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The potential impact of current animal research on the meat industry and consumer attitudes towards meat

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Abstract

Progress in animal nutrition, reproduction, quantitative genetics, and the development of molecular genetics, proteomics, and functional genomics open new perspectives for the meat sector. The most promising developments include a wider utilisation of molecular markers, the possibilities of semen sexing and the targeted use of nutrition to modify the composition of meat. The increased use of biotechnology will have a considerable impact on the economics of production of meat and further processed products. New technologies will increase the possibilities for product differentiation and improve homogeneity of live animals. The consumer and society in general will influence the direction of these developments. This review will focus on the long-term impact of new technologies for the meat production chain.

1. Introduction

A huge increase in life science and biotechnology research expenditure has been witnessed since the 1970s. For example, in 2000, biotechnology companies in the USA raised $ 40,000,000,000 on the US stock exchange (Griffith, 2001). The GMO crisis in Europe, Japan and increasingly in the USA, however, has had a negative impact on research and development. Many companies operating in this field have been disappointed with the profitability of their agricultural activities and have refocused their activities towards the pharmaceutical industries (*Les groupes mondiaux se délestent de leur agrochimie* 2000; Eichenwald, Kolata, & Petersen, 2001). The limited and decreasing worldwide public funding on animal and meat science (with the exception of BSE) and limited private financing of research in this field has left the meat production sector lagging behind other sectors of life science. Animal biotechnology is a poor fourth to human, microbial and plant biotechnology. Nonetheless, the worldwide research effort is very important and the developments are rapid and momentous, particularly with genomic studies. The growing knowledge of the human and mouse genome can be utilised in farm animal research (so-called comparative genomics) and may lead to several applications in the meat industry.

This paper reviews the principal trends in the various research disciplines and future options for animal science, using pigs as the main example, and examines the potential implications of technological developments on the meat sector and attempts to take account of consumer attitudes.

2. Animal sciences and the consumer

The consumer is increasingly involved in, and influencing the whole food chain, agriculture, and science. Food safety crises and livestock epizooties have shaken both consumers and political confidence in animal sciences and the meat chain at large. Harington's (1994) list of consumer concerns: ethical, food safety, nutrition and fat, animal welfare, "third world", the environment and genetic engineering, still remains valid. In a recent review Heiney (2001) describes modern agriculture as fuelled by unproven science and focuses on the great distrust by consumers of modern agriculture and agricultural sciences. The consumer's lack of control of the

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food production is at the core of this distrust, however small the real safety risk may be (Apfelbaum, 1998; Rozin, 2001). A return to smaller-scale, environmental-fiendly farming with preferably organic and locally marketed products is advocated (Report of the Policy on Food and Farming (2002)). The agriculture and food industries, including fish farming and agricultural science, must not avoid the debate, since consumers expect to be more involved in a dialogue concerning the issues that affect or could affect their lives (Moore, 2000).

There seems no doubt that the livestock sciences have contributed to the crisis of consumer and political confidence. Strong selection for increased growth rate and reduced fat cover in pigs has had a negative effect on fresh pig meat quality (Brocks, Klont, Buist, Greef, Tieman, & Engel, 2000; Petersen, Oksbjerg, Henckel, & Støier, 1997; Pringle & William, 2000). Similar results have been found with beef. The use of pigs carrying the Halothane gene in order to improve carcase conformation has been detrimental to the quality of fresh meat and meat products (Garnier & Sosnicki, 2002). Poultry breeding has revolutionized chicken farming, although it is claimed that broilers are likely to reach the maximum potential of the gene pool in the next 15 years (Albers, 2000). However, a satisfactory balance between muscle and bone and internal organ growth has not always been found (for a review see Farm Animal Welfare Council, 1992, and Rauw, Kanis, Noordhuizen-Stassen, & Grommers, 1998). This has been highly detrimental to poultry welfare in terms of heart and leg problems. Other animal welfare and environmental issues may also be linked to poor selection practices and system design.

There is a perception that there has been a weakening of pathogen resistance as a result of selection for higher production performance animals. For example, breeding goals in general do not include selection for robustness and resistance to disease. Recourse to prophylactic medication is perceived negatively by consumers and can only be a short-term palliative. Tauxe (2001) states that new food borne pathogens are discovered at a rate of at least one every 2 years. The number of food poisoning cases in the developed world is growing rapidly and we have not yet reached the safety level expected from the consumer. Farm hygiene must be a fundamental part of food safety. Animal borne pathogen responsible for zoonoses such as Salmonella, *Campylobacter jejuni* and *Escherichia coli* O157:H7 are a growing concern (for a review, see Alexander, 1998). It has generally been assumed that it is the responsibility of the food processor to eliminate animal borne pathogens (Rubery, 2001). However, efforts to reduce the incidence of such organisms must be undertaken at all levels of the meat production chain.

In some situations, consumer pressure is translated towards a push to organic production as seen in Switzerland, Austria, and Germany (Koechlin, 1999; Moses, 1999). Questions on the future direction of agriculture are also being asked in the UK, France, Italy, USA and Australia among others. The question remains as to how the agricultural sector can find sustainable ways of being more productive. The meat industry as well as livestock, grazing and meat sciences are profoundly implicated in this debate. A first implication described here, is the development of two overlapping directions for animal science. On the one hand biotechnology will push forward in the sphere of high-input livestock production systems, particularly for monogastric animals, and on the other hand, the science orientated towards low-input systems will expand, particularly for ruminants. It is also anticipated that technical advances in biotechnology will be used in the development of sustainable low-input livestock production systems. These scenarios are set out in Netteson et al. (1999).

3. Animal reproduction biotechnologies

Progress in animal reproduction science and the application of new technologies in livestock and poultry production have been relatively slow. However, new technologies for the production of embryos in vitro may accelerate the transfer of genetic progress to the production level by reducing genetic lag and by providing more customised or tailored genetics to specific markets (Simpson, Kojima, Kada, Miyazaki, & Yoshida, 1996). This is already possible with cattle and sheep but technical difficulties remain in the case of pigs (Prather & Day, 1998). Even so progress is taking place. For example, the viability of frozen pig embryos has been increased by the reduction of fat content of the embryo, before vitrification (Dobrinski, Nagashima, Pursel, Long, & Johnson, 1999). Embryo splitting techniques, first developed 20 years ago, can increase the number of offspring of high genetic value. There have been problems like "large calf syndrome" but in the main, high costs and a lack of technical progress has hampered the development of practical applications of this technique.

The value and importance of disseminating superior genetics worldwide with a minimum animal health risk and at a lower cost than live animals is such that the techniques of embryo collection, preservation and implantation should progress in the near future. Nonetheless, the transfer of semen, either fresh or frozen (a more recent development), will continue to be favoured for most situations due to its lower cost (Wilmut, Young, DeSousa, & King, 2000).

Techniques for semen sexing already exist, for example, fluorescence activated cell sorting (FACS) of semen is now commercially available for cattle and horses (XY Inc., Fort Collins, Colorado, USA; www.xyinc.com). This process is still too slow and expensive for applications in pigs and sheep. However, efforts are underway to improve efficiency of fertilisation so as to enable the use of FACS sexed semen. Efficient semen sexing will have a large impact on the farm animal production sector and this drives research on alternative sorting techniques, for example using specific antibodies. For the meat sector, the benefits include a higher homogeneity of carcases and a better-targeted production.

The development of nuclear transfer and cloning culminating in *Dolly* was heralded as a landmark in the history of science (Wilmut, Schnieke, McWhir, Kind, & Campbell, 1997). However, the human aspects of the cloning debate have somehow obscured the implications for livestock production. Despite recent developments in the cloning of high value breeding stock (Infigen™, De Forest, Wisc. USA, www.infigen.com) the widespread application of nuclear transfer in animal selection is not practical at this stage because of its low efficiency (see Table 1; Demataweva & Berger, 1998; Ruane, Klemetsal, & Sehested, 1997). Improvements in the technique may lead to future applications, although it is envisaged that these will be primarily from genetic modification or by the introduction of precise genetic change in livestock in addition to the beneficial effect in selection schemes (Wilmut et al., 2000).

Current research on the cloning of poultry involves the mass multiplication of stem cells and their automatic injection in eggs' embryos (Graves, 2001). Strictly speaking, the end products are chimeras rather than clones. Stem cell production of poultry and egg embryo injection are long-established techniques and the mass production of identical chicken is therefore feasible. Again, the effect on meat processing industries of new reproduction technologies could be significant. Factors like carcase quality and homogeneity of slaughter animals could be greatly enhanced through the use of cloning or large-scale in vitro embryo production. In the medium term, an integration of the biotechnologies of reproduction with quantitative and molecular genetics is envisaged (Sellier, 2000). In the longer term, the competitiveness of sheep and goat meat might be greatly increased by new reproductive and genetic techniques for the improvement of the reproductive performance of ewes (MAFF, 2000). However, it is not clear at this time when such approaches will be acceptable to consumers in the developed world.

Table 1
Farm animal cloning: rate of success

Species	Cell type	Born alive/ transplants	Overall efficiency
Pigs	Fetal fibroblasts	1 / 110	0.2%
Sheep	Genetically modified fetal fibroblasts	7 / 67	1.4%
Goats	Genetically modified fetal cells	3 / 112	1.9%
Cattle	Hide cells of adult cattle	9 / 191	1.6%

Source: Les Echos 02.04.01—INRA.

4. Quantitative and molecular genetics

Progress is continuing in the area of quantitative genetics (Hill, 1999) and is fuelled by the opportunities provided by biotechnology in terms of data collection (genomics) and dissemination of genetic improvement (reproduction). For example, the technique of *optimal genetic contribution* can improve genetic improvement by 10–20% (Hanenberg & Merks, 2000). Other examples include methods for the optimal use of DNA markers in selection schemes. For example, the combination of Best Linear Unbiased Prediction (BLUP) and Marker Assisted Selection (MAS) can improve genetic progress compared to the two techniques used in isolation. Although, quantitative genetics is not normally considered as biotechnology, it plays an essential part in the implementation of these developments and the same consumer issues apply. This is particularly relevant for meat production as the integration of meat quality traits in breeding programmes often has a negative or at best neutral impact on performance traits such as growth (Hovenier, Knap, & Kanis, 1993).

The potential impact of molecular genetics for farm animals is large, particularly for traits such as meat quality, which are expensive to measure (see De Vries, Faucitano, Sosnicki, & Plastow, 2000a; De Vries, Sosnicki, Garnier, Plastow, 1998). For reviews describing the various molecular techniques see Haley and Visscher (2000) and *Génétique Moléculaire* (2000). Knowledge of the genome and the establishment of genetic maps are essential in order to isolate and characterise genes of interest. Table 2 presents initial results for three genetic maps of the pig genome. The pig genome consists of 38 chromomes with about 3×10^9 base pairs and is estimated to contain about 50,000 different genes. A large international effort is underway to improve their resolution, including the mapping of 2000–4000 new markers in the European PIGMaP families and the mapping of 2000 new markers by the University of Minnesota (Milan, Yerle et al., 2000). These developments include the establishment of new map types (the RH map, Yerle et al., 1998) and the comparison of the maps of the pig and the human genome and their integration by 'reciprocal chromosome painting' (Gellin, 2000).

A marker is defined as "a fragment of DNA corresponding to loci for which exist in the genome of a species, different forms or alleles: the polymorphism" (Pitel & Riquet, 2000). Several groups have initiated molecular genetic studies designed to identify genes influencing meat quality. There are more than 20 resource populations working with pigs, involving the following breeds: Large White, Landrace, Meishan, Piétrain,

Table 2
Genetic cartography of pig genome

Genetic maps	Races of reference families	Number of mapped genetic markers
PIGMaP (Europe, 1994)	Large White, Meishan, wild boar, Piétrain	230 Markers
USDA (USA, 1996)	European composite white line (WC), Meishan	1042 Markers
Nordic (Nordic Countries, 1996)	Large White, wild boar	236 Markers

Adapted from Milan, Yerle et al. (2000) See www.thearkdb.org for up-to-date genome maps of farm animals.

Iberian, Duroc, Mangalitsa, Berkshire and wild boar (De Vries et al., 1998). Andersson-Eklund, Marklund, Lundström, Haley, Andersson, and Hanssen. (1998) found Quantitative Trait Loci (QTLs) for fatness and muscle growth. A French group has identified 115 potential markers, including five for backfat thickness, three for the androsterone content of fat (boar taint), and one for the intramuscular fat content of pork (Bidanel et al., 2000). Malek, Dekkers, Lee, Baas, Prusa et al. (2001) and Malek, Dekkers, Lee, Baas, and Rothschild (2001) in the USA, reports 100 significant QTLs markers for growth, backfat, meat quality and sensory traits. Ovilo et al. (2000) and Pérez-Enricso et al. (2000) used crosses of Iberian and Landrace pigs and have identified potential markers involved with meat colour and pH, a site associated with variations of linoleic acid content, and three further sites linked to muscle fibre composition. An overview of identified and potential carcass and pork quality markers is given in Table 3.

Marker assisted selection (MAS) takes place by selection within populations (for example, pure lines) and between populations by the introgression of genes. This latter technique uses a combination of backcrossing and selection to introduce a favourable gene from one breed to another. MAS uses existing variations within and between breeds in relevant meat quality traits like water holding capacity and intramuscular fat. Selective breeding based on this technology can increase product uniformity and it allows differentiation of pork products for specific markets (de Vries, Sosnicki, & Plastow, 2000). According to Meuwissen and Goddard (1996) the use of MAS can improve the selection response in post-slaughter traits by 64% in the initial generation. Breeding organisations have two options. They can integrate and fix favourable genes within some lines, whilst eliminating them from others or they can maintain the segregation within lines and perform DNA tests to select for the presence or absence of a particular gene marker in breeding animals. Markers demonstrating significant effects are then tested further in specific trials and commercial production systems before being incorporated into a routine screening process by breeding companies.

The utilization of genetic fingerprinting to guarantee the origin or quality of meat (e.g the DNA Trace-Back™, Biopsytec™ systems) is likely to be considerably widened in the future as the price of the DNA genotyping falls. In addition, DNA tests are available to confirm the breed origin of meat (PICSpec™, Plastow, 2000), which are especially useful where quality is associated with a particular breed. Examples include the Kuro Buta or black pork (Berkshire) in Japan and the Iberian pig in Spain.

5. Animal physiology and biochemistry

New developments in the area of animal physiology and biochemistry will result from the use of functional genomics and proteomics techniques in muscle biology research. Skeletal muscle is composed of fibres and adipose and connective tissues. It becomes meat at slaughter. Muscle fibre number and condition are important physiological parameters in the live animal and key determinants of muscle quality and quantity (Swatland, 1973; Lengerken, von Maak, Wicke, Fiedler, & Ender, 1994). Early embryonic development and myogenesis determine the number of fibres and muscle fibre differentiation (Pette & Staron, 1990). Several genes that play a role in early myogenic differentiation also play an important role during muscle development and growth in adult muscle (Musaro, Cusella de Angelis, Germani, Ciccarelli, Molinaro, & Zani, 1995). Growth rate and the quality of lean tissue deposited are major factors of economic importance in meat-producing animals. These are complex traits reflecting the action and interactions of many different physiological pathways.

The study of gene expression in relation to different production and quality characteristics will enable greater understanding of genetic and molecular components of quality. Current identification of candidates genes affecting meat and carcase quality are focused on (1) positional cloning based on the results of reverse genetics (QTLs studies), (2) the knowledge of the physiology and biochemistry of interesting traits and (3) the utilisation of the knowledge of genome in other species (comparative genomics—comparative mapping). The developments in functional genomics and proteomics will increase the number of practical DNA markers that can be used in MAS. The discovery of the actual RN gene (Hampshire acid meat gene, linked to cooked meat yield) illustrates the potential of these techniques (Milan

Table 3
Carcass and meat quality genetic markers in pork

Name	Description	Reference
Hal-1843® gene	Malignant hyperthermia—porcine stress syndrome: linked to PSE meat, carcass leanness and muscle mass	Fuji et al. (1991)
RN gene	Acid pork (Hampshire)	Milan, Jeon et al. (2000)
PRKAG3	New alleles of the "RN" gene—ultimate pH and drip loss	Ciobanu et al. (2001)
MC4R	Appetite, fatness and homogeneity of pig carcases	Kim, Larsen, Short, Plastrow and Rothschild (2000)
BETTERgen™ / IGF2	Lean meat content of muscled breeds	Nezer et al. (1999), Jeon et al. (1999)
H-FABP	Level of intramuscular fat (Duroc)	Gerbens, Rettenberger, Lenstra, Veerkamp, & Te Pas (1997), Gerbens et al. (1998)
Unidentified (QTL)	Level of intramuscular fat and backfat thickness (Iberian pig)	Ovilo et al. (2000)
Unidentified (QTL)	Level of intramuscular fat (Meishan)	Janss, Van Arendonk, & Brascamp (1994, 1997)
Unidentified (QTL)	Level of intramuscular fat (Duroc)	Monin, Sellier, & Bonneau (1998)
Unidentified (QTL)	Level of intramuscular fat (Meishan)	Renard and Mourot (2000)
Unidentified (QTL)	Level of calpain—pork tenderness	Parr et al. (1999)
Unidentified (QTL)	Level of cathepsin activity—quality of dry-cured ham	Armero, Flores, Barbosa, Toldra, & Pla (1998)
MyoG (myf4)	Muscle yield	Soumillion, Erkens, Lenstra, Rettenberger, & Te Pas (1997)
MyHC-	Fibre type—pork tenderness	Beuzen, Stear, & Chang (2000)
CAST-	Level of calpastatin—pork tenderness	Ernst, Robic, Yerle, Wang, & Rotschild (1998)
Unidentified (QTL)	Level of androstenone—boar taint	Fouilloux, Le Roy, Gruand, Renard, Sellier, & Bonneau (1997)
Unidentified (QTL)	Level of skatole—boar taint	Lundström et al. (1994)
Unidentified (QTL)	Linoleic acid content of pork fat	Pérez-Enricso et al. (2000)
KIT-	Coat colour of pigs	Johannson-Møller, Chaudhary, Hellman, Höyheim, Chowdhary, & Andersson (1996)

& Robic, 2000). The detrimental allele of the RN gene causes a high glycogen content of pig muscle and induces low ultimate pH post-mortem and low cooking yield.

Interactions between different genes and physiological processes determine both meat quality and quantity. In the future, the emphasis of muscle physiology should be aimed at discovering networks of multiple genes that determine a specific quality trait. This will benefit the meat processing industries by improving lean quantity of the raw material with optimal quality characteristics and less variation for a more uniform end product. Klont, Plastow, Wilson, Garnier, & Sosnicki (2001) predict that the on-line control of end product quality will be replaced in the long-term by the predictive use of DNA markers, assisted by increasingly sophisticated process control techniques. Process control will be used to evaluate the environmental interaction with the genetics within a production framework to limit end product variation.

6. Nutrition

Improvement of meat production efficiency, including its environmental impact, remains the main priority for the feed industries. The manipulation of the sensorial and nutritional quality of meat through animal nutrition strategies, however, is gaining importance. The composition of the macro-elements within the feed may be altered by the introduction of new plant varieties and species, some of them genetically modified for a targeted chemical composition. The targeted use of fats, vitamins and minerals will improve the sensory and nutritional quality of meat, and will allow the production of differentiated meat products (for a review see Lynch & Kerry, 2000). For example, the benefits of supplemental Vitamin E in feed have not been fully exploited by the meat processing industry. The effects of Vitamin E on beef colour, on the water retention in pork and turkey meat, the sensory quality of chicken meat and oxidation in meat and poultry have been well researched (for a review see Decker, Faustman, & Lopez-Bote, 2000). The benefits of the utilisation of Vitamin E and of other microelements in feed include the quality of fresh meat and of processed products such as cooked or dry cured ham, salamis and cooked poultry.

There are possibilities of manipulating fat composition, principally for pig, chicken and turkey meat but also in beef to improve meat flavour and fat by short-term feeding strategies (Moloney, 2001). The monounsaturated fatty acid content of pork can be increased without major negative effect on fat processing quality (Lopez-Bote, Fructuoso, & Mateos, 2000) with great potential benefits for human health, within a Mediterranean diet framework (Campillo Àlvarez, 2001). Strategies of manipulating the ratio of n-6/n-3 polyunsaturated fatty acid in pork and increasing the content of long-chain polyunsaturated fatty acids (EPA-DHA), by the use of linseed and marine fats have been very successful (see Table 4; Enser, Richardson, Wood, Gill, & Sheard, 2000; Riley, Enser, Nute, & Wood, 2000). Importantly in these experiments, sensory analysis on fresh meat and processed products showed that there are no deleterious effects of the application of the targeted diet on fat and lean processing and organoleptic quality. Commercial developments are now taking place in order to create differentiated products based on this approach. The n-6/n-3 polyunsaturated fatty acid ratio in pork could be lowered from 7 to 10, to the more healthy level of 4–5. Given the importance of pork in the European diet, the potential human health benefits are substantial.

In the medium term the use of conjugated linoleic acids (CLAs) in diets offers potential benefits for meat quality, i.e. lower drip loss and better lean colour but above all, a large potential effect on human health (Beitz, 2000; Dungan, Aalhus, Schaefer, & Kramer, 1997; Thiel-Cooper, Sparks, Wiegand, Parrish & Ewan, 1998; Blanksen et al., 2000). The UK Government foresees that in 2015, nutritionally improved meat and dairy products with specified ratios of different fats will be available for the consumer (Department of Trade and Industry, 1997a,b). To achieve this ambitious goal and a 'new meat' vision based on market segmentation based on the nutritional quality of meat, differentiated products and added value, collaborations within the whole meat chain are essential (Garnier, 1999a).

7. Low input systems

Consumer concerns regarding livestock farming, the interaction between sustainable livestock farming systems and the environment, the increasing lack of manpower in farming and end-product quality requirements have led to considerable scientific developments in the area of low-input extensive farming systems (see New Scientist, 2001; Pretty, 1998; and for review Gagnaux, Daccord, Gibon, Poffet, & Sibbald, 2000; Galal, Boyazoglu, & Hammoud, 2000). The integration of different scientific disciplines like soil and grass science, environmental science, genetics, animal behaviour, health and management, and meat science is needed in order to develop fully sustainable farming systems. Ruminants as grazing animals are primarily implicated but pigs and poultry are also of interest. For example, there is a considerable body of data regarding the traditional rearing of Iberian pigs (for a review see Buxardé Cardó & Daza Andrada, 2000). The integration of end-product quality goals in the development of sustainable farming systems is new. This includes the evaluation of the nutritional quality of the meat produced. Also new is the integration of biodiversity and genetic resources objectives (Brittante, 1998).

This approach has been so far limited to the niche marketing of meat. But market segmentation, consumer requirements for higher quality products, particularly for beef and other ruminant meat will ensure that niche markets will grow in importance and may even become the norm in the future. It is estimated that 50% of European and US fresh beef in Europe and the USA will be marketed under a quality scheme by 2004 (Garnier, 1999b). For the meat industry the possibilities of adding value in this notoriously low margin industry are enticing. For example, this may be in the form of purebred animals of a specific origin and ecosystem. The role of biotechnology will be at first mainly limited to the preservation of biodiversity and product authenticity but will play a key role at term in the development of sustainable extensive livestock systems.

Of particular importance to ruminant meat and to a lower extent to pig and poultry meat, is the reducing use of the fifth quarter such as offal and carcase sub-products as edible meat as increasingly affluent consumers switch to high-class cuts (Sybesma, 1995). This poses an economic conundrum for producers of high-value extensively reared livestock. In effect, it is difficult to pass higher costs of production on a small part of the carcase.

Extensive livestock production will undoubtedly coexist with more intensive production systems. There is a growing demand for meat world-wide, due to the growth of population, which will not be satisfied without recourse to them.

Table 4
n-6/n-3 Ratio in loin muscle, backfat and sausages from pigs raised on a diet supplemented with n-3 fatty acids

	Control		Supplemented diet	
	Male	Female	Male	Female
Loin (*Longissimus lumborum*)	8.61	9.02	5.06	5.03
Backfat (inner layer)	8.91	9.08	4.85	5.58
Sausages	8.13	8.05	4.91	5.21

Adapted from Enser et al. (2000).

8. Transgenesis

The case against genetically modified meat is clear. In a recent survey of EU opinion formers, no retailer, food manufacturer, consumer association, NGO, pharmaceutical company, biotechnology organisation or Government body saw the possibility of any involvement of transgenic animals in food production (Moses, 1999). Other surveys showed that genetically modified foods ranked the highest in concerns of UK consumers (Mintel, 2000). However, this must be considered in relation to developments in fish farming, where numerous techniques like gynogenesis, androgenesis, induced polyploidy (triploidy and tetraploidy) and transgenesis are now routinely used (Lakka & Das, 1998).

Some like Uzogara (2000) predict safer food, low fat and low cholesterol meats, and lower environmental impact with transgenic meat animals. It remains the case that some desirable characteristics such as disease resistance may only be achievable through genetic modification. It is also argued that many of the above benefits can be gained without the use of transgenic techniques (Garnier, 2002) and that there is a debatable lack of research in the USA and China on safety issues (Ewen & Putzai, 1999; Millstone, Brunner, & Mayer, 1999). There are also problems inherent to the technique used for the DNA-recombination (Schwägele, 2001), namely that gene expression is underlined by chromosomal positional effect. Meanwhile, European consumers, retailers and authorities, however, are in the process of eliminating GMO feed from livestock diets (Davies & Ward, 2000).

9. Conclusion

The logic of biotechnology points to a possible long-term future without meat animals. Muscle proteins may be derived from tissue culture and 'cheap protein' for further processing grown hydroponically (Tudge, 1993). The rapid progresses in molecular and quantitative genetics, reproduction technologies, animal nutrition and muscle science carry with them a huge potential. The possibilities of higher quality meat, of differentiated products with high added value and uniformity of slaughter animals are of great interest for the meat processing sector and the consumer. Long-term implications for animal welfare and behaviour, disease resistance, biodiversity, the environment, sustainability, and rural life need to be taken into account. These need to be expressed within a bio-ethical framework (Sandøe & Holtung, 1996), towards a position based on the *responsibility principle* (Jonas, 1979). New farming techniques have been introduced without thorough analysis of their impact (Hunt, 2001). However, the breeding industry is already responding to these demands. A recent EU-funded project on *Future Developments in Farm Animal Breeding* (Neeteson et al., 1999; Robinson, 1999) concluded that modern biotechnology would allow huge advances to be made. However, in making these advances, we must ensure that ethical, legal and consumer concerns are met.

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