding environmental costs of producing livestock. In this regard the meat industry must take into account how this information will influence the perception of meat quality by the consumer. While meat production is a traditional farming practice and often contributes to the preservation of traditional grasslands, an FAO report (Steinfeld et al., 2006) concluded that beef production results in considerable damage to the environment. Furthermore, although the growth in demand for animal products will be significant, almost doubling from 2000 to 2050, meat production and consumption will be more strongly linked to environmental impact and ultimately, climate change.

The agricultural sector accounts for about 22% of global total greenhouse gas emissions of which livestock production (including transport and feed) makes up 80% (McMichael et al., 2007). There is a growing trend in some reports to relate both the production of greenhouse gas from livestock production and the so called “health benefits” from consuming less meat (Stehfest et al., 2009). Stehfest et al. (2009) reported that a global transition to a low meat diet “as recommended” for health reasons can play an important role in future climate change mitigation policies.

Rightly or wrongly the meat industry must take these trends seriously. The growing field of sustainable consumption is offering consumers more information on the environmental impact of their food choices. The so called “carbon food print” gives the consumer a metric with which to measure the consumers responsibility for greenhouse gas emissions. The growth in farmers markets, organically grown food and locally produced products is a symptom of how the consumer is contributing and taking notice of these developments. In a study in the U.S., Weber and Matthews (2008) reported that a
dietary shift from red meat and dairy products towards chicken/fish/eggs could significantly reduce greenhouse gas emissions more than shifting to buying locally. It must be stated that at this point in the review, the concerns pertaining to sustainable meat production is presented in the context of current, or rapidly approaching, pressures being brought to bear on the meat industry. However, another factor which might be a more decisive factor in determining or shaping the future meat industry, and ultimately the level of meat consumption globally, will be when global economies encounter what has now been coined “peak oil”. In fact Aleklett et al. (2010) concluded that “the world appears to have most likely passed the peak of oil production and have entered the descent phase”. In any event, sustainability and sustainable agriculture will probably take on very different meanings into the future.

When “peak oil” has been declared, the ramifications for the global meat industry will be enormous, primarily because animal production costs will increase, but more importantly, the costs associated with the movement and transportation of meat products to existing markets may become unsustainable. In a very recent report from the International Energy Agency (2007) indicated that fossil energy made up about 81% of the total energy consumed in the world and that 98% of this was used by the transport sector. Clearly, if current practice is to continue, then alternative energy sources will need to be sought and adopted as a matter of urgency by the meat industry.

It is concluded that sustainability issues in relation to food choice is here to stay, diet shifts will be effected as part of the solution to climate change and that red meat will continue to be front and middle in these discussions.

5.2. Animal welfare

There is a growing concern by consumers with regard to how meat is produced especially in relation to animal welfare and organic/natural production. Consumers demand that animals are reared, transported and slaughtered under humane conditions. In Europe especially animal welfare is very important to its consumers (European Commission, 2005) and many countries have adopted legislation to administer and control recognised welfare standards.

The meat industry also places considerable importance on animal welfare. It is essential that consumers are confident that the meat they purchase is derived from ethically robust production systems. Retailers and other larger purchasers of meat are demanding transparency and in-depth auditing of production and processing facilities in order to ensure that their product (a) complies with legal standards and (b) satisfies at least the basic minimum animal welfare demands of their customers. The World Organisation for Animal Health (OIE) guidelines (OIE, 2005) are being adopted in more countries. Widespread use of animal welfare assurance programmes for corporate customers are now in use by the meat industry in industrialised countries (Fraser, 2006). The various formats and requirements to create animal welfare assurance programmes and the level of likely industry buy-in are examined by Fraser (2006).

As animal welfare can only be inferred from many external parameters, its measurement is difficult (Blokhuis, Jones, Geers, Miele, & Veissier, 2003). In order to ensure best practice the scientific basis for reliable welfare assessment systems must be clear, incorporated into welfare programmes and clearly communicated to consumers. This will allow the industry to clearly market their products on a sound footing. More recently risk assessment approaches to welfare are being developed (Blokhuis, Keeling, Gavinielli, & Serratosa, 2008). This should allow for greater understanding and appreciation of welfare issues and for the implementation of standards. It is important that the meat industry fully engages in this regard.

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<tr>
<th>Name of technology</th>
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<td>Visual scoring systems/cards</td>
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<td>Colorimetry</td>
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<td>Chilling</td>
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<td>Tenderstretch hanging methods</td>
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<td>Electrical stimulation</td>
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<td>Hot-boning</td>
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<td>Muscle restraining systems</td>
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+++ extensive, ++ moderate, + limited.

Table 4 summarizes in general terms our current scientific knowledge and understanding of the major background cues and an indicative level of take up of this knowledge by the meat industry. With regard to nutrition the industry has potential to exploit more the positive health benefits of meat and meat products.

6. Industry response

Consumer perceptions of meat quality are complex and difficult to measure. From the foregoing discussion it is clear that the meat industry must continually respond to consumer and market-led quality cues in order to remain competitive and sustainable (Table 5).

An excellent case study of such a response is that of the Meat Standards Australia (MSA) model which was developed to manage beef palatability (Thompson, 2002). The main critical control points (CCPs) from production, processing and value adding sectors of the beef supply chain were identified and their relative importance and impact on beef palatability, as measured by the consumer, was quantified and now forms the basis of the MSA grading schemes.

In general, there is a need for greater innovation and knowledge utilisation to enhance consumer perception (both expected and experienced) by the meat industry. The authors believe there has been much research carried out at various institutes and universities which has not transferred or been adopted by the industry. A number of reasons for this are evident. Firstly, the meat industry, although global, is quite fragmented with limited research capability. Secondly, the research and development investment by the industry is relatively small compared with other sectors. Thirdly, most meat research is carried out by public entities often with little intellectual “buy-in” from the industry. This creates a disconnect between the research outputs and their utilisation by the industry.

However, there are many major challenges and opportunities (not all presented in this paper) facing the industry presently. The negative publicity that red meat has received regarding its role in health, its impact on climate change and issues pertaining to biosecurity, have not helped in the further development of the meat industry which must evolve and expand to meet growing and future challenges. The positive attitudes towards meat are very much centred on its own unique selling points and composition, namely; as a source of high quality protein, its highly sought after taste and the foreseen increase in demand for such products over the next 30 years are some of the opportunities which could be exploited further. Issues such as our changing lifestyle, the demand for convenience and the predicted ageing profiles of the western world will require the meat industry to be more innovative.

Innovation is a key driver for economic growth. It requires investment aimed at producing new knowledge in a usable format.
It is not just about generating new ideas but translating these ideas into new value-added products and services. The current trends in innovation have identified the need for increased partnering and collaboration (e.g. along the supply chain, developing relationships between producers, processors and retailers), the need to utilise the latest information technology and participating in the growth of e-commerce in the meat industry (Henchion & McIntyre, 2010). The meat industry should develop a more strategic relationship with researchers and education providers. The industry and its leaders should be capable of articulating its needs in terms of enhancing consumer perception. Meat derives from a theatre comprised of a complex food chain possessing many actors. Generally, it is a conservatively minded industry and is often dominated by the international multiple retailers. For innovation to flourish, research and development activity must be fully supported from senior management. The industry should focus primarily on achieving consumer need or want. The rate of technological change is ever increasing. Key technologies of the future such as nutrigenomics (the impact of foods on genes), personalised food for health, exploitation of animal derived bio-active components (possibly already present in meat), smart technologies and nanotechnologies delivered via packaging materials and biotechnology will have major impacts in the food sector generally. However, for any new technology or process, consumer trust is paramount. Consumers must see clear benefits and any communication of risk must be well managed and transparent. Many companies are now embracing an open innovation policy whereby skills and knowledge are sourced outside the company. Initially this form of innovation was associated with fast growing high technology companies are now embracing an open innovation policy where any form of innovation was associated with fast growing high technology firms. More recently, large food companies are examining this form of innovation.

For the meat industry to remain competitive, while addressing consumer wants and needs, it must utilise knowledge from research while at the same time inputting into the research agenda. Table 5 summarises in general terms an indicative level of take up of technologies available to the meat industry.

### 7. Conclusion

Tarrant (1998) pointed out a number of research priority areas for the meat industry in product safety, product quality and product development. Technological developments in product safety have been taken up to a great extent by the industry in terms of robust HACCP systems and product traceability. Although the recent introduction by the beef industry in Ireland and other industrialised countries of an automatic carcass grading system the grade is still based on carcass fat cover, fat depth and conformation and not based on commercial yield nor eating quality attributes. A research goal for the industry should be the development of an objective grading system for eating quality attributes. The MSA system presents a strong basis for further development in this regard.

Finally product science based development and innovation still remains weak in the red meat sector and will need to be addressed in order for the sector to remain competitive.

### Acknowledgements

The authors would like to thank Drs. Geraldine Duffy and Maevie Henchion, Teagasc, Ashtown Food Research Centre, Michael O'Grady and Maurice O'Sullivan, School of Food & Nutritional Science, University College Cork, for their useful comments in the preparation of this manuscript. The authors would like to acknowledge the support of the European Commission Integrated Framework 6 Project ProSafeBeef “Advancing Beef Safety and Quality through Research and Innovation”, Project FOOD-CT-2006-36241.

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