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Ethics, Animal Welfare and Transgenic Farm Animals

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Introduction

The application of biotechnology to farm animals has the potential to benefit both humans and animals in significant ways (Seidel, 1986; Robinson and McEvoy, 1993; Müller and Brem, 1994; Powell *et al*., 1994; Romagnolo and DiAugustine, 1994; Wilmut, 1995; this volume). However, the ethical ramifications of the development and implementation of new biotechnologies have been the subject of recent, and often heated, debate. These ethical concerns have been summarized by many others (e.g. Thompson, 1997a; Donnelley *et al*., 1994; Mepham *et al*., 1995; Rollin, 1995; Tannenbaum, 1995; Mepham *et al*., 1998). Genetic engineering of animals and plants for agricultural use is probably the most contentious application of biotechnology, with the exception of cloning and other genetic manipulations of humans. Sociologist Frederick Buttel observed that medical technology accounts for about 90% of the products from genetic engineering, while food biotechnology accounts for 90% of the controversy (quoted in Thompson, 1997b). In this chapter, I will refer briefly to the spectrum of general ethical issues associated with food animal biotechnology, and then focus specifically on animal welfare concerns that arise as a consequence of transgenic manipulation of agricultural animals.

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General Ethical Concerns

Distribution of benefits

Many genetic manipulations of farm animals are intended to increase productivity. Yield increasing technologies like this, unlike labour-saving technologies, result in product surpluses and lower prices, and hence the removal of less efficient producers and a reduction in the number of production units (Dorner, 1983). Questions arise regarding whether the benefits from the use of transgenic technologies will be fairly distributed, particularly if transgenic animals are patented. Will small farmers be able to afford to purchase transgenic animals, or will they be driven out of business? If so, is this fair considering that much transgenic animal research has been publicly funded? How will the loss of small farms affect the quality of rural life in developed countries? What effects will the concentration of food production in increasingly fewer hands have on consumers? And what will be the effects of patenting and the increasing use of genetic technology on farmers in developing countries?

Dietary or food safety concerns

Although there seems to be a general consensus among scientists that genetically engineered foods are no more or less likely to pose food safety hazards than are traditionally produced foods (Berkowitz, 1993; Thompson, 1997b), food safety of bioengineered products is nonetheless a significant public concern. Market research in Britain has shown that 81% of consumers are concerned about genetically modified foods and would avoid them if possible (United Press International, 1998). In response, one of Britain's largest supermarket chains, Iceland, recently announced that it would not market genetically engineered foods under its own brand name.

Concerns about eating bioengineered foods can also arise for religious reasons. Chaudry and Regenstein (1994) have discussed some of the potential controversies that consuming such foods would create for Jews and Muslims who observe dietary laws. They conclude that, under Jewish law, gene transfer of one or two genes would be acceptable, even if that material came from prohibited species like swine, because the amount of material transferred would be considered trivial. However, 'mixing' characteristics to create something new could pose significant concerns. For Muslims, problems would arise if bioengineered products contain biologically active agents in high enough amounts, particularly if those agents are derived from prohibited animals.

Environmental impacts

The potential environmental impact of the intentional or unintentional release of genetically engineered organisms is a significant concern to many people (Hoban and Kendall, 1993). The greatest risks as far as transgenic agricultural animals are concerned are likely to be transgenic maricultured fish, which cannot easily be contained (Kapuscinski and Hallerman, 1990; Bruggemann, 1993). The wisdom of engineering farm animals to adapt to previously inhospitable habitats, thus displacing native wildlife and causing further damage to ecosystems, has also been questioned (Fox, 1989; Rollin, 1995).

Respect for life and 'unnaturalness' of genetic engineering

Ethical concern has also been voiced about the 'unnaturalness' of genetic engineering and the ways in which it might devalue nature and commercialize life. These concerns are more likely to be expressed by those who consider themselves religious, but are by no means restricted to religious individuals (Hoban and Kendall, 1993; Rollin, 1995; Thompson, 1997b). At the deepest level, these represent concerns about the ways in which technology might corrupt basic human values (Donnelly *et al.*, 1994). Strachan Donnelley of the Hastings Center (1993, p. 98) is a particularly eloquent advocate of this view:

> Animal biotechnology, inspired by often genuine and legitimate desires to meet human and animal need and interests, must beware that it does not pre-empt 'nature natural' in the minds and hearts of us human beings and replace it with its own 'nature contrived.' … This would be the end of us as seekers after 'living' natural norms and ways of being human, and given the press of our present technological powers, no doubt the end of nature's richness and goodness itself. This would decidedly be a double moral disaster and irresponsibility.

Some critics of animal biotechnology explicitly claim that animals have a natural genetic integrity that must be respected (Rifkin, 1985; Fox, 1986). Notions of animal integrity and the challenges they raise for transgenic animal production will be discussed in more detail later in this paper.

Public Attitudes towards Agricultural Biotechnology

Ethical concerns are reflected in public attitudes towards biotechnology. In a recent Eurobarometer survey (Biotechnology and the European Public Concerted Action Group, 1997), over 16,000 people in the European Union were asked for their opinions about the use of biotechnology for genetic testing, production of medicines and vaccines, increasing crop pest resistance, food production, developing genetically modified animals for research, and xenotransplantation. Although all of these applications of biotechnology were thought to be useful, the last three, which involve genetic manipulation of animals, were viewed negatively. Perception of risk appeared to play relatively little role in this judgment, except in the case of food production. What was most important was whether or not the application of the technology was felt to be *morally* acceptable. The committee that interpreted the survey concluded that the results indicated that perceived usefulness was a precondition for support and that people were prepared to accept some risks for those benefits, but that moral doubts acted as a veto irrespective of views on risks and benefits.

The Eurobarometer survey also showed that opposition to applications of biotechnology was not based on a lack of knowledge about science and technology. The belief that biotechnology and genetic engineering can make a positive contribution to people's lives had declined since a 1993 survey, even though the level of knowledge about basic biology had increased slightly. Furthermore, level of knowledge was poorly correlated with support for particular applications of biotechnology.

Similar views were aired at a consensus conference held in Copenhagen in 1992 (Sandoe *et al.*, 1996). The welfare of genetically engineered animals was a major concern of the participants, but they also thought it morally unacceptable to induce genetic changes in animals in order to adjust the animals to existing agricultural methods or to produce cheaper food. Likewise, a 1993 (Hoban and Kendall, 1993) survey of approximately 1300 adults in the USA followed by focus group discussions revealed that, while most believed that biotechnology would be personally beneficial to them, 53% also believed that it was morally wrong to use biotechnology to change animals, while only 24% believed that changing plants was wrong. The least acceptable applications of biotechnology were those that changed the composition of meat or milk, or increased animal growth rates. In the focus groups, women were particularly concerned about the humane treatment of animals and animal welfare issues arising from biotechnology.

These opinions reflect a fundamental shift in the way society views the use and treatment of animals, a phenomenon that Rollin (1995) refers to as 'the new social ethic for animals.' Throughout history, animals have largely been viewed as property, of value only because of their usefulness to humans. The treatment of animals was governed by obligations to other humans (i.e. the obligation not to damage another person's property) rather than directly to animals. However, because of a confluence of social forces in industrialized countries in the 19th century (Ritvo, 1987) this view of animals began to change. The passage of anti-cruelty statutes like the 1897 Cruelty to Animals Act in Great Britain, which stipulated that animals used in painful experiments be provided with pain relief, are evidence of the emergence of a new view – that animals themselves are entitled to certain kinds of treatment. There is still a broad-based acceptance in industrialized countries that using animals for human benefit is appropriate. However, it is also clear that this acceptance is no longer unreserved. Numerous public opinion polls have shown that approximately 80% of people in the USA believe that animals have rights (Hoban and Kendall, 1993; Craig and Swanson, 1994). This belief seems to encompass the following views: that animal pain and suffering should be minimized whenever possible, that animals should only be used for sufficiently important reasons (that is, that the costs and benefits of animal use should be fairly weighed), that animals cared for by humans deserve to have some quality of life that goes beyond the minimization of pain and suffering, and that animals should have legal protection. These views have important implications for transgenic animal technology.

Animal Welfare Concerns and Transgenic Farm Animals

There are a number of potential animal welfare problems associated with the production of transgenic animals, both in terms of the animals that are used to produce transgenic offspring and the transgenic offspring themselves (Murphy, 1988; Fox, 1989; Van Reenen and Blokhuis, 1993; Moore and Mepham, 1995; Rollin, 1995; Tannenbaum, 1995, Mepham *et al.*, 1998). The nature of the transgene, the route by which the transgene is introduced, and the degree of control that is possible over the expression of the transgene are important determinants of the extent to which a transgenic animal's welfare might be compromised (Seamark, 1993).

Methods Used to Produce Transgenic Animals

Most transgenic farm animals are created using a technique called microinjection, which involves the injection of purified DNA into the nucleus of a single-cell fertilized egg collected from a donor female. With microinjection, the site of insertion of the DNA into the genome and the number of copies of the DNA actually inserted cannot be predicted or controlled. Another method for producing transgenic animals is to use embryonic stem cells rather than fertilized eggs (Gordon, 1997). This method has the advantage of allowing the number of gene copies that are inserted and the site of insertion to be controlled, but at present this technology is developed only for mice. Although genes can be added to the genome using embryonic stem cell manipulation, this method is more commonly used to produce 'knockouts', that is animals that have had one of their own genes modified or deleted. Many different types of knockout mice are now used in biomedical research for the study of human diseases and disorders (Majzoub and Muglia, 1996). In livestock, potential uses for knockouts would include modifying the protein composition of milk, for example by removing proteins from bovine milk that are absent in human milk and that cause allergies (Eyestone, 1994).

Reproductive technologies

Reproductive manipulations including superovulation, semen collection, artificial insemination (AI), embryo collection and embryo transfer, are used in the production of transgenic farm animals. Whilst these manipulations are also used routinely by commercial breeders, they do raise a number of animal welfare concerns (Matthews, 1992; Seamark, 1993; Moore and Mepham, 1995), although their effects on animal welfare have thus far not been assessed systematically.

Handling and restraint, which are required for all of these manipulations, can be aversive to farm animals (Grandin, 1993). The administration of injections to induce ovulation or pseudopregnancy can cause transient distress, and the use of inserted controlled drug release devices or single injection regimes have been suggested in order to minimize this problem (Matthews, 1992). It has also been argued that electroejaculation can be stressful for some species, and that animals should be anaesthetized or tranquillized prior to this procedure being performed.

In cattle, AI and embryo collection and transfer can be accomplished using minimally invasive procedures, the latter under epidural anesthesia. However, these manipulations involve surgical or invasive procedures (laparotomy or laparoscopy) in sheep and pigs, and hence the potential for postoperative pain. Since livestock are valuable, they may be subjected to these procedures repeatedly during their lifetime. In particular, because of the problems involved in screening cattle embryos prior to implantation to ensure that they are actually carrying the transgene (Eyestone, 1994), cows found to be carrying non-transgenic offspring may be aborted and then reused as recipients. In poultry species, on the other hand, the hen is killed in order to obtain early-stage embryos.

Replacements for some of these manipulations are available (see Seamark, 1993; Moore and Mepham, 1995). A method has been devised for non-surgical embryo transfer in pigs. There has also been progress in developing *in vitro* oocyte maturation techniques and in obtaining ova from slaughterhouses, which would obviate the need for manipulation of live donor livestock females. However, lambs and calves produced using *in vitro* fertilization and embryo culture techniques tend to have higher birth weights and longer gestation lengths (Walker *et al.*, 1992; Van Reenen and Blokhuis, 1993), and difficult calvings (dystocia) can be a problem. In a recent study, Van Reenen and Blokhuis found that nearly 50% of cows carrying transgenic or non-transgenic offspring produced using *in vitro* techniques had calving difficulties. As a result, it is becoming more common to deliver offspring using Caesarean section (see Chapter 13). Again, the number of times that this procedure should be performed on any individual animal during her lifetime is a matter for scrutiny.

Efficiency of production and numbers of animals needed

Microinjection is an extremely inefficient method for producing transgenic offspring. Although the success of the method varies by species and gene construct, it has been estimated that fewer than 1% of injected livestock embryos result in transgenic offspring, and of those typically fewer than half actually express the transgene (Pursel *et al.*, 1989; Rexroad, 1994). About 80–90% of the mortality occurs very early during development, before the eggs are even mature enough to be transferred to the recipient female (Eyestone, 1994), but postnatal mortality also occurs (Pursel *et al.*, 1989). The effect of transgene insertion on mortality can be compounded by the use of certain reproductive technologies. Walker *et al.* (1992) found that more lambs produced by *in vitro* methods (20%) and/or carrying a transgene (22%) were dead at birth than were lambs produced *in vivo* (0–3.4%). Eyestone (this volume) reports that, in one study where cattle embryos were microinjected with a gene intended to cause expression of a human protein in the cow's milk, only 9% of 11,507 microinjected eggs developed to the stage where it was possible to transfer them to recipient cows. Only 19% of the cows produced calves, just nine of the 90 calves born were transgenic, and only one of those nine calves actually expressed the transgene. Even if an individual does express the transgene, it may not be transmitted to subsequent generations. Approximately 30% of transgenic animals are mosaics, which means that they carry the transgene in only some of their cells (Wilkie *et al.*, 1986). Mosaic animals may not pass the transgene to their offspring at all, or they may transmit it at a reduced rate.

In mice, the inefficiency associated with microinjection can be compensated for to a great extent by implanting recipient females with multiple embryos. In livestock, however, this can result in difficult births as well as masculinization of the female offspring if both a male and a female embryo are transferred to a cow. Most researchers therefore include an intermediate step in the production of transgenic cattle, which involves temporarily 'culturing' the embryos *in vitro* or in recipient cows or rabbit oviducts until the stage at which longer-term viability can be established (Eyestone, 1994). If cows are used, these developed embryos need to be recovered and then transferred to the recipient animals. Although this technique can therefore require the use of additional animals for the 'culturing' stage, it can reduce the number of recipient cows needed by up to 90%.

Mutations

Because microinjected DNA can insert itself in the middle of a functional gene, insertional mutations that alter or prevent the expression of that functional gene may inadvertently be created. Meisler (1992) estimates that

5–10% of established transgenic mice lines produced by microinjection have such mutations, and it is likely that similar rates would be found in microinjected livestock. Most (about 75%) of these are lethal prenatally, but those that are not are responsible for an array of defects in mice, including severe muscle weakness, missing kidneys, seizures, behavioural changes, sterility, disruptions of brain structure, neuronal degeneration, inner ear deformities and limb deformities. Individuals with such mutations can vary enormously with respect to the degree and type of impairment shown. Also, because many insertional mutations are recessive, their effects may not be obvious until subsequent generations. For example, even though mice engineered with a transgene for herpesvirus thymidine kinase were normal, 25% of their progeny had truncated hindlimbs, forelimbs lacking anterior structures and digits, brain defects, congenital facial malformations in the form of clefts, and a greatly shortened life expectancy (McNeish *et al*., 1988).

Gene expression

Welfare problems can also arise because of poorly controlled expression of the introduced gene. The expression of genes is normally strictly regulated both with respect to the stage of the organism's development during which the gene is active and the cells or tissues in which the gene product is produced. In an attempt to control gene expression in transgenic animals, regulatory sequences including promoters, which allow genes to be switched on (and off) at specific times developmentally or expressed only in specific tissues, are attached to the gene to be inserted.

Nevertheless, transgenes may still be expressed inappropriately, since the efficiency of regulation can vary from one promoter to another, as well as among different species of animals even when the same promoter is used (Murray *et al*., 1989; Rexroad, 1994). Furthermore, under certain circumstances the animal's own gene control sequences can influence the expression of the introduced gene. In addition, problems can arise because of the influence of the animal's own genes or gene products on the expression of the inserted gene (epigenetic effects), or because the inserted gene has multiple (and sometimes unexpected) effects on the animal (pleiotropy). It has been estimated that 80% of transgenic animals either do not express the gene or show variable or uncontrolled expression (Seamark, 1993), although the percentage of inappropriate expression is probably decreasing as genetic technologies are refined.

As Mepham *et al.* (1998) state, the potential welfare problems associated with any particular type of transgenic animal lie on a continuum from benign (e.g. the production of proteins that are biologically inactive for that particular species and that are secreted at a low level in specific tissues isolated from the bloodstream) to severe (biologically active proteins synthesized in large amounts in many tissues with abundant access to the bloodstream).

The most frequently cited example of welfare problems arising from inappropriate transgene expression is that of the Beltsville pigs, which were engineered with a gene for human growth hormone in an attempt to improve growth rate and decrease carcass fat content (Pursel *et al*., 1987). Backfat was reduced, although growth rate was not increased. However, the pigs were plagued by a variety of physical problems, including diarrhoea, mammary development in males, lethargy, arthritis, lameness, skin and eye problems, loss of libido, and disruption of oestrous cycles. Out of 19 expressing pigs produced, 17 died within the first year. Two were stillborn and four died as neonates, while the remainder died between 2 and 12 months of age. The main causes of death were pneumonia, pericarditis and peptic ulcers. Several pigs died during or immediately after confinement in a restraint device (a metabolism stall), demonstrating an increased susceptibility to stress. Similar problems are seen in mice transgenic for human growth hormone (Berlanga *et al*., 1993). Sheep in which growth hormone is inappropriately expressed are lean but diabetic (Murray *et al.*, 1989; Rexroad, 1994), while some coho salmon that express high levels of sockeye salmon growth hormone have grossly enlarged heads and reduced swimming ability (see Chapter 15). Unlike the Beltsville pigs, however, these salmon also have a phenomenally improved growth rate – an 11-fold increase in growth during the first year.

The genetic background of particular selected strains of farm animals is probably also important in determining the severity of the defects associated with the transgene. Pursel *et al.* (1989) have speculated that the deformities found in the Beltsville pigs would have been less severe if the foundation stock had been selected for leg soundness and adaptation to commercial rearing conditions.

Typically, fewer welfare problems are encountered when farm animals are engineered for the production of milk-borne pharmaceuticals (Van Reenen and Blokhuis, 1993), unless those pharmaceuticals are biologically active in the species in which they are produced and are also expressed in non-mammary tissues and/or ‘leak’ out of the mammary gland into the circulation. However, the expression of some proteins has been associated with lactational shutdown in goats (Ebert and Schindler, 1993) and pigs, and there is evidence in the case of the pigs that the mammary tissue developed abnormally due to premature expression of the transgene (Shamay *et al.*, 1992). The condition of the mammary gland may have caused lactation to be painful.

Uniqueness of transgenic animals

Because there can be so much variation in the sites of gene insertion, the numbers of gene copies transferred, and gene expression, every transgenic animal produced using microinjection is (theoretically, at least) unique in terms of its phenotype. Pigs transgenic for growth hormone, for example, vary enormously in the number of the DNA copies that they have per cell (from one to 490) and in the amount of growth hormone that they secrete (from 3 to 949 ng ml^{-1}). Only 50% of pigs transgenic for a gene (*c-ski*) intended to enhance muscle development experienced muscle weakness in their front legs, and in general the degree and site of muscle abnormality in these pigs varied considerably from one individual to another (Pursel *et al*., 1992).

This makes the task of evaluating the welfare of transgenic animals particularly difficult, since adverse effects are almost impossible to predict in advance and each individual animal must be assessed for such effects. Van Reenen and Blokhuis (1993) describe the difficulties involved in such assessments. In most cases deleterious phenotypic changes in transgenic farm animals, particularly animals transgenic for growth hormone or other growth-promoting factors, have been easy to detect because they cause such gross pathologies. However, more subtle effects are also possible. Growth hormone, for example, has many systemic effects, including effects on the efficiency of nutrient absorption (Bird *et al*., 1994). It has been reported that pigs injected with growth hormone have different nutrient requirements (Fox, 1989), and similar effects might be expected to occur in animals transgenic for growth hormone. Some types of knockout mice have also been found to have behavioural problems, like increased aggressiveness and impaired maternal and spatial behaviours (Nelson, 1997), that are not immediately apparent, but that could significantly affect housing and care requirements.

Sometimes adverse effects are seen only when animals are challenged in some way. The abnormal stress response of the Beltsville pigs when restrained is an obvious example. In addition, some problems may not become evident until later in development. Mice transgenic for an immune system regulatory factor, interleukin 4, develop osteoporosis, but not until about 2 months of age (Lewis *et al*., 1993). This emphasizes the importance of monitoring the welfare of transgenic animals throughout their lifetime.

Welfare Benefits to Animals and Animal Integrity

Of course, genetic engineering also has the potential to improve the welfare of animals. Decreasing mortality and morbidity by increasing resistance to diseases or parasites is an obvious example of welfare benefits, and an area in which much transgenic research is focused (Müller and Brem, 1994). It has also been pointed out that transgenic animals may well receive a higher standard of care than non-transgenic animals because of their greater economic worth (Morton *et al*., 1993).

Genetic engineering could also be used to deal with non-disease-related welfare problems. It might be possible, for example, to engineer hens or cows that produce only female offspring (Banner, 1995). This would eliminate the problems associated with surplus male chicks or calves, the former of which are killed at the hatchery and the latter of which are reared for veal, both practices that have been the target of a great deal of criticism. The need for the so-called standard agricultural practices like castration and dehorning could also be reduced or eliminated by genetic engineering. Pigs are castrated to prevent boar taint in the meat, but this trait is strongly genetically linked and thus amenable to genetic manipulation. Similarly, horns on cattle, which are removed because they cause injuries to humans and other cattle, are the result of a single gene that could be knocked out using genetic manipulation without affecting other desirable performance traits.

Applications of biotechnology to further adapt farm animals to intensive production systems might also be possible, but are likely to generate the most controversy. Should animals be engineered so that they are less responsive, tolerate crowding, or show fewer behavioural abnormalities, or to eliminate behaviours that are difficult to accommodate in intensive confinement while maintaining economic efficiencies? In an address to the Royal Society of Agriculture, Heap (1995) stated, 'Programmes which threaten an animal's characteristics and form by restricting its ability to reproduce normally, or which may in the future diminish its behaviour or cognition to improve productivity would raise serious intrinsic objections because of their assault on an animal's essential nature.'

But what is the animal's 'essential nature'? Some critics of genetic engineering argue that genetic engineering is inherently wrong because animals have a natural genetic integrity that should not be disturbed. Fox (1986), for example, states that biotechnology makes it possible for the first time for the boundaries that separate species to be breached, which will lead to the unique genetic make-up of particular species being drastically modified to serve human ends. Biologists (and others) find this concept particularly problematical, since it suggests that genetic traits constitutive of species are somehow 'fixed' through time, contrary to the theory of evolution. Species boundaries in nature are fluid. In addition, healthy, successful animal hybrids have also been produced using traditional breeding technologies (Pluhar, 1986; Russow, 1998; Singleton, 1998), and the genotypes and phenotypes of domesticated animals have already been changed significantly by selective breeding.

Pluhar (1985) argues that the difference between genetic engineering and traditional breeding is one of degree only. And it is clear that serious welfare problems can also arise because of traditional breeding techniques. Broiler chickens are a case in point. Breeding for increased growth has also led to serious physical disabilities, including skeletal and cardiovascular weakness. Ninety per cent of broilers have gait abnormalities (Kestin *et al*., 1992), and these may be painful and make it difficult for the birds to walk to the feeders and waterers. In addition, the parents of these birds must be severely feed restricted to prevent obesity, and this feed restriction is associated with extreme hunger and a variety of behavioural problems (Mench, 1993). Banner (1995) notes that our special scrutiny of biotechnology in this regard creates anomalies – a transgenic modification that created the modern broiler chicken would have been closely regulated in Britain, while the broiler chicken produced using traditional breeding methods receives far less protection.

Since the genetic makeup of species is not fixed, then, is there any sense in which animal integrity raises genuine ethical issues? A perhaps more fruitful framing of the concerns raised by violations of animal integrity is that it is the *interests* of animals (Pluhar, 1986; Rollin, 1986) that need to be considered when making decisions not only about genetic engineering, but about any aspect of animal treatment. An animal's interests are a product both of its genetic background and its experience. Relevant interests as far as animal welfare is concerned might include avoiding pain, distress or suffering; experiencing pleasure; having social relationships; and pursuing (even short-term) goals (Mench, 1998). These are also the traits that are recognized as conferring moral relevance on animals, which may be the reason that there is particular controversy about interfering with them (Moore and Mepham, 1995).

Ideas about integrity are closely tied to ideas about the human responsibility to respect animals and treat them with dignity (Vorstenbosch, 1993). As Heap's statement above makes clear, changing fundamental animal interests to improve the 'fit' between animals and the human-created environment may well be construed as ethically problematical (see also Tannenbaum, 1995), regardless of whether that change occurs through transgenic technology or through more traditional means. Sapontzis (1991) reminds us that the traditional goal of ethics – a better world – refers to a world in which frustrations have been reduced by *fulfilling* interests rather than eliminating them.

Transgenic technology may consider and respect animal interests, in the same way that traditional selection techniques may fail to consider those interests (Pluhar, 1985). Improving disease resistance to decrease pain and suffering is an application of transgenic technology that considers animal interests. But it should be stressed that animal welfare is multi-faceted. Important elements of animal welfare include freedom from disease, pain or distress, physiological normality, and the opportunity to perform normal behaviours (Broom, 1993). While reducing disease is clearly beneficial, if this also permits animals to be more closely confined and thus decreases the opportunity for them to perform their normal behaviours then the net effect on welfare may be negative.

Is there anything special, then, about genetic engineering *vis à vis* traditional breeding? The primary difference between traditional breeding and genetic engineering is the speed at which change typically occurs (although naturally occurring mutations and recombination events can also cause rapid and dramatic change) and the single-gene nature of the change. As Russow (1998) notes, traditional methods of selection are more likely to be subject to the checks and balances imposed by natural selection. Many related and apparently unrelated traits are genetically correlated, and selective breeding thus involves selecting for a whole phenotype rather than a single gene product. Because most production and behavioural traits in livestock are polygenic and our understanding of livestock genomes is poor, few traits can reliably and predictably be modified or introduced by manipulating only one gene (Moore and Mepham, 1995). In addition, because changes occur more gradually with selective breeding, there is more time to figure out how to correct problems. Speed is also a strength of genetic engineering, however, since it can permit ‘quick fixes’ for problems arising from other practices. Given the special concern about transgenic technology, it would be ironic if genetic engineering turned out to be the fastest and best solution for some of the welfare problems that we have created using traditional breeding methods like leg problems in broilers.

What Future for Animal Transgenesis?

Transgenic animal technology, like other areas of applied science, has both risks and benefits. Whether public concerns about animal biotechnology prove groundless or not, it seems clear that this technology will be subjected to increasing scrutiny, and that the public will favour some form of regulation, either self-regulation or government regulation (Hoban and Kendall, 1993; Biotechnology and the European Public Concerted Action Group, 1997). Mechanisms are already in place in several European countries for the ethical evaluation of proposed genetic manipulations of animals. In The Netherlands, for example, no manipulation of animals is permitted until an independent committee has reviewed the ethics. The intrinsic value of the animal is taken as a starting point for such assessment, and the effects of the manipulation on animal health and welfare and animal autonomy are carefully considered (Brom and Schroten, 1993).

In making such assessments, costs and benefits need to be weighed carefully. Ignoring ethical costs for a moment, the financial cost of producing transgenic livestock is substantial. It has been estimated that it costs US$60,000 to produce one transgenic sheep and US$300,000 to produce one transgenic cow (Chapter 3). In the long term, are these costs proportional to the benefits that will be gained in terms of increased productivity? When expression of growth hormone is appropriately regulated in transgenic pigs, the increases shown in growth and feed efficiency are modest, and similar to the increases that can be attained by simply injecting pigs with porcine growth hormone (Pursel *et al.*, 1989; Chapter 11, this volume). Pursel *et al.* (1989) suggest that centuries of selection for growth and body composition may limit the ability of the pig to respond to additional growth hormone. Indeed, it is possible that we have already pushed some farm animals to the limits of productivity that are possible using selective breeding, and that further increases will only exacerbate the welfare problems that have arisen during selection.

Financial costs, of course, are only one of the many factors that need to be weighed in deciding whether it is appropriate to pursue particular applications of transgenic animal technology (or for that matter any other agricultural innovations). Short- and long-term impacts on animals, farmers, consumers and the environment all need to be carefully evaluated. Mepham (1995) outlines impacts that need to be considered within the framework of respect for well-being, autonomy and justice. For animals, these include welfare, behavioural freedom and respect for integrity. For farmers, these include adequate working conditions, freedom to adopt or avoid technologies, and fair treatment in trade and law. For consumers, these include the availability of safe and affordable food and consumer choice. Lastly, environmental considerations encompass protection and sustainability of populations and maintenance of biodiversity.

Many schemes are being proposed for a more formal approach to ethical evaluation and oversight of proposed biotechnologies (Appleby, 1988; Hoban and Kendall, 1993; Mepham, 1993; Donnelley *et al.*, 1994; Sandøe and Holtung, 1996; Mepham *et al.*, 1998). In the past, scientists have tended to isolate themselves from these debates. This posture needs to change. Scientists need to become full and fully informed participants in the debate about the ethical effects of the technologies that their work is instrumental in developing. Otherwise, consumer confidence in science and scientists may well be lost.

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