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SOME RECENT ADVANCES AND FUTURE PRIORITIES IN RESEARCH FOR THE MEAT INDUSTRY

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ABSTRACT

The meat industry is undergoing a period of very mixed fortunes with beef in particular losing market share; however, longer term forecasts are good for all meat species with demand growth coming mainly from developing countries. This review deals in particular with the main problems that are responsible for the decline of beef as a consumer product in developed markets. These are the meat safety crisis and the unreliability of meat eating quality, especially tenderness. The review suggests that recent research has defined and clarified these problems but they have not been elucidated to the extent that is needed for product assurance. Hence, meat safety and consistent quality are two of the core issues to be addressed in future research priorities. The third core issue is product development which is very active in the most competitive sectors of the food industry and is weak in the red meat sector.

INTRODUCTION

The main activities in meat science fall into the areas of product development, product quality, and safety. The prioritisation of R & D activities between and within these broad categories is dictated in the final analysis by supermarkets and consumers. Market signals, sometimes magnified enormously by the news media as with issues of food safety and wholesomeness, are transmitted back along the food production chain by the retailers, mainly the powerful multiples. The resulting search by industry for innovative solutions to market needs is the main driving force behind meat research. This paper examines current priorities and how they can be addressed by way of further investment in R & D. It is based on the recent literature and is not intended to be a comprehensive review.

Twenty-five years ago, as pointed out by Livingston and Van Luling (1995), a great deal of excitement surrounded the entire meat industry. This excitement was associated with having a premium product, a product consumers wanted because it met their quality expectations and lifestyles. Today, meat is no longer the king protein. For example, in the USA nearly one-third of beef's share of the red meat and poultry market has been lost to poultry. Meat and meat products were once thought to be a vital daily component of a healthy diet, and indeed meat is still intimately associated with strength and virility in our culture. Nonetheless, nutritionists now advise us to seek our protein from alternative sources (Vines, 1997), reflecting a swing in attitude away from meat as a central part of a healthy diet in developed countries.

The long-term viability of some meat production systems is also in doubt. World water demand has tripled in the past two decades (Pimentel et al. 1997). The disparities in the amounts of water used to produce different foods are great; whereas only 500 l are needed to produce a kg of potatoes, a kg of broiler chicken needs 3,500 l of water, while a kg of beef needs a staggering 100,000 l. Put another way, it takes 11,000 l of water to raise the beef in a quarter pound hamburger. The animals drink little of the water - most of it is used to grow their feed.

Consumer research (Glitsch, 1997) shows that beef consumption has decreased since 1992 in EU countries, especially in Germany, Ireland and the United Kingdom. Pork consumption has undergone less change, but shows a tendency towards reduction. In each of the countries, chicken is increasingly consumed in comparison to five years ago. The long term outlook for the global meat trade is more positive (Young, 1997), with world population projected to rise by one billion between now and 2010, meat consumption is expected to rise by about two percent per annum. World trade in the coming decade is expected to grow by 25 to 33 percent in beef, 40 percent in pork and 35 percent in broilers. Much of the growth in demand is expected to come from less developed countries, where anticipated economic growth will strengthen demand levels for food, and specifically for more animal protein products in the years to come. US economists predict that the growth in livestock markets is likely to be captured by the United States - with the natural resources, the grain supplies and the policy structures in place, the United States should be able to extend its domination of the broiler market into pork and possibly into the beef market over the course of the next 10 years (Young, 1997).

Nowadays, the challenges faced by meat scientists in most countries are converging, as a result of the growth in free trade and increasing similarities in consumer demands everywhere. The common challenge faced by meat scientists is to develop better technologies for safe, wholesome, palatable and convenient products that offer real value for money. To do this, research resources should be focussed on the development of profit-enhancing technologies in process and product development. It is therefore a cause of concern that a growing share of research resources is being diverted into addressing problems that are the unexpected side effects of new technology, for example BSE and many problems with chemical residues, pathogens and animal welfare.

Unless meat eating becomes compatible with the humane treatment of animals, with environmentally sustainable production, and with eating that is healthy, wholesome and safe, it will be consigned to a minor role in the diet in developed countries during the next decade. These are the challenges of the future; they are commercial, sociological and economic in nature, but can be overcome by meat research and development, and better consumer education and information.

THE MEAT SAFETY CRISIS

A genuine crisis has developed in food safety which has its roots in the series of food scandals that erupted over the past decade. Meat products featured prominently in these, including *Salmonella* in chicken, antibiotics in pork, *Escherichia coli* and banned growth promoters in beef, and finally the BSE crisis. The public health statistics are alarming. In the USA millions of Americans are stricken by illness every year caused by the food they consume, and some 9,000 a year die as a result (USDA, 1997). More Britons were poisoned by their food in 1997 than ever before, with one million cases estimated (Coughlan, 1998). EU consumers are more concerned about safety in food than in any other consumer products including medicines (Prendergast, 1997). Research linking BSE and new variant Creutzfeldt Jakob disease (nvCJD) has triggered a sudden lack of consumer confidence in beef products and led to a dramatic fall in demand, with cattle prices plummeting to a 20-year low in Ireland in early 1998.

Under pressure from consumers' associations and the media, governments have been forced to change their approach to food control. In Ireland and in the United Kingdom (UK), and at the level of the European Union (EU) the responsibility for food safety control and scientific advice has shifted away from the agriculture administrations, which were seen to advocate primarily the interests of farmers with consumers' interests seen as, at best, secondary. Legislatively independent food standards agencies have been set up with responsibility for food safety. These moves are intended to improve the flow of independent and verifiable information about food safety to the public. Furthermore, EU product liability law is being changed to include primary food, so that a beef farmer could be sued for meat found subsequently to be unsafe; producers were not held liable in the past. These changes signal a significant shift from producerism to consumerism in the public services.

In the USA President Clinton announced a nationwide early-warning system for foodborne illness and directed the administration to identify specific steps to improve the safety of the food supply (USDA 1997). The new national early-warning system is intended to provide earlier detection and response to outbreaks of foodborne illness through enhanced surveillance for foodborne disease, improved risk assessment methods, new pathogen research methods, improved inspection and compliance, and better education.

In a move designed to calm growing public fears over food safety and to appease a beleaguered food industry trying to end a string of food poisoning incidents, regulators are introducing irradiation of meat as a potential failsafe technology despite consumer apathy toward irradiated foods. In December 1997, after a three-year review, the US Food and Drug Administration approved food irradiation for use on red meat; food irradiation rules are also the subject of two proposed new EU directives for 1998. Last year WHO experts reviewed safety and nutrition data and declared irradiation of any magnitude to be safe; in so doing WHO is confident that it has laid to rest fears that irradiated food is unsafe to eat (Coughlan, 1998a). It is reported that many consumer groups now agree that irradiation is safe (Coughlan, 1998a). Fears over the identification and labelling of irradiated foods may also be subsiding, for this is the area in which most technical progress has been made. Several tests are now able to distinguish irradiated foods from non-irradiated ones. For example, the Northern Ireland Department of Agriculture in Belfast has developed a fast, cheap test that detects irradiated chicken meat by a simple colour change (C. McMurray, pers. comm.). The test contains antibodies that detect cyclobutanones, lipolytic fragments that provide a definitive fingerprint of irradiation.

These public developments have effectively put food safety at the top of the research agenda and researchers increasingly look to market and consumer studies for direction. Concerns about beef vary between countries; for example, consumers in Ireland, Spain and Italy have greatest concern about hormones, in Sweden and Germany BSE causes greatest concern; in the UK, *Salmonella* and other bacteria are of most concern (Cowan, 1997). Compared with food safety, the top nutritional issues of fat and cholesterol were found to be of much less concern to consumers in all countries surveyed.

Why is it that despite high levels of concern about *Salmonella* in chicken consumption has continued to increase ? Clearly some concerns are impacting on consumption to a much greater degree than others. It must be concluded that the need for consumer safety assurance is greater for beef than for any other meat (Cowan, 1997).

Real versus perceived hazards: While the trade obviously must address all of the concerns of consumers, it is up to research to quantify the real risks, and to identify where public concern, although genuine, is unfounded. Thus, there is evidence that health concerns about genetically modified organisms (GMOs) in food is mostly without foundation (McConnell, 1997). This is based on the excellent safety record of the pharmaceutical industry which has exploited GMOs successfully and without adverse health effects since the 1970s. Genetic recombination is a precise technology with a 27-year record of safety, and although perceived by the public as a hazard, as currently practised and regulated it does not constitute a real risk (McConnell, 1997).

Chemical residues in meat: Here, also, there is little scientific evidence to support the public's perception of risk. Due to good surveillance and detection methods, the residues of agrochemicals and veterinary drugs found in meat products very seldom exceed regulatory MRLs (Maximum Residue Levels) (O'Keeffe, 1997). Continued vigilance is required, however, to prevent abuse and to assure consumers; instances of misuse of chemicals do occur and these have a negative impact on consumer confidence (Test-Achats, 1996). The provision of independent information on the residue content of foods for use by the industry and consumers is essential in this regard.

In the case of antibiotics an additional problem stems from the hotly-debated question of bacterial resistance and to what extent the use of antibiotics in intensive animal production systems contributes to this problem. This is of course a microbiological hazard rather than strictly a chemical residue one. The magnitude of the problem is not known but there is enough evidence to cause concern. Because the same antibiotics, largely, are used in human medicine as are used in treatment of animals it is not easy to establish the contribution from each source to the development of resistant bacteria. Antibiotics are used in animals as growth promoters (at sub-therapeutic doses), prophylactically for disease prevention, for example after mixing stock from different farms, or therapeutically for treatment of infections. Microbiological and clinical evidence is growing that resistant bacteria might be passed from animals to humans resulting in infections that are more difficult to treat. Recent examples of food poisoning from meat products infected by resistant pathogens include emerging strains of *Salmonella typhimurium* DT 104 and *Campylobacter jejuni*. WHO has recommended that the use of any antibiotic for growth promotion should be terminated if it is used in human medicine or is known to select for cross-resistance to antibiotics used in human medicine (WHO, 1997).

Emerging pathogens: Undoubtedly the major threat to food safety is the emergence of 'new' pathogens. Miller (1997) listed only four food pathogens recognised in 1942, compared with over a dozen which have emerged in the past two decades. For example, *Listeria monocytogenes,* E. coli O157:H7 and *Campylobacter* species were not recognised foodborne pathogens 20 years ago. Further new pathogenic strains continue to emerge, such as *Salmonella enteritidis* and *S. typhimurium* DT104, which was first recognised in the UK in 1984 and in the US in 1996 (Shank and Carson, 1998). The causative factor is believed to be the continuing industrialisation of food processing, creating ecological niches for previously suppressed pathogens. For example, the increased prevalence of *E. coli* O157:H7 in food may be associated with the consolidation of the beef and dairy industries into fewer but larger production and processing units (Miller, 1997). Microorganisms are also adapting to the traditional methods of preventing and controlling foodborne pathogens including refrigeration, heat, pH and disinfection techniques.

Enterohemorrhagic *E. coli* strains are more significant than other well-recognised foodborne pathogens because of the severe consequences of infection, their low infectious dose, their unusual acid tolerance and their apparent special but inexplicable association with ruminants that are used for food (Buchanan & Doyle, 1997). Investigation of the 1996 outbreak of *E. coli* O157:H7 in Scotland showed that smaller butchers shops had a poor record of hygiene, and that infection was entering the food chain through faecal contamination on slaughterlines (Pennington 1997). These findings have resulted in regulatory enforcement of clean cattle for slaughter in Ireland (S.I. No. 425, 1997). Although research has shown that carcass decontamination procedures are effective as part of a HACCP plan, in general, advances in meat slaughter technology have not yielded the anticipated benefits in meat hygiene (Sheridan, 1997), possibly because such changes may have been accompanied by faster line speeds or reduced manning levels.

Changes in the food chain will continue to create opportunities for the emergence of new disease and the re-emergence of old diseases. Forecasts of likely future pathogen threats include bacteria *(Citrobacter freundii, Arcobacter butzleri, Salmonella)* viruses, prions, and parasites. Hazard management is widely seen as the best approach to the control of emerging pathogens, once they have been isolated and identified by researchers (Miller, 1997).

Prion diseases: The identification in Britain in 1996 of the human disease equivalent of BSE gave rise to fears of a future epidemic of nvCJD, mirroring the BSE epidemic of the past decade. At the peak of the outbreak in 1992, the annual incidence was nearly 1% among British cows. There is now compelling evidence that BSE and nvCJD are caused by the same strain of prion protein. The controversial proposal by Stanley Prusinger that a protein, like viruses and bacteria, can cause infectious disease won him the Nobel Prize in 1997 for establishing a new biological principle of infection. The most likely explanation of the twenty-four deaths from nvCJD to-date in Britain remains exposure to BSE before the introduction of the ban on specified bovine offal in 1989; until the 1989 ban, homogenates of pooled bovine brains were used as binders in products such as hamburgers and sausages (Verdrager, 1996). The absence of a diagnostic test for BSE in the live animal, or for the prion in carcass meat (Rogers, 1997) is a serious obstacle in the development of a comprehensive HACCP plan for beef. However, a monoclonal antibody that can discriminate between normal and disease-specific forms of prion protein has been described by Korth et al (1997). Although the infectious particle has an identical amino acid sequence to that of the ubiquitous cellular prion protein, the antibody can recognise the conformational difference that characterises the disease-causing form of the prion and that provides the basis for a possible diagnostic tool for BSE, or nvCJD in humans. An antibody-based rapid method for detection of BSE in postmortem brain tissue has recently been developed as a screening test by the Irish company Enfer Scientific using diagnostic technology licensed from Proteus International in Britain. It is not yet clear if the test can identify carcasses of infected animals which had not shown clinical symptoms.

There is concern about the long incubation period for nvCJD of up to a decade or maybe longer; thus, the number of cases in Britain currently is unpredictable and this more than anything else about the disease is responsible for the public dismay and political turmoil surrounding BSE. There is also concern about the safe disposal of BSE-infected tissues following reports of extraordinary thermal stability of the infectious agent; research shows that rendering by the recommended procedure (Commission Decision, 1996) of steam at 3.0 bar absolute pressure, giving a temperature of 133°C, for at least 20 min may still leave infection in the resulting meat and bone meal (Taylor, 1997). Work is in progress at Britain's Meat and Livestock Commission to devise a practical and efficient method of removing cattle spinal cord before the splitting of the carcass. A double bandsaw which makes use of parallel blades to remove a 50mm wide slice from the centre of the carcass, encasing the spinal cord, is undergoing factory trials (MLC Technical Developments, Winter 1997).

Food allergies: Meat products have emerged relatively unscathed from the growing concern about allergies. These adverse reactions to foods are caused by an immune response that leads to the release of histamines. The incidence of food allergies is high, for example in the US some 8% of children and 2% of adults exhibit allergy (Bush, 1997). Over 170 foods have been documented in the scientific literature as causing allergic reactions, chief amongst which are the "major serious allergens" (MSAs). These include the so-called "big eight" namely milk, eggs, soya, wheat, peanuts, shellfish, fruits and treenuts, which between them account for the great majority of food allergies. Meat products do not feature in the "big eight" or "second eight" list of food allergens.

Food safety assurance systems: In an attempt to guarantee the safety of its products to the consumer, the meat industry is adopting a systems approach. Complementary schemes are developing at two levels - trade or commercial systems, and national schemes. The commercial systems are driven by supermarkets, the standards are set above the legal minimum and suppliers, including farmers, are forced to meet specifications or lose the business.

The uptake of commercially driven schemes by manufacturers can be impressive. A recent survey of the Irish food processing industry showed that 71% of firms have HACCP based systems in place, and encouragingly that the main reason for implementation was the internal need for better control, rather than pressure from buyers (Doyle, 1997). A current priority is the development of appropriate food safety systems for application on farms to facilitate full traceback. Already ISO 9000 and HACCP based systems have been successfully applied to intensive production systems, including pig, poultry and grain. Systems based on workable codes of practice are now needed for smaller farmers and less intensive producers.

At the national level, food safety schemes are intended to ensure compliance with regulations. If they are effective they will benefit trade by facilitating the trade-driven systems. A successful national scheme should provide animal traceability from birth to slaughter, surveillance of residues and pathogens, and the enforcement of legal food safety standards in farms and factories.

Traceback is increasingly being demanded as a central element of meat quality assurance systems. A DNA fingerprint technique that can match meat cuts to slaughtered cattle has been developed by Identigen Ltd of Trinity College, Dublin. Traceability is more difficult for comminuted meat products and would appear to require changes to the traditional manufacturing processes where raw materials from many animals are mixed together.

The research and development priorities in meat safety are considered at the end of the paper.

INCONSISTENT QUALITY IN MEAT

The number one influence on food choice is quality/freshness, which EU consumers rated higher than price, taste, or trying to 'eat healthy' (Anon. 1996). Consistency of quality causes particular problems in meats and other 'whole' or 'intact' foods, where between-animal differences add to those arising from batch and season. Despite a lot of research, consistent eating quality remains an elusive goal in meat science.

Research also shows that tenderness and flavour were rated by consumers as the most important elements of eating quality, well ahead of leanness, while colour was the most important attribute at point of purchase (Glitsch, 1997). Our understanding of the causes of toughness and the mechanism of tenderisation is improving (for reviews see Lepetit and Culioli, 1994: Purslow, 1991). In view of the scale of the worldwide effort, there may be a breakthrough in the medium term in our understanding of why fresh meat varies so much in basic qualities, predominantly tenderness (Anon. 1997).

Meat toughness: Of the two components responsible for toughness in meat, the muscle fibre and the connective tissue, the fibres have received most attention because the myofibrils respond to manipulation of the carcass during dressing and chilling with beneficial effects on tenderness. In contrast, collagen, the principal fibrous protein of connective tissue, and to a lesser extent elastin, are seen as responsible for a relatively fixed background toughness. Whereas the myofibrillar component has been intensively studied over the last two decades and is quite well understood, our understanding of the connective tissue component is limited. Collagen toughness reflects the properties of the endomysium and perimysium, as the epimysium is usually removed during preparation because it is too tough to eat. Since the perimysium typically accounts for over 90% of the total collagen content of beef muscle (McCormick, 1994) it is regarded as the key structure in determining collagen toughness.

Collagen toughness: The strong inverse correlation between cost and collagen content in different cuts of beef (Kuypers and Kurth, 1995) shows the decisive influence of collagen on tenderness. Collagen's contribution to meat toughness increases with animal age, due to an increase in the number of thermally stable covalent cross-links that bond individual collagen molecules together. The crosslinks arise from the condensation of lysine or hydroxylysine residues and their aldehydes. They are reducible but are transformed into more stable non-reducible compounds with ageing. Such alterations in collagen characteristics, rather than significant changes in collagen concentration, are responsible for the toughening of meat as animals age (McCormick, 1994). As differences in toughness between different cuts and between animals of different ages are mostly explained by the amount of collagen in the different cuts and the number of thermally stable cross-links, it has been concluded that the collagen content of muscle determines its overall toughness.

Manipulating collagen: Progress in lowering the level of collagen or background toughness in meat has been painfully slow. There is no clear evidence for proteolytic breakdown of collagen during ageing of meat, and it seems to be completely resistant to proteolytic enzyme attack at normal meat pH values, i.e. between 5 and 7; although it is vulnerable to attack at more acidic values, as in marinades. There is recent evidence for the structural weakening of the perimysium and endomysium during extended ageing of meat. This may be caused by the degradation of the proteoglycans that comprise the ground substance of connective tissue, and in which the collagen fibres of the endomysium and perimysium are embedded. Work in Japan suggests that proteoglycan degradation may occur spontaneously due to the massive rise in free Ca^{2+} in the cytoplasm post rigor (Takahashi, 1996).

Collagen structure may be subtly influenced by on-farm management, and these changes may persist from farm through abattoir (Harper et al, 1997). It is thought that a high plane of nutrition and more rapid growth results in greater rates of collagen synthesis. The newly synthesised collagen dilutes the older, heat stable collagen making it on average more heat labile (McCormick, 1994). This results in muscle with increased collagen lability and hence more tender meat. McCormick cautioned, however, that there is a complex relationship between collagen synthesis and changes in collagen characteristics (cross-linking) which cannot be explained satisfactorily by the dilution effect alone.

Another approach to reducing connective tissue toughness is by genetic manipulation of the chemistry of the collagen cross-link. By switching cross-link pathways in the live animal it may be possible to increase tenderness by increasing the number of thermally labile allysine cross-links over the thermally stable hydroxyallysine cross-links (Kuypers and Kurth, 1995).

However, the problem of *inconsistency* as distinct from *degree* of tenderness needs another approach. As put by Swatland (1996) "collagen may have an effect on meat tenderness and on the way in which we prepare retail cuts of meat, but using this knowledge to produce some improvement or control of variability in meat tenderness is difficult. Few of the experiments that have been published in this area deal directly with material that represents the top quality meat, the most important commercially. Stewing steak may be tougher than prime steak because of collagen, and beef from old cows may be tougher than from young cattle, but how important is collagen in explaining the taste panel variation between prime steaks from top grade carcasses ?"

Myofibrillar toughness: A consistent level of tenderness in the more valuable cuts requires much greater control over myofibrillar toughness than is now possible in the meat industry. In contrast to connective tissue, myofibrillar toughness does not increase with animal age. Whereas the contribution of connective tissue to meat toughness is comparatively fixed, that of the myofibrils is highly variable and at any given time post-mortem is the net effect of two opposing processes, the rigor or toughening process and the natural tenderising process. Finding ways to minimise the former process and to maximise the latter is a worldwide research goal.

The myofibrillar toughening reaction: As post-mortem toughening is caused by the binding of myosin heads to actin in the 'rigor complex', and toughness increases in direct proportion to the number of such cross-bridges that are formed, the extent of muscle shortening, or overlap of the actin and myosin filaments, is important. Carcass handling procedures that reduce pre-rigor shortening, such as the tenderstretch process, and avoid cold, heat or thaw-induced shortening, reduce the degree of toughening. Despite the apparently straightforward relationship between post-mortem toughening and actin/myosin crossbridge formation, researchers have not always found a good relationship between sarcomere length and toughness. For example, Smulders and colleagues (1990) observed that the normally strong relationship found in beef was absent in fast glycolysing carcasses with a pH of 6.3 or less at 3 h post-mortem.

Two proposals have been put forward to explain why, depending upon post-mortem conditions in the muscle, the relationship between sarcomere length and toughness may break down. They are, firstly, that the strength of the actin/myosin interaction in rigor is variable thus affecting tenderness, and secondly, that early commencement of proteolytic tenderisation may obscure the sarcomere length-toughness relationship. Advocates of the first explanation argue that studies of the crossbridge cycle in contracting muscle suggest that the actin/myosin interaction is likely to be in one of at least four possible binding states, ranging from weak to strong binding. Goll and colleagues (1995) argued that the relative proportions of these four states may depend on the intracellular conditions at which the muscle entered rigor mortis; for example, whether the ATP concentration fell before Ca^{2+} content in the cytoplasm was high enough to initiate the strong-binding state ? They speculated that the percentage of myosin heads in each of the four possible binding states is likely to have profound effects on tenderness. Thus, myofibrillar toughness could vary independently of sarcomere length as a consequence of the strength of the actin/myosin binding interaction. The alternative viewpoint is that the inconsistent relationship between sarcomere length and toughness is caused by the acceleration of natural tenderisation in fast glycolysising muscles.

The natural tenderisation process: It is believed that significant protein breakdown can commence soon after slaughter and continue during ageing, although at a diminishing rate. The extent of tenderisation depends upon the activation of the calpain protease, especially the μ-calpain form of the enzyme (Koohmaraie, 1996; Tornberg, 1996). It is now considered less likely that m-calpain or the lysosomal cathepsins are major contributors to tenderisation. μ-calpain attacks the giant cytoskeletal proteins nebulin and titin severing their connection to the Z-disc and also degrades the proteins of the costameres and intermediate filaments such as desmin, vinculin and dystrophin. Furthermore, the calpains attack their inhibitor calpastatin and are subject themselves to autolysis. The consequence of all these processes is that the extent of proteolytic tenderisation depends on the activation and inactivation of calpains, especially μ-calpain. By modelling the temperature and pH dependence of the inactivation of calpains, Dransfield (1994) found an intermediate temperature region at approximately 25-10°C where preferential activity occurs. This provides a window of opportunity to influence tenderisation during carcass chilling.

More attention is now being given to the matrix or 'glue' that holds the muscle fibres and connective tissue together, and Dransfield (1997) proposed that its weakening during ageing of meat explains the observed pattern of fragmentation in aged fibres. The matrix is thought to comprise proteoglycans of connective tissue and certain proteins of the cytoskeleton including desmin, vinculin and dystropin. Its weakening may result from calpain action on the cytoskeletal proteins and proteoglycan degradation by Ca^{++} as already discussed.

Tenderness enhancing technologies: These advances in the biochemistry of meat tenderness have stimulated the development of technologies, some of which, such as feeding regimes, are applied on the farm but most relate to the post-slaughter operations. The post-slaughter technologies for improving tenderness, reducing variability, and enhancing the desirable biochemical changes during conditioning of meat were divided into three groups: established methods; emerging methods; and new methods (Troy, 1995). The first group includes slow chilling and electrical stimulation; the second comprises the tenderstretch and tendercut processes and method of ageing. The third group, new methods, includes calcium chloride injection, high pressure treatments, ultrasound, very fast chilling, hydrodyne (explosive shock) process, and injection of organic acids. The various technological procedures can be evaluated and may form part of an integrated specification. However, Fisher and colleagues (1994) cautioned that adding together treatments such as slow chilling, electrical stimulation and pelvic suspension which individually conferred greater tenderness was not always cumulative. The uptake of new technology by the meat trade is a slow process, for example the industry in Britain and Ireland has taken up to 25 years to implement the tenderstretch (pelvic suspension) technology. Its recent widespread use in the Irish beef industry is in response to increased market demand for a tender product as well as less concern about the changed shape of the primal cuts as demand by consumers shifts to more uniform, small prepackaged retail portions. Systems to help industry to adopt quality-enhancing technologies are discussed later.

Recent studies show a high level of inconsistency in the way fresh beef is handled in the trade. Tatum et al (1997) examined ageing time and tenderness of top loin and top sirloin steaks in the retail meat case in the United States. Ageing time averaged 20 days which is sufficient to ensure tenderness, however, the variability in ageing time was from 2 to 90 days ! The authors concluded that variability in ageing time should be reduced as it most likely contributes to variability in tenderness. They also concluded that the beef industry must have automated probes in place to sort carcasses on the day after slaughter into tenderness categories so that postmortem technologies can be used to improve tenderness. Automated probes are necessary to provide a tool to pay producers for increased tenderness.

Genetic manipulation of meat quality: Probably the best opportunities for innovative, quality-enhancing technologies for the meat industry in the future lie in the use of DNA technology to manipulate the biochemical pathways that determine meat quality. Obviously, there is a whole host of opportunities here. Work in the USA indicates that genetic influences on beef tenderness are important (see Miller, 1996). For example, heritability estimates of post-rigor calpastatin activity, the main regulator of the calpain protease system, indicate that selection against calpastatin activity may be a feasible approach to improving tenderness in beef cattle. Likewise, searching for genes coding for a high calpain activity is another approach toward the same goal. However, the selection of live cattle using DNA markers is not a simple process as tenderness is influenced by multiple factors in addition to the calpain/calpastatin system, including collagen characteristics, marbling and sarcomere length (Miller, 1997).

The conventional approach to genetic improvement, based on including the desired traits in a selection index for use in breeding schemes, is much less successful for improving eating quality than for improvements in animal production traits. The measurement of eating quality by taste panels is not very accurate and for that reason eating quality has a much lower heritability value. The way around this problem suggested by de Vries et al (1995) is to replace subjective evaluation with more accurate, indirect, objective physical or chemical measurements of eating quality; the closer the measurements are to the biological determinants of eating quality the higher the apparent genetic variability is, which can be exploited by selection (Renaud, 1995). This approach has accelerated the search for genes coding for eating quality traits. It is already successful in dairy cattle where marker assisted genetic selection is used to increase the milk content of specific proteins that affect the quality of dairy products.

The best example of the use of gene technology to control meat quality is the PCR-based halothane gene test, now commercially available and used by pig breeders around the world. When the halothane gene was finally identified as a point mutation of the gene coding for the Ca^{2+} release channel in the sarcoplasmic reticulum (SR) of muscle cells, the test was developed to facilitate its removal. Although the halothane gene confers some advantages in terms of leanness and conformation, these are outweighted by the disadvantages of higher mortality rates (PSS) and lower meat quality (PSE). The test also enables pig breeders to exploit the positive values of the mutation by producing heterozygous carrier pigs while avoiding the homozygous PSS-prone animals.

Another major gene influencing the technological properties of pigmeat is the RN (Rendement Napole) gene, which primarily acts by increasing the glycogen content of the white or fast-twitch glycolytic muscle fibres. This results in a higher content of lactic acid in the meat and higher cooking loss (Monin et al, 1992). There are also indications of a single gene affecting intramuscular fat in pigs (Janss et al, 1994). This gene does not affect overall fatness, and selection for it may permit further reduction of backfat while maintaining a desirable amount of marbling in the meat. Tests for detecting these genes have not yet been developed.

Schemes for assuring palatability: Koohmaraie (1996) questioned why new meat technologies were not being adopted by the industry and concluded that it is perhaps far more urgent to answer this question rather than to develop more technologies. However, a momentum is developing, for example in Australia (Webster, 1997), USA (Miller, 1997) and Britain (Warkup, 1997) to implement new technologies that will improve eating quality by using a systems approach that is analagous to the HACCP approach used in safety assurance. This approach, dubbed PACCP (palatability assurance at critical control points), facilitates the add-on at every stage of production, from genetic selection to final meat preparation and cooking, of new technologies that can help to optimise eating quality and reduce its variability in the end product. In the USA beef industry, efforts to implement a palatability system have concentrated on three areas: (1) identifying genetic markers for improving tenderness by breeding and selection; (2) developing and testing critical control points for beef tenderness, e.g. feeding of high energy diets prior to slaughter, the use of electrical stimulation, and post-mortem ageing; (3) developing automated grading techniques that will provide a tool to pay for increased tenderness; the rationale being that tenderness has to impact on the value of meat, otherwise there is no incentive to make changes and the signal to improve tenderness is weak (Miller, 1997).

CONCLUSIONS

In this section an attempt is made to identify future priorities for meat research and development. Where new topics are introduced that have not featured in the review thus far, some background is given for reasons of clarity. Inevitably, the listing will include the most obvious priorities and miss some important ones; it is deliberately kept brief and omits some areas such as market research. The categories used are product safety, quality, and development.

1. Product safety:

The top priority is the control of emerging pathogens by developing improved detection and identification methods, and improved prevention technologies. By definition, HACCP systems cannot manage unknown emerging pathogens so research-based knowledge is needed as specified by Buchanan (1997). There is a general lack of validated critical control points in meat slaughter operations. There is a need to reduce the pathogen load of animals ex-farm (Anon. 1997). A particular need in the beef industry is the development of a test capable of detecting BSE in live cattle at the earliest pre-clinical stages of the disease to permit the elimination of contaminated cattle from the food chain. Another area of particular interest is the indentification of factors that lead to the development of antibiotic resistance in human pathogens carried by food animals and development of preventative measures. Among the priorities in this area is the generation of more information about the rate of transfer of resistant bacteria from animals to humans and the search for alternative approaches to growth promotion that do not require use of antibiotics. The experience of the Swedish pig industry is important in this regard.

Research is also needed on method development for chemical residues to support the essential monitoring and surveillance activities. Here, residues of veterinary drugs and prohibited substances are the main concern.

The two priorities in systems development must be the extension of HACCP-type safety management systems to farms, and the development of traceback to origin at the level of the individual animal. In national meat safety schemes the most important element is to increase transparency and public trust, thereby reducing the vulnerability of the whole food chain to scares and crises.

2. Product quality:

New technology to control and predict meat tenderness is undoubtedly the top priority for research on eating quality.

a) Genetic manipulation of meat quality: Probably the best opportunities for innovative, quality-enhancing technology for the meat industry in the future lie in the development of gene-mapping and related technologies to manipulate the biochemical pathways that determine meat quality. For example, target pathways already discussed would include the biosynthetic pathways for collagen cross-links in the perimysium, and those leading to the formation of the calpain proteases and their inhibitor calpastatin. The genes controlling intramuscular fat are an obvious target. Looking farther ahead, the use of embryo sexing technology may permit the development of all-female lines of slaughter pigs, thereby eliminating tainted pigmeat, and improving animal welfare.

Consumer information and education (see below) will be needed, particularly where the transfer of genes between species of animals is contemplated, objections are likely to be greater than for manipulations involving plants or microorganisms (Frewer, 1997).

b) Muscle Ca^{2+} regulation: Improved techniques for the study of Ca^{2+} movements in the muscle cell are a priority. The post-mortem toughening and tenderising processes are both regulated by Ca^{2+}, hence the timing of the post-mortem release of Ca^{2+} from the SR is important. The earlier it occurs the sooner the calpains are activated to cause tenderisation but also the greater is the risk that muscle shortening will occur causing toughening. The obvious but daunting challenge for meat scientists is to find ways to preferentially stimulate the tenderisation process.

c) Feeding systems: The elevated rates of protein synthesis and degradation found in faster growing animals may accelerate post-mortem proteolysis and improve tenderness in animals finished off high-energy diets. The effect of feed on meat flavour also needs research, especially in beef and lamb. Meat flavour is a priority issue because consumers rate it on a par with tenderness in evaluating the eating quality of meat (Glitsch, 1997).

d) Very fast chilling: VFC, for example to $0^{\circ}C$ within five hours of slaughter, offers considerable incentives to industry in terms of faster carcass throughput and lower weight loss, provided that an acceptable level and consistency of tenderness can be achieved. Current research suggests that VFC may be a processing option for lamb carcasses in the future. The reported absence of toughening of VFC lamb carcasses could result from two mechanisms. Firstly, the outer surface of the muscle may be frozen and this may prevent cold shortening. Secondly, Ca^{2+} released from the SR by low temperature pre-rigor, while the muscle pH is still high, could activate the calpain protease system and accelerate tenderisation (Jaime et al 1992). Due to heat flow limits VFC could only be used on beef muscle which has been hot boned from the carcass, and then constrained to prevent cold shortening. In general, research is needed to reorganise meat boning, cooling and packaging operations in order to streamline them and to reduce overall processing costs.

e) Automation of carcass grading: Objective grading systems are needed to pay producers and feed back information about quality to the production system, and to sort carcasses for further processing and merchandising. Current beef and lamb carcass grading is based on visual assessment of fat cover and conformation and suffers from lack of objectivity. Electronic grading probes are used in pig carcass grading but the development of instrumental methods for beef and lamb lags behind (Allen, 1995). Development of automated grading technologies is a top priority in the US beef industry where five systems are under development; these are (1) video image analysis for carcass fat thickness, ribeye area, lean colour and marbling, (2) real-time ultrasound to predict fat thickness, ribeye area and marbling, (3) ultrasonic elastography to predict beef tenderness and marbling, (4) the CT (connective tissue) probe from Canada and (5) 1-day shear force value (Miller, 1997). Near infrared spectroscopy also has potential for predicting meat quality soon after slaughter.

f) Automating carcass dressing, cutting and boning: The early stages of the development of automation and more recently robotics for the meat industry have been painfully slow (Harrington, 1995). In recent years there are signs of real progress for pig dressing and cutting in Europe and for lamb dressing and boning in New Zealand. Progress on beef systems has proved more difficult with relatively little development work pushed through to commercialisation so far, apart from the mechanically assisted boning systems where the emphasis has shifted from machines to replace men to machines to help men.

g) PSE and DFD: Greatly improved systems that are compatible with industry needs are required for pre-slaughter animal handling. Systems should include suitable equipment and the training and supervision of animal handlers at farm and abattoir. PSE cannot be eliminated by use of the PCR-based halothane gene test, as the halothane gene probably accounts for only 25-

35 percent of the PSE meat observed in commercial abattoirs. The most important factors affecting PSE and DFD occur after the animal has left the farm (Diestre, 1991).

h) Nutrition: Although meat is widely recognised as an excellent source of protein and iron, and is increasingly presented to consumers in a trimmed state so that fat levels are lower than formerly, there is still concern about the saturated nature of the fat especially in beef and lamb, which is said to be a risk factor in cardiovascular disease. The meat industry needs to address the consumer interest in healthy eating as, for example, is being done by the US National Cattlemen's Beef Association in a 'nutritional parity' study which is comparing beef with chicken and fish in low fat diets designed to reduce the risk of heart disease. Research is needed on ways to improve the fatty acid composition of muscle, for example the beneficial ratio of omega-6 to omega-3 fatty acids which is present in grass-fed beef and lambs (Woods et al. 1995), and conjugated linoleic acid (CLA) which has been demonstrated to have anticarcinogenic properties and of which beef is a natural dietary source.

There is a strong need for more information on the interrelation of diet, lifestyle and cancer, because several studies have implicated red meat as a slight risk factor in cancer. In late 1997, reports fuelled new concerns by claiming an association of colorectal cancer with red meat consumption (COMA, 1998; World Cancer Research Fund, 1997). The British Nutrition Foundation found no evidence of a link between meat intake and colorectal cancer in Europe, noting that the higher consumption of fruit and vegetables, especially in Mediterranean countries, appeared to have a protective effect against cancer. The COMA report (1998) called for dietary studies to elucidate the 'reciprocal relationship' between meat consumption and fruit and vegetable consumption.

3. New product development:

The dearth of product development activity in red meats compared to almost any other food sector has led to criticisms:

- that the red meat industry has failed to develop beyond the primary processing stage;
- that preparation of prime cuts is no longer compatible with a modern lifestyle;
- that the high quality convenience products are slow to emerge.

The hamburger is probably the most successful convenience food item of all time, but apart from ground beef, beef and lamb are not consumer-friendly and convenient. There is a major need for innovative research to initiate product development in red meats. There is an on-going need to find functional fat replacers for use in processed meat products, that impart the desirable flavour and mouthfeel as well as the binding characteristics of fat; the new ingredients and processes must also be cost competitive. High pressure processing is gaining in popularity and has the potential to impart new functional properties to meat ingredients and raw materials, thereby reducing the need for additives.

Consumer information and education: Many negative images have been created in the public mind about meat production by media reports that are often prompted by special interest consumer groups. Scientists have not excelled at informing the public about the nature of scientific developments and the potential benefits for consumers; indeed, scientists are their own worst enemies in this regard. Meat scientists must redress the balance by making available objective information about meat production, particularly on issues of safety, wholesomeness and welfare. The goal of such communication should be to create an informed consumer, rather than an attempt to persuade or educate the public to accept new technology (Frewer, 1997). It is essential for ICoMST to play an active role in stimulating this activity.

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