INTERNATIONAL AWARD LECTURE

A Future For Beef

Patrick Vivion Tarrant

Beef has been a prized part of man's diet since prehistory, powerfully associated with health and strength and with superb satiety and gustatory properties. Beef eating is a long established feature of the Irish diet as illustrated in the ninth century tale Fled Bricrenn, where beef was the centre piece for a great banquet:

> *'A lordly cow that is also seven years old, and, since it was a calf,*
>
> *it has eaten nothing but heather and twigs and fresh milk and herbs*
>
> *and meadow grass and corn' (recounted by Cowan and Sexton, 1997)*

Here, the quality of the meat is described in terms of the naturalness of the environment and feed used in its production. That link, still dominant in the mind of today's consumer, is given scant regard in an industry driven by the economics of competition. Technology has delivered beef, pork and lamb at affordable prices in developed countries but at a high price in loss of perceived wholesomeness.

For this and other reasons, beef consumption in Europe has dropped from 25 to 19kg/head between 1985 and 2000. Red meats (beef, veal and lamb) make up 26% of total consumption in Europe today, as against 45% in 1960 (EAAP, 2003). Predicting future trends is risky. At the height of the bovine spongiform encephalopathy (BSE) crisis the outlook was bleak --- 'unless meat eating becomes compatible with the humane treatment of animals, with environmentally sustainable production, and with eating that is healthy, wholesome and safe, meat will be consigned to a minor role in the diet of developed countries during the next decade' (Tarrant, 1998). Since then, beef has seldom been out of the news and for all the wrong reasons.

Thus, a future strategy for beef has to be planned against a downbeat scenario of steady erosion of market share, punctuated by sporadic health scares that cause sudden, albeit short-term, drops in consumption.

Ireland, like Kentucky, is famous for its grass - the Emerald Isle and Bluegrass Country, respectively. Anything that thrives on grass does well in Ireland, so there is excellent beef, lamb and milk, together with fine racehorses and excellent golf courses! This natural resource makes it a priority to win consumers back to beef. There is increasing competition from low cost producers like Brazil. These are the forces driving beef research in Ireland. Similar situations arise elsewhere, providing opportunities for international research collaboration.

An account of our recent work on beef follows; my earlier work on animal stress, welfare and meat quality is recounted elsewhere (Tarrant, 1989a; 1989b; Tarrant and Grandin, 2000).

Redesigning Beef for the Consumer

The beef industry in Europe, shielded by state intervention in support of farmers' incomes, has been slow to address its declining competitiveness by taking action to improve the product. Beef is perceived by consumers to be weak on some key attributes - convenience, healthy eating and safety. It is also vulnerable on the ethical concerns of a growing minority - animal welfare, environmental sustainability and fair trade. Beef is in need of a complete overhaul to increase its competitiveness and to win back market share. The starting point is the consumer.

Market-led New Product Development

In a meat industry characterised by low overall volume growth, efficient new product development is essential for gaining competitive advantage. Product development is a risky business, with 80% of food product launches failing to have a market presence after two years (Barrett, 1996). Success with new consumer products requires constant input from consumers, where the development of new product ideas, the screening of ideas, the development and testing of prototypes, the development of the overall marketing mix, and finally the launch on the market are all consumer-led (Daly, 2002; Grunert *et al.*, 2004). Much product innovation in the food sector is still not geared towards specific consumer segments. This is especially true for products like meat, which are mostly sold unbranded. We adopted a 'lifestyle' approach to understanding consumer needs with the

Patrick Vivion Tarrant
The National Food Centre, Teagasc
Ashtown
Dublin 15
Ireland

Email: viviontarrant@iformix.com

Proceedings of the 57th American Meat Science Association Reciprocal Meat Conference *(pp. 1-6)*
June 20-23, 2004, Lexington, Kentucky
www.meatscience.org

help of its Danish originators (Grunert and Valli, 2001), as discussed below.

Food Related Lifestyles

The lifestyle approach is used by manufacturers to segment consumers into sub-groups that can then be targeted independently. The food related lifestyle (FRL) instrument measures consumers' attitudes and behaviour towards food, based on their response to attitudinal statements within five 'domains' (ways of shopping, cooking methods, quality aspects, purchasing motives, and consumption situations).

In Britain, Ireland's largest export market, the FRL revealed six segments: the 'snacking', the 'careless', the 'uninvolved', the 'rational', the 'adventurous' and the 'conservative' food consumers (Cowan *et al.*, 2003). Each segment can then be profiled to measure attitudes and behaviour towards the particular food category of interest. For example 'adventurous' consumers are interested in new products, so beef should be presented in new ways; they are well educated, in full-time work, they love cooking and like dining 'in style', so recipes are important, and interesting ways of preparing beef. This segment may be of more interest for the future – perhaps not buying beef now because there are few exciting new products. Market segmentation increases competitiveness by facilitating the design, promotion and targeting of new products at particular consumer groups.

Repeat segmentation reveals market trends over time, for example, comparing our study with an earlier Danish one showed the emergence of an entirely new segment in the British market, the 'snackers'. It may be possible to predict future trends by extrapolation, with correction for changes in societal or economic 'market drivers' (the trend towards individuality, time pressures, health, etc.). The ultimate goal is to enable food companies to predict future food lifestyles and develop products to match.

Product Differentiation

This is a two-step process. Firstly, consumer needs have to be translated into measurable product characteristics that can be used for product development and for sorting of products with natural biological variation. Secondly, a way to signal improved quality to the consumer is needed.

The most obvious way to signal improved quality is by branding. When a producer improves the eating quality of beef, the only way consumers can identify this improved product, in the absence of a brand or a trusted 'quality mark', is by its visual appearance. Consumers are no meat experts and, even if they were, appearance has little to do with eating quality. Their judgement, based on the appearance of meat (visible fat and colour), is therefore not very good (Grunert *et al.*, 2004) and the improved quality will not be recognised by consumers in the shop. As long as fresh meat is mainly sold as a commodity there is limited incentive for meat producers to differentiate their product. To be valuable, a brand or a 'quality mark' must develop a history of constant and reliable quality. To do this for meat requires an exceptional level of cooperation along the chain. Country of origin is another way to signal quality to consumers and is obligatory for beef retailed in the EU. Technologies for beef product differentiation to which we have contributed will now be discussed.

Healthy Eating

Health-based differentiation of beef should aim at positive health benefits, as distinct from safety issues, for example developing meat-based functional foods. If good eating quality could be combined with low fat, or if the fat could be modified to give it better health properties, this would be a type of product development firmly rooted in our knowledge of consumer meat quality perception (Grunert *et al.*, 2004).

Lean meat is an important source of nutrients, but this is negated by the perception that beef is a fatty food with a high proportion of saturated fatty acids (SFA). The ratio of SFA to polyunsaturated fatty acids (PUFA) is higher in beef than pork or chicken, because bacteria in the rumen hydrogenate dietary PUFA.

Simple feeding practices can go a long way in optimising beef fatty acid composition. A proportion of dietary PUFA bypasses the rumen intact and is deposited in beef fat. Raising the dietary supply of PUFA, for example by including oilseeds or fishoil in the feed, can increase the PUFA content in beef. An important advantage in beef is that the desirable n-3 PUFAs are mainly incorporated into the membrane phospholipids and are therefore found predominantly in the lean (Enser *et al.*, 1996).

Nutritional Benefits of Grass-Fed Beef

Grass has higher PUFA and particularly higher n-3 PUFA (primarily as linolenic acid) than grain-based ruminant feeds. Increasing the grass content in the diet of finishing steers, ranging from concentrate-only to grass-only diets, gave lean meat with less SFA and up to 60% more n-3 PUFA (French *et al.*, 2000).

Conjugated linoleic acid (CLA, C18:2) is a PUFA of particular interest because it has reasonably well documented anti-cancer activity and is found in highest concentrations in the fat of ruminants. Although CLA isomers are absent from grass, it is rich in the precursors, linoleic and linolenic acids. Many years ago it was observed that the CLA content of butter increased when cows were turned out to pasture in the spring. We found that CLA increased from 4 to 11g/kg intramuscular fat going from concentrate-only to grass-only diets (French *et al.*, 2000). Furthermore, supplementing grass with sunflower oil doubled the CLA value. Researchers are now seeking ways to alter the bacterial population of the rumen to further increase CLA production (www.lipgene.tcd.ie).

Grass-fed beef has a natural health advantage. With only 30 to 50g fat per kg, lean beef could be considered a reduced-fat food, especially when compared to the values in many tables of food composition (70 to 100g/kg). Cost-effective strategies can be devised to exploit the diet of cat-

tle to produce tender flavoursome beef that has an increased content of CLA, lower fat content and a fatty acid profile more compatible with current human dietary guidelines (Moloney *et al.*, 2001).

Mechanical Grading

Miller and colleagues (2000) considered that more consistent meat quality will not emerge until carcasses can be differentiated by grading according to consumer preferences and until such measurements are included in the pricing matrix. However, mechanical grading for consumer preferences such as tenderness is some way off.

Although technologies based on ultrasound, electrical conductivity or X-rays are capable of measuring lean content, implementation of machine grading of beef in Europe was delayed by the requirement to calibrate machines against human graders. Video image analysis (VIA) can classify carcasses, as human graders do, into conformation and fat classes.

The first comparative trial of VIA systems was carried out four years ago (Allen, 2003) by installing the Danish (BCC-2), German (VBS 2000) and Australian (VIAscan) systems side by side in an Irish abattoir. Ten thousand carcasses were visually graded by an experienced panel of graders and were then measured by the three machines. The percentage of carcasses for which the machine prediction agreed with that of the graders (to within one third of a class) was calculated. For conformation the agreement was 94-97% for the three machines, and for fat class 74-80%. The lower performance of the machines in predicting fatness may be linked to the greater variability in the fat score given by the reference panel, thus any inconsistency in the graders' score is included in the error of the VIA systems. The principle that fat classification is more difficult for human graders and, therefore, the required standard for machines should be lower, was eventually accepted by the authorities in the European Union. The Irish trial assisted in changing the beef grading Regulation (EC/1981/1208), which now permits machines to be used. Machines will be installed in Irish meat plants this year. Denmark, France and Germany had installed VIA systems prior to the change in the regulations. Meanwhile, the search for an objective measurement of palatability for use in grading continues (Allen, 2003).

On-line Tenderness Tests

Physical or chemical indicators of meat texture are needed for applications in breeding, grading and for quality assurance in the fresh meat trade. Ideally such methods should be on-line and non-destructive. A probe measuring the near infra-red reflectance of meat has potential, but considerable work needs to be done to improve its predictive accuracy and to develop an application suited to industry (Venel *et al.*, 2001) and a novel high resolution ultrasound approach also shows promise, but this is even further from an on-line application (Allen *et al.*, 2001).

The early detection of fragments of the structural proteins of muscle is useful, for example the increase in the 30-kDa fragment originating from troponin T. An ELISA using an antibody against the soluble troponin T (16-31) fragment (Tsitsilonis *et al.*, 2002) is under test and a search for other protein fragments that are potentially indicative of tenderness is ongoing.

Tenderness Enhancing Technologies

Unacceptable variation in tenderness is a major reason for consumer dissatisfaction with beef in America (Koohmaraie, 1996). Likewise, in Europe there is an opportunity to differentiate product by reducing the variability of the tenderness of beef currently on the market (Grunert *et al.*, 2004). Control of variability in everyday practice requires better meat processing technology and, at a more fundamental level, an understanding of the interplay of animal genetics and production practices.

The differential expression of muscle genes and their protein products in response to environmental stimuli, such as nutrition and growth rate, is under investigation. Animals displaying extremes of quality traits (e.g. very tender versus very tough) provide a possible means of linking a particular gene expression pattern with a quality trait. Interest has focused on the genes associated with the early post-mortem cleavage of the myofibrillar linkage proteins - titin, nebulin and desmin - by the calpain proteolytic system, as this is believed to constitute the natural tenderisation process in meat. Page *et al.* (2002) presented evidence that polymorphisms for calpain I are markers for meat tenderness variation. A possible link between beef tenderness and polymorphisms in calpains I and II is being examined by our laboratory (A. M. Mullen; E. O'Doherty) with MSU (C. Ernst; M. Doumit).

High growth rates before slaughter were suggested to give more tender beef, independent of any change in fatness, due to a higher rate of muscle protein turnover (Aberle *et al.*, 1981). We found little evidence to support this hypothesis (Troy *et al.*, 2002); post-mortem tenderisation was the same in cattle slaughtered at high, normal or low daily weight gains (1.08, 0.72 and 0.36 kg/day, respectively).

With cattle of similar type, carcass handling techniques have a major influence on tenderness. A good example of a tenderness-enhancing technology that has successfully transferred to industry is hip suspension during the pre-rigor period (Hostetler *et al.*, 1970; Troy, 1999; Lundesjo *et al.*, 2003). A factor contributing to texture problems is the considerable unexplained variation in the rate of muscle pH fall post-mortem between similar types of cattle, carcasses with faster rates of pH fall being more tender (O'Halloran *et al.*, 1997).

A novel wrapping process. Due to the size and shape of the beef side, pre-rigor meat is subjected to varying profiles of temperature, pH and contraction, with profound effects on eating quality. Hot boning offers a more uniform chilling

rate; other well-known benefits include faster throughput, reduced evaporative weight loss, reduced drip and lower chilling costs. However, hot boning is not widely practiced in the beef industry because the muscles tend to contract and toughen. To prevent contraction, O'Sullivan and Troy (2003) applied a tough highly elastic film to hot-boned striploin, rump, topside and silverside using a novel packaging machine called Pi-Vac. Carcasses were deboned 1.5 h after slaughter, Pi-Vac-packed and chilled quickly to 0ºC. The eating quality was found to be the same as conventional, cold-boned vac-packed cuts from carcasses that were chilled at 10ºC for 10 h, then at 2ºC until 48 h post mortem. After 7 days ageing the Pi-Vac striploins had longer sarcomere lengths than the conventional vac-packed loins. After 14 days ageing the meat from both systems had the same tenderness, juiciness, overall flavour and overall acceptability. The Pi-Vac system has the potential to accelerate the processing of prime beef while improving the consistency of the product.

Food Safety in the Beef Sector

'Trust lies at the basis of any society's smooth functioning . . . this requirement pervades every aspect of social life, but there are perhaps few where it is so straightforwardly crucial as in relation to food safety' (Aengus Collins, Irish Times, May 3, 2003).

The best recent example of the impact of food safety on the industry, its consumers and the whole of society is the BSE epidemic, which began in 1986 and is now gradually coming to an end in Europe. The cost of the epidemic has been enormous, because, unlike most outbreaks of animal disease, new and permanent measures have been introduced, which impose substantial costs for the future (EAAP, 2003). The discounted current value of these costs is estimated at €92bn, approximately equal to the whole annual budget of the EU!

Meat safety hazards are often linked with farming (e.g. E. coli, Salmonella and Campylobacter) and technology (e.g. prions, antibiotics, dioxins and coplanar PCBs, pesticides, PAHs). EU food policy now has food safety as its top objective and places primary legal responsibility with the food business operator (Regulation 2002/178/EC). Food safety is also at the top of the public research agenda and is likely to stay there due to:

- The continuing evolution and emergence of pathogens, bypassing existing food safety controls;
- The growing number of prohibited substances, providing greater scope for breaches of the law, and improvements in analysis;
- The fact that food scares are now more newsworthy than in the past; also consumers are becoming more litigious;
- Better surveillance and reporting of illness.

Food safety issues can dominate food choice in situations of crisis, but have limited effect under normal conditions. Normally, consumers like to assume that all food on sale in supermarkets is safe, and trying to position a differentiated product on the safety issue may hurt the category as a whole. Consumer confidence in beef will increasingly depend on full traceability, allowing liability to spread to all parties in the production chain (EAAP, 2003). The use of DNA for traceability, whereby the product acts as its own label, was commercialised in the Irish beef sector under the trademark TraceBack™ (Cunningham, 2000).

Pathogens. Food safety research, as a public good, is uniquely suited to international collaboration. Working with the USDA in Philadelphia and elsewhere we developed skills in microbial risk assessment, notably for verocytotoxin (VT)-producing *Escherichia coli* (VTEC). This enabled us to initiate several EU research projects, including:

- A European study on animal, food and biomedical aspects of VTEC, which addressed methods of detection, survival in the food chain, pathogenicity and virulence in human illness, control measures, and epidemiology (Duffy *et al*., 2001);
- The EU Risk Analysis Information Network (2003 – 2006) in which data on six common food pathogens is shared to generate a central on-line resource for risk assessment (Maunsell and Bolton, 2004);
- A study of *Cryptosporidium parvum* in food and water (Duffy, 2003), including a novel method for detecting this emerging pathogen in beef.

Our work on VTEC includes a quantitative risk assessment of serogroup O157 in the beef chain and development of real-time PCR methods for genotypes O157, O26 and O111 (O'Hanlon *et al*., 2003); demonstration of the horizontal transmission of O157:H7 in steers in winter housing (McGee *et al*., 2003); confirmation of the beef hide as an important source of contamination in the abattoir; and demonstration that VTEC O157:H7 multiply during burger manufacture and distribution (Carney *et al*., 2003).

Chemical residues. Although residues cause many food scares, there is little evidence to support the public's perception of risk. The residues of agro chemicals and veterinary drugs found in meat products seldom exceed MRLs (maximum residue levels) due to good surveillance and detection (O'Keeffe and Kennedy, 1998). Continued vigilance is required, however, to prevent abuse and to assure consumers. Current interest is mainly focused on industrial pollutants including dioxins, and antibiotics in meats. Also, there is continuing controversy surrounding the use of hormonal growth promoters in meat production.

Implementation. Knowledge-based guidance materials are needed to enable the industry to benefit from research advances. This is critically important for the implementation of HACCP because there is a lack of validated critical control points in meat slaughter operations. The combined work of researchers, trainers and auditors (K. Brennan, D. Bolton and colleagues) has transformed the Irish meat sector capability in this area, providing the technical skills and

operating procedures that are essential to comply with the law (2001/471/EC).

Future Research Strategy

The future of the industry rests on how well beef is brought into harmony with a discerning, knowledgeable and demanding consumer. The task of research is to deliver knowledge and innovation for enterprises and regulators to build on. Much of the science is already known, as discussed above, now industry must play the lead role in commercialisation.

Research goals are quite similar internationally, particularly for issues of quality, safety and ethics, so the sector benefits considerably through research collaboration. EU-funded research is moving to large integrated projects with a wide spectrum of research expertise, and with participation by industry and consumer organisations. Research inputs from areas outside conventional food science are encouraged, including genomics, medicine, information technologies, ethics, environment, economic and social sciences, as appropriate. The overall research aim is to improve the health and quality of life of people, by producing food of higher quality and safety with clear health benefits, within the limits of sustainability of the industry.

References

Aberle, E.D.; Reeves, E.J.; Judge, M.D.; Hunsley, R.E.; Perry, T.W. 1981. Palatability and muscle characteristics of cattle with controlled weight gain: time on a high energy diet. Journal of Animal Science 52: 757-763.

Allen, P. Beef carcass grading in Europe and USA – the prospects for using VIA systems. International Congress of Meat Science and Technology, Campinas, Brazil. 2003, L1.

Allen, P.; Dwyer, C.; Mullen, A.; Buchin, V. Research Report no. 35, The National Food Centre, Ashtown, Dublin 15. 2001, 16 pages. ISBN 1 84170 202 1.

Barrett, P. 1996. The good (and bad) die young, Marketing, July 11, p16.

Carney, E.; O'Brien, S.; Duffy, G. A risk assessment on E. coli O157 in Irish minced beef. The National Food Centre Research Report 2003, Dublin 15.

Cowan, C., Buckley, M., Mahon, D.; McCarthy, M. FRL consumer segments in Great Britain, Report, The National Food Centre, Dublin 15. 2003, 30 pages.

Cowan, C.; Sexton, R. Ireland's Traditional Foods. The National Food Centre, Dublin 15. 1997, 220 pages. ISBN 1 901138046.

Cunningham, E.P. Traceability from farm to consumption. 46th International Congress of Meat Science and Technology, Buenos Aires. 2000, 10-L1, 798-801.

Daly, E. Managing new food product development. Research Report no. 60, The National Food Centre, Dublin 15. 2002, 19 pages. ISBN 1 84170 317 6.

Duffy, G. Cryptosporidium parvum in food and water. Conference Proceedings. The National Food Centre, Ashtown, Dublin 15. 2003. ISBN 1 84170 327 3.

Duffy, G.; Garvey, P.; Wasteson, Y.; McDowell, D.; Coia, J. (guest editors) 2001. Control of verocytotoxigenic E.coli. International Journal of Food Microbiology, Special Issue, 66 (1-2), 129 pages.

EAAP. After BSE - A future for the European livestock sector. European Association for Animal Production Publication No.108, Cunningham, E.P. Wageningen Academic Publishers. 2003, 90 pages.

Enser, M.; Hallett, K.; Hewett, B.; Fursey, G.A.J.; Wood, J.D. 1996. Fatty acid content and composition of English beef, lamb and pork at retail. Meat Science, 44, 443-458.

French, P.; Stanton, C.; Lawless, F.; O'Riordan, E.G.; Monahan, F.; Caffrey, P.J.; Moloney, A.P. 2000. Fatty acid composition, including conjugated linoleic acid, of intra-muscular fat from steers offered grazed grass, grass silage or concentrate-based diets. Journal of Animal Science, 78, 2849-2855.

Grunert, K.G.; Bredahl, L.; Brunsø, K. 2004. Consumer perception of meat quality and implications for product development in the meat sector - a review. Meat Science, 66, 259-272.

Grunert, K.G.; Valli, C. 2001. Designer-made meat and dairy products: consumer-led product development. Livestock Production Science, 72, 83-98.

Hostetler, R.L.; Landmann, W.A.; Link, B.A.; Fitzhugh Jr., H.A. 1970. Influence of carcass position during rigor mortis on tenderness of beef muscles: comparison of two treatments. Journal of Animal Science, 31, 47-50

Koohmaraie, M. 1996. Biochemical factors regulating the toughening and tenderisation processes of meat. Meat Science, 43, 193-201.

Lundesjo, M.; Enfalt, L.; Johansson, J.; Virhammar, K.; Hansson, I.; Hohansson, L.; Lundstrom, K. 49th International Congress of Meat Science and Technology, Campinas, Brazil. 2003, 161-162.

Maunsell, B.; Bolton, D. 2004. European catering food safety: a recipe for success. Food Science and Technology, 18 (1), 37-38.

McGee, P.; Scott, L.; Sheridan, J.J.; Earley, B.; Leonard, N. Transmission of E.coli O157:H7 during cattle housing. The National Food Centre Research Report 2003. Dublin 15.

Miller, R.K.; Moeller; S.J.; Goodwin, R.N.; Lorenzen, C.L.; Savell, J.W. Consistency in meat quality. 46th International Congress of Meat Science and Technology, Buenos Aires. 2000, 5-L1, 566-580.

Moloney, A.P.; Mooney, M.T.; Kerry, J.P.; Troy, D.J. 2001. Producing tender and flavoursome beef with enhanced nutritional characteristics. Proceedings of the Nutrition Society, 60, 221-229.

O'Halloran, G.R.; Troy, D.J.; Buckley, D.J. 1997. The relationship between early post-mortem pH and the tenderisation of beef muscles. Meat Science, 45, 239.

O'Hanlon, K.; Catarme, T.; Duffy, G. Detection of E.coli O26 and O111 in retail beef using a real time PCR and a cultural method. The National Food Centre Research Report 2003, Dublin 15.

O'Keeffe, M.: Kennedy, O. Residues – a food safety problem? Food Safety, the Implications of Change from Producerism to Consumerism. Sheridan, J.J.; O'Keeffe, M.: Rogers, M. Food and Nutrition Press, Inc., Trumbull, Connecticut. 1998, 55-73.

O'Sullivan, A.; Troy, D. A new processing system to ensure consistent eating quality of hot boned beef. The National Food Centre Research Report 2003. Dublin 15.

Page, B.T.; Casas, E.; Heaton, M.P.; Cullen, N.G.; Hyndman, D.L.; Morris, C.A.; Crawford, A.M.; Wheeler, T.L.; Koohmaraie, M.; Keele, J.W.; Smith, T.P.L. 2002. Evaluation of single-nucleotide polymorphisms in CAPN1 for association with meat tenderness in cattle. Journal of Animal Science, 80, 3077-3085.

Tarrant, P.V. Animal behaviour and environment in the dark-cutting condition. In: Dark-cutting in Cattle and Sheep. Fabiansson, S.U.; Shorthose, W.R.; Warner, R.D. Australian Meat and Livestock Research and Development Corporation, Sydney. I989a, 8-18.

Tarrant, P.V. The effects of handling, transport, slaughter and chilling on meat quality and yield in pigs. Proceedings of the Biennial Conference

of the Australasian Pig Science Association. Barnett, J.L.; Hennessy, D.P. Animal Research Institute, Werribee, Victoria 3030. 1989b, 1-25.

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

Tarrant, P.V.; Grandin, T. Cattle transport. Livestock Handling and Transport. Grandin, T. 2nd Edition, CABI Publishing. 2000, 151-173.

Troy, D.; Murray, B.; O'Sullivan, A.; Mooney, T.; Moloney, A.; Kerry, J. Influence of feeding systems on the eating quality of beef. Research Report no.58. The National Food Centre, Dublin 15. 2000, 22 pages. ISBN 1 84170 315x.

Troy, D.J. Enhancing the tenderness of beef. Research Report no. 11. The National Food Centre, Dublin 15. 1999, 28 pages. ISBN 1 84170 010 4.

Tsitsilonis, O.E.; Stoeva, S.; Echner, H.; Balafas, A.; Margomenou, L.; Katsoulas, H. L.; Troy, D. J.; Voelter, W.; Papamichail. M.; Lymberi, P. 2002. Journal of Immunological Methods, 268, 141-148.

Venel, C.; Mullen, A.M.; Downey, G.; Troy, D.J. 2001. Prediction of tenderness and other quality attributes of beef by near infrared reflectance spectroscopy between 750 and 1100 nm; further studies. Journal of Near Infrared Spectroscopy, 9, 185-198.