Potential quality control tools in the production of fresh pork, beef and lamb demanded by the European society

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Abstract

As a result of the rapid changes in the market situation for foods, the market conditions for fresh meat have never faced bigger challenges than today. Ever-increasing consumer demands and subsequent claims from the retail trades combined with political ideas and increasing competitiveness are all issues which set new framework conditions for the present and future food production. This combined with, e.g., incidences of Salmonella outbreaks, use of antibiotics, dioxin in the feed, BSE (Bovine spongiform encephalopathy) and Foot and Mouth Disease in the production of meat animals have confronted the fresh meat marketing with enormous challenges to expand or even maintain present market shares of the total food production.

This paper outlines potential tools that can be implemented in the production of meat animals to control fresh meat quality and hereby fulfil some of the customer demands expected to dominate the market in the years to come. The quality control tools in question cover the whole chain from conception to consumption and include selection of genotype, feeding strategy, production system, pre-slaughter handling, stunning method and slaughter procedure, which separately or in combination can be used to meet customer demands for safety, technological quality, eating quality and nutritional quality together with sustainable and ethic quality aspects.

Keywords: Meat quality; Safety; Breed; Feeding; Management; Pre-slaughter handling; Slaughter procedure

1. Introduction

The ongoing dramatic changes in the international market place, caused by changing lifestyles and requirements of consumers in Europe and around the world, require high standards of quality assurance regarding diversity, quality and safety of products and the environmental, ethic and animal welfare aspects of the food production (Jamison, 2000). Consequently, the need for inclusion of the whole food production chain (from conception to consumption) to develop strategies for production of foods with high quality has never been more urgent. In relation to fresh meat, some of the most crucial quality characteristics demanded by the European society of today and tomorrow are outlined in Table 1.
The following is a systematic review of some of the more evident production traits, which have been shown to control the quality of fresh beef, lamb and pork.

2. Safety

Safety has become the number one issue of concern in modern food production. Consumers have become increasingly anxious, most often driven by the large number of safety crises, which especially has hit the meat area (hormones, BSE, antibiotics, tranquilizers, dioxin) and subsequently exposed by the media. These consumer concerns and the focus from the media have enforced the politicians to act on this very emotive issue.

A comprehensive “conception to consumption” approach is the most effective way to address the safety issue in fresh meat production. The combination of serologic and bacteriologic surveys in the whole production chain coupled with improved management (e.g., sectioning and all-in-all-out production), feed structure (e.g., wet feeding and increased coarseness), feed regulations (e.g., required heat treatment of the feed and regulation/termination of antimicrobial growth promoters) and hygiene standards in national control programs have already shown impressive results in the campaigns towards pathogens (Wierup et al., 1992; Wegener et al., 2003).

Strong international actions have been taken to combat food born pathogens. One such example is the WHO Global Salm-Surv (GSS) network with the objective to strengthen and enhance the capacities of national and regional laboratories in the surveillance of *Salmonella*, the other major food borne pathogens and the antimicrobial resistance in *Salmonella* and *Campylobacter* from humans, food and animals [http://www.who.int/salmsurv/en/].

Likewise, actions and new control plans will continuously be developed (Reinders et al., 2001) and implemented to control and eliminate other safety factors of importance for fresh meat production. Most of these will be included in regulation of feed (e.g., allowed components, limit values etc); however, further spreading of outdoor production systems in the light of demand for organic or well-fare enriched systems might also call for environmental claims in the future.

### Table 1
Demanded fresh meat characteristics

<table>
<thead>
<tr>
<th>Trades</th>
<th>Individual elements</th>
<th>Examples</th>
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<tr>
<td>Safety</td>
<td>Pathogens</td>
<td><em>Salmonella</em> DT104, <em>E.coli</em> 0157</td>
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<td></td>
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<td>Residues</td>
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<td>Contaminants</td>
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<td>Eating quality</td>
<td>Appearance</td>
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<td>Flavour</td>
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<td></td>
<td>Tenderness</td>
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<td></td>
<td>Juiciness</td>
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<td>Healthiness</td>
<td>Lean</td>
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<td></td>
<td>Lipid content/composition</td>
<td>PUFA, CLA</td>
</tr>
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<td></td>
<td>Vitamins</td>
<td>Vitamin B</td>
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<td></td>
<td>Minerals</td>
<td>Iron</td>
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<tr>
<td>Traceability</td>
<td>Origin</td>
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<td></td>
<td>History</td>
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<td></td>
<td>Diversity</td>
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<td>Wholesomeness</td>
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<td>Outdoor rearing</td>
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<td>Ethics</td>
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<td></td>
<td>Sustainability</td>
<td>Organic farming</td>
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<tr>
<td>Convenience</td>
<td>“Fresh and appealing” for days</td>
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<td>Technological quality</td>
<td>Water holding capacity (WHC)</td>
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<td>pH-value</td>
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<td>Protein content and its characteristics</td>
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<td>Lipid content and its characteristics</td>
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<td></td>
<td>Content of connective tissue</td>
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<td></td>
<td>Anti-oxidative status</td>
<td></td>
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<tr>
<td>Price</td>
<td>WHC</td>
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</tbody>
</table>

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2. Safety

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3. Eating quality

The eating quality of meat is still the most important factor for the consumers in relation to rebuying meat products. The single eating quality attributes of interest are:

- **Appearance**: Appearance determinates the consumer’s purchase of meat in the modern society, as
appearance most often has become the customer’s single factor to evaluate the quality of the product. Consequently, consumers look for colour, fluid retaining characteristics and fat content of meat.

- **Flavour**: Meat flavour represents a large number of compounds formed during heating of the product. The flavour development mainly depends on constituents in the fresh meat, e.g., fat composition, peptides, glycogen concentration, vitamin content, especially thiamine and vitamin E, etc., and the heat treatment of the product. Increasing temperatures increase flavour development.

- **Tenderness**: For years, the tenderness of meat has been recognized to be the single most important factor in consumer acceptance (Bratzler, 1978; Taylor et al., 1995a), as this attribute is often the cause of consumer complaints (Pearson, 1994).

- **Juiciness**: Juiciness is associated with the amount of moisture present in the cooked product and the amount of intramuscular fat.

### 3.1. Genotypes and breeds

Even though genotype is known to have significant effect on the eating quality of meat, the present knowledge within the area is scattered. Existing knowledge about pigs are often based on rather old data and the general acceptance of the Duroc breed resulting in pork of higher eating quality might be historic, as this often has been associated with the high IMF content of this breed. This characteristic has almost been eliminated due to the substantial effort to increase carcass lean content using the combination of breeding and improved nutritional and management practices. In Sweden, there is a general acceptance of better eating quality characteristics of pork products from the Hampshire breed carrying the RN gene despite the inferior effect of the gene on the technological quality of the meat (Lundström et al., 1996). Finally, as ultimate pH is directly related to tenderness, a reduction in muscle glycogen level obtained through selection ($h^2=0.37$) (Oksbjerg et al., 2001) will indirectly increase tenderness in pork meat. However, an uncritical selection for increased pH could lead to an increased incidence of DFD (Dark firm and dry) carcasses.

In lambs, no general pattern can be set up regarding differences in eating quality between breeds (Hoffman et al., 2003). The only well-described difference in eating quality is between lambs expressing the callipyge phenotype and normal lambs, with inferior juiciness and tenderness of meat from fast twitch muscles of callipyge lambs (Koohmaraie et al., 1995; Shackelford et al., 1997; Goodson et al., 2001).

In cattle, one well-known breed difference with regard to eating quality is the one found between Bos indicus and Bos taurus cattle. Thus cattle with 1/4 or more influence of B. indicus are rated less tender than B. taurus cattle. This seems to be associated with differences in muscle protein turnover in the living cattle (Wheeler et al., 1994). With regard to differences between B. taurus breeds, it is very much a question of maturity, weight, fatness and management system. However, a Danish survey of eating quality between breeds clearly showed that meat from Jersey is rated superior regarding tenderness compared with beef cattle breeds (Ovesen and Pedersen, 1999). The same pattern was seen in an experiment with beef cattle crossed with Danish Friesian compared with purebred Friesian, as meat from the purebred Friesian was more tender than that of the beef cattle crosses (Refsgaard Andersen et al., 2001). The animal gender may also be a cause of variation in the eating quality of beef. Meat from steers is often more tender compared with meat from bulls, which can be related to the rate of proteolysis postmortem in favour of steers (Morgan et al., 1993a,b). Less intramuscular fat (IMF) and higher risk of stress in relation to transport, lairage and slaughter are other causes to the inferior quality of meat from bulls compared with meat from steers and heifers.

### 3.2. Management systems

A few traditional production systems, e.g., Iberian pig production in La Dehesa (Lopez-Bote, 1998) and the certified Parma ham production, are examples of unconventional production systems which have survived due to production of products with specific and highly demanded characteristics. These production systems have served as models for several attempts to introduce new production systems, e.g., free-range systems. At present, only scarce knowledge is
available regarding the influence of these systems on eating quality, and some of the data available often encounter eating quality problems rather than improvements. Thus, the introduction of these systems may just be another challenge for the future as suggested by Jakobsen and Hermansen (2001), Nilzen et al. (2001) and Lopez-Bote and Rey (2001).

However, as stated by Sanchai-Jarurasitha et al. (1998), variation in carcasses and meat quality from these ‘new’ production systems are not due to the rearing system alone; genetic factors, feeding and pre-slaughter handling are just as important. In conclusion, introduction of many of these ‘new’ production systems calls for establishment of quality assurance programs, which can ensure that the demands of the customers are fulfilled, for the production systems to be competitive.

3.3. Feeding strategy and diet composition

The feeding strategy and the composition of the diet may influence the eating quality.

Thus, restrictive feeding gives rise to inferior eating quality (tenderness) compared with ad libitum feeding in pigs (Ellis et al., 1996; Danielsen et al., 2000; Kristensen et al., 2002) and cattle (Aberle et al., 1981; Therkildsen et al., 2002a). Recently, it has been shown that a feeding strategy allowing for compensatory growth, i.e., restrictive feeding followed by ad libitum feeding may increase tenderness in meat from pigs (Kristensen et al., 2002; Therkildsen et al., 2002b) and cattle (Allingham et al., 1998) beyond meat from ad libitum fed animals. Likewise, feeding strategies based on pasture may lead to inferior eating quality such as lower tenderness and off-flavour ratings compared with grain-fed animals; however, this can be dealt with by introducing a finishing feeding period on concentrate (Vestergaard et al., 2000).

No convincing data exist regarding a direct positive effect of feed composition on meat flavour; however, several examples are described in the literature where feed components give rise to off-flavours such as rape seed (Brassica napus) with high content of bitter compounds or fish meal (Hertzman et al., 1988). Consequently, such feed components should be excluded from the diets, especially when dealing with monogastric animals.

3.4. Pre-slaughter handling

Transport of cattle has long been recognized to influence the quality of beef, e.g., incidence of DFD (dark, firm and dry) meat (Price and Tennessen, 1981), which in turn is known to influence eating quality. A recent study has shown that 3 h transport of bulls before slaughter gave rise to optimal tenderness and overall liking of the meat compared with either 30 min or 6 h of transport (Villarroel et al., 2003), indicating that a delicate balance between long-term stress and short-term stress is of importance for beef quality development. Likewise, the time of lairage before slaughter and mixing of animals are factors that may lead to depletion of glycogen and increase the incidence of DFD meat (Price and Tennessen, 1981; Bartos et al., 1993; Kreikemeier et al., 1998).

Likewise, it is known that transport of pigs may influence final pork quality. Thus, 8 h of transport compared to 0.5 h has been found to improve tenderness due to reduced glycolytic potential at the time of slaughter and subsequent higher ultimate pH (Leheska et al., 2003). In addition, van der Wal et al. (1997) found that 3 to 4 h resting period before slaughter was optimal with respect to pork quality.

3.5. Slaughter procedures

Chilling rate has been found to influence tenderness development in meat and both too rapid and too slow chilling rates results in inferior tenderness development. However, moderate chilling rates, which slow down postmortem processes and hereby minimize muscle contraction, have been developed and implemented as a control tool in the production of beef and lamb meat in many countries.

According to Pearson and Dutson (1985), electrical stimulation of beef and lamb carcasses reduces cold shortening in muscles exposed to accelerated chilling. This has a beneficial effect on tenderness. Moreover, data has also confirmed that electrical stimulation may be a control tool in the production of pork with superior tenderness, when rapid chilling of carcasses is used (Savell et al., 1977; Smith et al., 1977, 1980; Taylor et al., 1980, 1995b; Chrystall, 1980; McKeith et al., 1981; Taylor and Martoccia, 1995; Bowker et al., 1999; Maribo et al., 1999; Aalhus et al., 2001).
Finally, suspension of carcasses from the aitch bone (pelvis) shortly after slaughter and before commencement of rigor is an alternative to electrical stimulation upon use of accelerated chilling systems (Taylor, 1996), and hereby improves tenderness in valuable cuts of pork, beef and lamb (Joseph and Connolly, 1977; Dreyer et al., 1979; Møller and Vestergaard, 1986; Møller et al., 1987; Eikelenboom et al., 1998; Solomon and Lynch, 1991; Taylor, 1996).

4. Healthiness and nutrition

From a nutritional viewpoint, meat has in general suffered from a bad reputation, and excessive meat intake has been coupled to the epidemic development of obesity and increased risk of certain cancer forms (American Institute for Cancer Research, 1997; Baghurst et al., 1997). This has given and still gives meat a negative image in the public. However, recent results show the opposite, when meat is consumed in moderate quantities (Singh et al., 2003; Michaud et al., 2003). In addition, meat is rich in iron, vitamins and amino acids of which some can be controlled through dietary treatment of the meat-producing animals.

4.1. Genotypes and breeds

One of the most convincing examples of meat producers’ success in responding to market pressures is the increasing production of leaner meat. Especially, an enormous effort within pig production took place during the 60s, 70s and 80s in the past century, which led to more than a 50% reduction in back fat thickness and a simultaneous increase in lean meat content in many European countries (Wood, 1995; Cameron et al., 1999). This substantial improvement in carcass lean content was the result of implementation of several changes in production, especially, better genetics and nutrition.

Meat is known as a superior iron source. Moreover, intake of meat is known to enhance the absorption of non-heme- (Martinez-Torres and Layrisse, 1971; Cook and Monsen, 1976) and heme-iron (Hallberg et al., 1979; Martinez-Torres and Layrisse, 1971) from other foods. This is probably due to presence of a yet undefined ‘meat-factor’. Consequently, increased intake of meat may lead to improved iron status in iron-deficient populations.

The heritability of muscle pigment (myoglobin and haemoglobin), which is an iron source known for its high bioavailability, is found to be 0.17 in vivo (Oksbjerg et al., 2001) and 0.39 in postmortem samples from pigs (Larzul et al., 1997). This renders that the muscle pigment content in pigs and most probably also in most other meat-producing animals could be increased through genetic selection and hereby contribute to an even more superior nutritional value of meat.

4.2. Management systems

Even though no direct data are available regarding the effect of management systems on the healthiness of fresh meat, free-range and organically reared pigs, fed restrictively with a concentrate diet (~70%) and with free access to roughage, have been reported to have increased lean yield (Sather et al., 1997; Danielsen et al., 2000; Sundrum et al., 2000). This can of course be used in nutritional recommendations from derived products. Moreover, the fatty acid composition of meat from free-range pigs including organic pig production systems has been reported to be more unsaturated compared with meat from conventionally reared pigs (Hansen et al., 2000; Nilzén et al., 2001).

4.3. Feeding strategy and diet composition

As mentioned above, improved nutritional practices in combination with genetic selection has improved the leanness of pork considerably, hereby conforming to the previous demands in relation to placing pork as a healthy ingredient in human nutrition.

Extensive experimental evidence exists for feed-induced optimisation of the fatty acid profile, i.e., optimal ratio between saturated, monounsaturated and polyunsaturated fatty acids, to meet the dietary recommendations for humans in their intake of pork, beef and lamb meat (Enser et al., 1998; Jakobsen, 1999; Ponnampalam et al., 2001).

Over the past two decades, numerous health benefits have been attributed to CLA in experimental animal models including actions to reduce carcino-
genesis, atherosclerosis, onset of diabetes and body fat mass (Belury, 2002). Ruminant meat is a natural source of conjugated linoleic acid (CLA) (Mulvihill, 2001). The CLA content in beef and lamb meat has been found to be able to increase through strategic feeding containing either grass (French et al., 2000; Nurnberg et al., 2001) or elevated levels of soybean oil and forage (Griswold et al., 2003).

5. Traceability

Since the 1980s, concerns about the safety and quality of food have increased at both governmental and consumer levels. This has been stimulated by a number of food scandals (hormones, salmonella, BSE, antibiotics, dioxin, etc.). The importance of traceability of animals and animal products has grown as food production and marketing have been removed further from consumer control.

Product traceability requires a transparent chain of custody to maintain credibility and to complete information transfer functions. It consists of two components, (I) a unique identification system, and (II) a credible and verifiable mechanism for identification of preservation (McKean, 2001). Moreover, traceability systems can be divided into subcategories, e.g., country of origin, retail, processor and farm to retail identity.

As a consequence of the recent outbreak of BSE in Canada, USDA has started a collaborative initiative through ‘The National Animal Identification Team’ (NAIT) under the title ‘Protecting American Animal Agriculture’, which aims to introduce a national registration of farm animals, one of the reasons being to facilitate extermination of livestock diseases and control outbreaks of especially foreign origin. This initiative falls in line with the growing wish for increased traceability by the American consumers.

Although present initiatives in using traceability systems do not live up to all the intentions in the introduction of these systems, further development in management technologies will undoubtedly fulfill and multiply product traceability requirements. In the near future, public and private sectors must be expected to seize the opportunities to improve public health and quality characteristics, or risk a narrowing of their markets upon introduction of traceability systems.

5.1. Management systems

In Europe, several countries have worked with and implemented different identification systems in meat production, most often based on different types of ear tag systems and more recently ear chips, which then follow the carcasses and in more developed systems also the products.

5.2. Feeding strategy and diet composition

Introduction of GMOs (genetically modified organisms) in the feed production and the ever-rising consumer concern continuously call for methods, which can test GMOs in feed. This is important; if the meat producers shall sustain, or maybe, what is even more urgent, regain trustworthiness of the consumers. New methods are currently developed to trace GMO in feed (Ronning et al., 2003; Lyn et al., 2000). This will create the basis for European legislation regarding organic meat production and general control of feed to fulfill consumer demands.

Like the GMO case, general assessment of the safety of animal feed becomes a necessary task in future traceability systems taking into consideration the feed-related safety crises of recent years (BSE, PCB [polychlorinated biphenyls], dioxin, etc.).

6. Experiences

The image of and the previous experience with a specific food become more and more decisive in the purchase situation (Grunert et al., 2004). Consequently, food image and reputation, whether based on facts or anecdotal, become more and more urgent in food marketing. This is also true for meats, for which reason overall image and reputation of fresh meat are absolutely vital, if the farmers, slaughterhouses and the manufacturers of processed meat are to remain in business. Image and reputation of meats are main obstacles in fresh meat marketing, as meat has a negative image in the public both due to food scandals of past years and the anecdotal statement of present-day meat being fat and not proper from a nutritional viewpoint. A recent survey of attitudes towards meat among adolescents in Norway supports the existence of this viewpoint, as females tended to associate meat
with “heavy” food that had negative impact on their bodies (Kubberud et al., 2002). Consequently, there is an enormous interest from the meat industry to find solutions to overcome this problem.

### 6.1. Genotypes and breeds

Introduction of old breeds, which have not been exposed to genetic selection for decades, has become one of the tools to improve the image of meat (Santos e Silva et al., 2000; Holló et al., 2003). This approach allows introduction of the term “original”, which has shown potential in successful marketing of foods.

### 6.2. Management systems

The change from confinement to more free-range systems has been one of the tools to sell stories and improve marketing of meats. The promotion of such meat production systems has been based on anecdotal information rather than on real fact regarding the obtained overall quality.

In several countries, the first attempts to use the information obtained throughout the whole production chain have been tested in different marketing strategies. The overall reason has been to give the consumer the possibility of full assessment of the chain and simultaneously evoke positive associations to the product through the efforts made to meet the demands of the consumers. In Denmark, a major project including marketing of high-quality beef was concluded in 1999. This project aimed to establish and test an integrated production of beef from heifers with full traceability from “gene to fork”, which was made visible for the consumers at the time of retailing specific beef products. This concept allowed the consumer to get all the information through five images: (1) Where does the meat come from?—(2) Where and how has the heifer been raised?—(3) What is eating quality?—(4) What is carcass quality?—(5) What is meat quality?; using a scanner placed immediately beside the cool display. In general, the concept was experienced positively; however, during the test period, the interest for using the facilities decreased. In general, the concept raised the expectations to the quality of the meat. This seems to be a general phenomenon when meats are appraised in one way or the other (Grunert et al., 2004).

Another successful example of building histories into foods is the growing popularity of farmers markets’ (FM), which attract customers through diversity of products and an opportunity for the public to learn more about local produce (Griffin and Frongillo, 2003). This direct exposure/contact with the used management system is in complete agreement with the consumer trend toward confidence and nearness in the marketing of foods. If FM is to constitute a sizeable market potential with the aim to build in experiences into food marketing, a continued focus on the experiences and perspectives of farmers and other market vendors is needed, in addition to an identification of ways for enhancing cooperative FM enterprises.

One of the more extreme ways of integrating management systems in the experiences of buying meat is to make the customers buy the meat while the animal is still alive and request that the customers only will receive the final product, if they take part in the management of the animal. Such concepts have already been developed in different parts of Europe. Most of these concentrate on beef production and often claims that the customer has to take part in the management for free in a period of 3 days to a week and sometimes twice this period, sometimes spread over 2 years. Such concepts draw heavily on the individual farmer and must be expected only to appeal to a limited number of prospective customers.

Finally, diversity is becoming a major factor in the experience of the daily buying situation. The consumers’ variety-seeking tendency (intrinsic desire for variety) is recognized as an important characteristic that influences consumers’ food choice behaviour (van Trijp and Steenkamp, 1992). Moreover, the recognized positive impact of household income on food variety (Thiele and Weiss, 2003) clearly states that diversity will become an ever-increasing factor in future food marketing due to the increasing allowances for food consumption in most industrialized countries.

Consequently, consumers’ demand for food diversity might be one of the driving forces in the development of new concepts for fresh meat production, i.e., meats that differ in quality attributes, using all the possible quality control tools from conception to consumption mentioned in the present paper and schematically outlined in Table 2. Hereby the
### Table 2
Tools for controlling quality traits of fresh meat

<table>
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<th>Quality traits</th>
<th>Specific characteristics</th>
<th>Tool</th>
<th>Response</th>
<th>Species</th>
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<td>Reduction, elimination</td>
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<td>Pigs</td>
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<td>Lean</td>
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<td>Wood and Ensler, 1997; Jakobsen, 1999</td>
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<td>Free fatty acids</td>
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<td>Improved FFA ratio</td>
<td>Lamb</td>
<td>Griffin and Frongillo, 2003</td>
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<td>Wholesomeness</td>
<td>Natural and healthy food</td>
<td>Organic products, GMO-free, functional foods</td>
<td>Positive aspects of meat safety and animal welfare</td>
<td>Raewell, 1999; Verbeke and Viaene, 2000</td>
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<td>Convenience</td>
<td>Pre-cooked products</td>
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<td>Pigs</td>
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<td>Water holding capacity</td>
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expected significance of the diversity attribute in meat marketing in the years to come could be decisive for the direction and demand for research and development within the area of meat production.

7. Wholesomeness

One of the most striking consumer trends during the past years is the increasing demand for natural and healthy foods where also the ethical issues (animal welfare and health) are taken into consideration. This has led to development of a new ‘wholesome food’ market category (organic products, GMO-free items, functional foods) (Raewell, 1999). Introduction of the wholesomeness concept in the meat production, most often represented by organic production, is mainly due to a wish for reestablishing a positive meat sector image, e.g., meat safety and animal welfare aspects (Verbeke and Viaene, 2000). Moreover, policy factors (e.g., governmental support) have also been identified as driving issues for conventional producers to slowly change towards organic production (McEachern and Willock, 2000). A recent survey in Scotland indicates that the consumers appear to delegate responsibility for ethical issues in meat production to the meat retailer or the government. This is so, because the consumers do not seem to wish to be reminded about issues connected with the animal when choosing conventionally produced or organic meat (McEachern and Schroeder, 2002). Moreover, organic meat was perceived as expensive even more so as the consumers did not perceive a positive difference in quality. This may be the reason why the consumers considering moral choices were more interested in conventional meats with added-value features (e.g., animal welfare).

8. Convenience

Convenience of food is related to three characteristics: (I) preparation, (II) delivery and (III) service. The ‘convenience-driven’ consumer segment is in general characterized by not being concerned with meat quality and safety and wanting to transfer the responsibility when purchasing meat (Bernués et al., 2003). In contrast, importance to brand names and not at least cooking recommendations are in focus. Other factors of importance are handling and shelf life, as these add flexibility and simplicity to the application of the meat. Finally, electronic trade seems to be another convenience element in the future and numerous virtual marketplaces and online shops connecting several chain levels already exist for meat products (Fritz et al., 2001). How this market will develop cannot be foreseen; however, the conventional way of marketing meat products will without doubt be transformed, as many virtual trade platforms will perform across numerous chain levels.

Even though factors in the production of meat have no direct influence on the convenience of the products, several factors are of importance in the production of meat marketed to the ‘consumer-driven’ consumer segment.

8.1. Feeding strategy and diet composition

The effort in past decades to produce uniform carcasses has been an indirect advantage in obtaining meat cuts and products, which fit into the ‘convenience-driven’ consumer segment, as this gives rise to higher uniformity suitable for simple handling/preparation procedures.

Lipid oxidation giving rise to off-flavour is the most important factor besides microbial spoilage, which determines the shelf life of meats. Consequently, the anti-oxidative status of meats is a limiting factor in the production of especially preheated meat products. Therefore, both lipid characteristics and the content of antioxidants, especially vitamin E, are factors of importance for the suitability of fresh meats in marketing and production of convenient products. Feeding favouring meat with a lipid composition, which does not make the products prone to oxidation and/or supplementation of vitamin E, should be recommended for meats used in several convenient meat products. These are often precooked and thereby develop inferior flavour upon re-heating, i.e., (warmed-over-flavour [WOF]) (Tims and Watts, 1958). This is reduced substantially upon dietary supplementation of vitamin E (Asghar et al., 1991; Granit et al., 2001; Lopez-Bote et al., 2001).
9. Technological quality

The meat-processing industry is the biggest customer of fresh meat, buying 65–80% of the total meat production. Characteristics demanded or needed by the food processing industry are therefore important issues to consider. Safety is the major issue, as control of safety during processing and distribution of meat products according to legislation calls for high safety demands. Even though the meat-processing industries have to fulfil many of the consumer demands mentioned elsewhere, they still need to be competitive to stay at the market. Consequently, also factors of importance for yield and shelf life of meat products are of main importance. These include:

- **Uniformity.** The term uniformity includes muscle size, lean meat content and marbling pattern. Uniformity is crucial in brand production and becomes increasingly important as a consequence of the ongoing automation at the slaughter line and in the meat-processing industry.

- **Water-holding capacity (WHC).** WHC includes the ability of the fresh meat to retain the water and bind extra water. The higher WHC, the more valuable the meat will be for use in highly processed products.

- **Lipid characteristics.** If the lipid becomes too unsaturated, the meat is not suited for, e.g., sausage production. Furthermore, products become oxidative unstable which accelerate rancidity problems, especially in many preheated catering products with increased incidence of development in warmed-over-flavour (WOF).

9.1. Genotypes and breeds

Identification of the halothane and RN\(^{-}\) genes (major genes) and their consequences for technological meat quality of pork (inferior WHC) are good examples on how such knowledge can be used in the control of demanded quality (Eikelenboom and Minkema, 1974; Mitchel and Heffron, 1982; Lundström et al., 1989; Naveau, 1986; Le Roy et al., 2000). The halothane gene has been almost eliminated within most of the major pig breeding companies, and a strong effort is made to eliminate the RN\(^{-}\) gene in the pig population in several countries. This has caused a dramatic decrease in the incidence of PSE (pale, soft and exudative) meat triggered by the presence of the halothane gene with positive consequences for the economy in pig production. Moreover, an elimination of the RN\(^{-}\) gene is expected to reduce the drip loss in pork with approximately 1% unit and improve the yield of cooked hams considerably.

Indications of a major gene for intramuscular fat in pigs (Janss et al., 1997) may also affect control of lipid characteristics in pork and hereby the technological quality, if this knowledge is used in the various breeding schemes.

Finally, the originally Bisaro pig breed, which despite its poor growth rate, bad conformation, and excessive adult weight and body size, is well known to give rise to an excellent meat quality, suitable for processing, may also be of interest (Santos e Silva et al., 2000).

9.2. Management systems

Standardized production systems are of high priority for the modern meat industry, which is based on slaughter lines with rapid carcass flow and renders meat of known quality (high uniformity) compared to many of the alternative management systems or niche productions, which are emerging due to customer demands. This paradox is often solved by the industry through contract production, which allows batch slaughtering, or implementation of quality assurance schemes (see below).

9.3. Feeding strategy and diet composition

An extensive number of feeding strategies have been proven to be potential control tools in the production of meat with superior technological quality. Especially in monogastric animals, feeding is an excellent control tool as many dietary components are readily transferred from the feed to the muscle and fat tissues. Thus, the fatty acid composition in the diet (Wood and Enser, 1997) and vitamin composition, e.g., vitamin E supplementation (Buckley et al., 1995), has a direct influence on the quality of the meat. Furthermore, it has recently been shown that the muscle glycogen stores in pigs at the time of slaughter can be reduced through feeding (Rosenvold et al., 2001a,b, 2002), which in turn reduces the rate...
of the pH decline. The rate of pH decline determines the development in technological pork quality. In contrast, controlling meat quality by feeding ruminants is more complicated. However, it has been shown to be possible in some cases, e.g., fat colour and fatty acid composition.

The “softness” of meat can be a problem for further processing (e.g., sausage production), and especially in pork this is recognized as a problem, when the animals have been fed too high a content of polyunsaturated fatty acids (Ellis and Isbell, 1926; Hays and Preston, 1994; Jorgensen et al., 1996; Warnants et al., 1998; Cameron et al., 1999). Consequently, 16 g linoleic acid/kg feed has been recommended as a common threshold value for formulating pig diets in the UK (Wood and Enser, 1997) and has become a rule-of-thumb in common slaughter pig production.

Oxidatively stable raw materials, which (I) can cope with conditions taking place during processing, (II) are suitable for production of meats that are meant for reheating and (III) fit the demand for products with a high content of polyunsaturated fatty acids, are necessary to obtain a profitable shelf life of the products (Allen and Foegeding, 1981; Sheard et al., 2000). Consequently, any possibility to elevate the anti-oxidative status of raw materials through supplementation of antioxidants to the animals is desirable, as supplemented antioxidants have shown to be a superior method to increase the oxidative status in muscles.

Fed supplementation of vitamin E has been shown to be the most optimal way to protect against lipid oxidation in meats and hereby increase the shelf life and palatability of the products. When fed above requirement levels (e.g., 200 mg/kg feed), vitamin E increases the oxidative stability in fresh pork and pork products considerably (Asghar et al., 1991; Buckley et al., 1995; Jensen et al., 1997, 1998; O’Sullivan et al., 1998; Lauridsen et al., 1999). However, also in ruminants, vitamin E supplementation has been shown to improve the oxidative stability of both lamb (Lopez-Bote et al., 2001; Macit et al., 2003) and beef (Granit et al., 2001).

Vitamin E supplementation not only diminishes lipid oxidation in meats but also stabilizes the colour of meats. The rate of discoloration of meat is believed to depend on both oxidative processes and enzymatic metmyoglobin reducing systems (Faustman and Cassens, 1990). Vitamin E supplementation has been used successfully to improve the colour stability of fresh beef (Faustman and Cassens, 1989; Morgan et al., 1993a,b; Schaefer et al., 1995; Zerby et al., 1999) and lamb (Guidera et al., 1997; Lopez-Bote et al., 2001). In contrast, the results obtained using the same strategy in relation to colour stability of pork have been inconclusive (Faustman and Wang, 2000). Consequently, at first glance, vitamin E supplementation seems to be most efficient in ruminants.

As mentioned above, WHC can also be controlled in pork through strategic finishing feeding (high in fat and low in digestible carbohydrates) reducing muscle glycogen at the time of slaughter (Rosenvold et al., 2001a,b, 2002). Moreover, several studies have shown that dietary magnesium supplementation a few days (2–5 days) prior to slaughter improves WHC of pork (Von Schmitten et al., 1984; Otten et al., 1992; Schaefer et al., 1993; D’Souza et al., 1998a, 1999, 2000; Apple et al., 2000). However, the effect seems to be pronounced in carriers of the Halothane gene (Von Schmitten et al., 1984; Apple et al., 2000; Caine et al., 2000), and therefore this has to be taken into consideration before introduction of this tool. Finally, increased intake of dietary tryptophan leads to increased brain serotonin synthesis in several species (Adeola and Ball, 1992), which has been shown to reduce aggression in pigs during the pre-slaughter period and hereby the incidence of PSE carcasses (Warner et al., 1998).

Even though WHC problems have not yet been a big issue in beef, a recent study shows that fed supplementation of vitamin D3 is able to improve the WHC of beef (Karges et al., 2001) and consequently might be a quality control tool to study in further details.

9.4. Pre-slaughter handling

Pre-slaughter handling may include mixing of unfamiliar animals, loading, transport and abattoir lairage. These handling practices can all induce stress either psychologically or physically. Pre-slaughter stress is both an animal welfare issue and it has for long time been recognized that pre-
slaughter stress can adversely affect the quality of meat (Fernandes et al., 1979; Warris, 1990).

Pre-slaughter stress can roughly be divided into long-term stress, e.g., on farm handling, mixing, loading and transport, and short-term stress, e.g., lairage conditions and driving to the stunner. The two types of stress may lead to various responses in meat quality as long-term stress mainly leads to meat quality approaching that of DFD meat in beef, lamb and pork while short-term stress, which until now mainly has been investigated in the pig industry due to the high speed at the slaughter lines, leads to pork quality approaching that of RSE (red, soft and exudative) or PSE meat.

Mixing of unfamiliar animals should be avoided during pre-slaughter handling (Guise and Penny, 1989; Tarrant, 1989) as this may promote fighting and lead to skin lacerations. This can be severe, and is a serious commercial problem as it decreases the value of the carcass (Faucitano, 2001). In addition, animals that have fought show glycogen depletion in muscles leading to a progressively higher ultimate pH in the meat, which results in an increase in the incidence of DFD meat (Warriss and Brown, 1985; Warris, 1990; Faucitano, 1998; Warris et al., 1998). Finally, results have shown that group sizes of 15 pigs reduce aggression, even when the groups were composed of “mixed” pigs (Barton-Gade, 1997).

Lairage time has been shown to affect the stress level in pigs (Faucitano, 1998). Optimal lairage time appears to be around 2 to 3 h (van der Wal et al., 1997; Milligan et al., 1998; Warris et al., 1998), as extended lairage increases the proportion of skin damage and DFD meat due to fighting and muscle glycogen depletion, respectively (Warris et al., 1998; Nanni Costa et al., 2002). In general, lairage of cattle should be avoided, and if lairage is unavoidable, individual penning should be recommended, as this reduces the incidence of DFD four to five times (Matzke et al., 1985). However, the optimal lairage time will depend strongly on the lairage conditions (e.g., pen size), mixing of unfamiliar animals and the intensity of the stress experienced by the animals during transport.

Short-term stress immediately prior to stunning is shown to result in lower pH values and higher temperatures early postmortem (Gariepy et al., 1989; van der Wal et al., 1997, 1999; D’Souza et al., 1998a,b; Stöier et al., 2001), which is generally accepted to reduce the WHC of meat, especially pork.

A low stress system for pre-slaughter handling during lairage and the last minutes prior to stunning has been developed for pigs (Christensen and Barton-Gade, 1997; Barton-Gade, 1997; Stöier et al., 2001). In this system, pigs are kept in groups of 15 during lairage and in the race. Before the stunner, the groups are divided into three groups of five pigs for CO₂-stunning. The reduced stress pre-slaughter results in lower carcass temperature immediately post-slaughter, which again has a positive effect on WHC of the meat (Stöier et al., 2001).

Finally, CO₂-stunning of pigs should be recommended when the aim is superior WHC, as it is generally accepted that this results in higher WHC compared with electrical stunning (Casteels et al., 1995; Channon et al., 2000, 2002).

9.5. Slaughter procedures

Accelerated air chilling has been shown to be a tool to improved WHC of meat (Taylor, 1971; Taylor and Dant, 1971; Kerth et al., 2001). The methods often seem to be combined with either electrical stimulation or pelvic suspension to counteract eventual negative effect as a result of cold shortening. Thus, the exact trigger of the effect cannot be determined.

Hallund and Bendall (1965) found electrical stimulation to accelerate the rate of the pH decline in pigs resulting in increased frequency of PSE meat. These early observations are later confirmed (Gigiel and James, 1984; Warris et al., 1995; Taylor et al., 1995a,b; Bowker et al., 1999; Maribo et al., 1999). In cattle, the type and time of electrical stimulation is also found to be critical for the drip and colour of the beef (Hwang and Thompson, 2000); however, in general, electrical stimulation is also found to result in inferior WHC in beef (Hertog-Meischke et al., 1997). Even though electrical stimulation might be a possible alternative to improve tenderness of meat (se above), it should not be recommended, if superior technological meat quality is the aim.

Finally, pelvic suspension of pork and beef carcasses has shown that stretched muscles have
improved WHC (Dransfield et al., 1991; Eikelenboom et al., 1998; Fisher et al., 2000). However, more extensive studies are needed before the method can be concluded to have significant potential as a tool in the control of WHC.

10. Price

As mentioned above, price is a critical factor for the competitiveness of the meat-processing industry. Consequently, every initiative in the whole chain, which improves performance of the animals or reduces the price of the final product, is of importance for the meat industry. At consumer level, the price is an extremely visible attribute related to quality by the notion “value”. When purchasing any meat product, the consumer assesses its “other” quality characteristics, i.e., the degree to which his/her needs and expectations have been met in relation to the price given. According to investigations in recent years, the willingness of consumers in industrialized countries to pay for specific food qualities seems to depend on consumer segments, e.g., city dwellers seem to be more willing to pay for specific qualities compared with residents in the country, and the willingness to pay a high price for food seems also to depend on whether it is going to be served during weekends and/or at social gatherings or as an everyday meal.

10.1. Management systems

Taking the above into consideration, all the traditional factors, which have been in focus during the time of commercial meat production, are still valid, i.e., optimal animal health status, litter size, superior performance, etc., together with factors known to satisfy existing payment systems meaning factors mentioned in the paragraph dealing with technological meat quality attributes.

10.2. Feeding strategy and diet composition

The exact economic consequences in the implementation of the developed feeding strategies known to influence the potential price of the final product are always difficult to calculate due to fluctuations in world market prices. However, the economic gain in, e.g.,

- Supplementation of vitamin E (500 IU/head/day) in the production of high-quality beef in the U.S. has been estimated on basis of the improved colour stability of resulting products (extended shelf life at the retail level). These estimates account $33.8—$7 ($28) and $46.8—$6.4 ($37.7) pr. 375 pound sold carcass where the prices represent best case, worst case and in brackets realistic economic scenarios (Smith et al., 2000).
- Introduction of strategic finishing feeding to improve the WHC (approx. 1% unit) in pork (Rosenvold et al., 2001a,b, 2002) has by a conservative estimate been calculated to render more than 13.5 million Euro per year in Denmark considering that 650,000 tons loin and ham muscles are produced.
- Introduction of a feeding strategy that includes compensatory growth principles in slaughter pig production (Therkildsen et al., 2004) can reduce total feeding cost with 3 to 5 Euro (15 to 20 kg less feed) depending on whether in the production is conventional or organic production, respectively, of 100 kg live weight pigs.

Overall, these estimates show that an extended use of production factors as quality control tools in production of demanded meat qualities represents a substantial economic advantage. This should serve as an example of the need for progressive implementation of such initiatives and further research to reveal additional possibilities.

11. Quality assurance schemes

The abovementioned examples mainly focus on single parameters; however, the ever-increasing customer demands become more and more complex and concurrent inclusion of multiple control trades must be general practice, if the meat-producing units have to be successful in the future. Production concepts taking several quality characteristics into consideration are most obviously handled in quality assurance (QA) schemes, which can guarantee the customer of the products that all characteristics are included in the
concept, as many of the quality characteristics of interest may be non-experienced during purchase and consumption, i.e., ‘hidden’ (Andersen, 2000).

QA schemes to satisfy customer demands regarding quality are already common in various industries. In the meat industry, schemes are rapidly developing and are beginning to embrace many of the quality attributes that are important to customers from ‘conception to consumption’. QA schemes present a possibility to raise especially customer confidence. Even though tightly regulated QA schemes which fulfil all future quality demands at present seem impossible to carry out, the existence of some traditional products (e.g., Parma ham) and organic meat production schemes, which operate with strict specifications, are examples of the potential when tools are available. For more comprehensive information on QA schemes in the meat industries, the excellent paper by Wood and colleagues should be encountered (Wood et al., 1998).

12. Future initiatives

Revealing the bovine and porcine genome and the genomes of all the other meat-producing animals will set a new platform for further exploitation of control tools in the production of fresh meat. A new universe will open of which all the abovementioned initiatives will be able to either take further advantage of or be refined as soon as functional genomic of importance for meat production becomes operational.

One of the great challenges within meat production in the near future is to be able to combine the different disciplines of relevance by making the most out of the advances obtained in the time of molecular biology, however, also in a time where the demarcations still separate the relevant disciplines and hinder this process to develop smoothly. When these main barriers are overcome, cross-disciplinary initiatives will without doubt come up with solutions where the advances obtained through a better molecular understanding of biological events in animals combined with the knowledge of agronomists, veterinarians, food scientists and legislators can be utilized to improve (I) performance, (II) welfare of farm animals, (III) meat quality, (IV) animal health status and (V) traceability systems.

The possibility for, e.g., gender selection may also set up a new basis for a substantial part of future meat production, if it finds legal acceptability, hereby changing focus of ongoing discussions and initiatives regarding castration of bulls and male pigs and how to control the quality of products from these animals.

Moreover, true causal relations in the whole ‘conception to consumption’ concept will undoubtedly contribute with knowledge of high importance in the development of quality control schemes and implementation of traceability systems, which are needed to live up to the demands of future customers of animal products.

Finally, a better understanding of consumer expectations in relation to perceived meat quality and their relation to existing and new objective quality control tools are areas that deserve further attention if the production of meat shall fulfil the demands of tomorrow.

References


