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ARTICLES

Ethical Issues and Potential Stakeholder Priorities Associated with the Application of Genomic Technologies Applied to Animal Production Systems

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Abstract This study considered the range of ethical issues and potential stakeholder priorities associated with the application of genomic technologies applied to animal production systems, in particular those which utilised genomic technologies in accelerated breeding rather than the application of genetic modification. A literature review was used to inform the development of an ethical matrix, which was used to scope the potential perspectives of different agents regarding the acceptability of genomic technologies, as opposed to genetic modification (GM) techniques applied to animal production systems. There are very few studies carried out on stakeholder (including consumer) attitudes regarding the application of genomics to animal production in the human food chain and it may be that this technology is perceived as no more than an extension of traditional breeding techniques. While this is an area which needs more research, it would appear from this study that genomics, because it avoids many of the disadvantages and consumer perceptions associated with GM, is likely to prove a more publicly acceptable route than is GM for the development of healthier and more productive animals. However, stakeholders also need to have an approach to the moral status of the animals involved that finds credibility and acceptability with civil society.

Keywords Genomic technology · Genetic modification · Animal production · Ethical matrix · Stakeholder

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Introduction

The demand for animal derived protein is increasing, driven by continued global population growth, and rising incomes and urbanisation in developing and emerging economies (Boland et al. 2013). At the same time, increasing levels of animal protein continued to be consumed in developed countries (Daniel et al. 2011). Increased demand raises questions about increased concern about production animal welfare standards associated with increasingly intensive animal production systems being introduced to meet societal requirements (Fraser 2008). It has been argued that improved breeding technologies are required to deliver improved efficiencies in animal production systems, while at the same time ensuring optimal standards of animal welfare and environmental protection are maintained. In this context, animal welfare may be *difficult* to assess (Blokhuis et al. 2003; Botreau et al. 2009), but *should* be taken into account when applying novel technologies to animal production systems. There has been considerable scientific and economic investment in developing scientific approaches to improved production animals (Mora et al. 2012), which may also deliver enhanced animal welfare through improved animal health (Rothschild and Plastow 2008). Within this context, societal debate about *if*, and *how*, genomic technologies should be applied to animal production systems remains an area of (potentially controversial) discussion (e.g. see Fiester 2008).

Not least among the arguments presented in relation to the application of genomic technologies are those related to ethical issues, which may apply to consideration of the negative or positive impacts of genomic technologies on animal welfare (Pascalev 2006; Palmer 2011), economic factors such as impacts on the livelihoods of primary producers who adopt or do not adopt genomics utilised in animal breeding (Menozzi et al. 2012), or societal concerns about risks to human or animal health, the environment, or consumer choice regarding the products of such technologies (e.g. see *inter alia* Kaiser 2005; Frewer et al. 2013a). In addition, the use of genomic technologies for agricultural purposes is potentially less cost effective than for medical applications (e.g., Laible and Alonso-González 2009), such that scientific and infrastructure investment may not deliver increased efficiencies in the supply chain proportionate to increased food security, or profitability for producers. From this, two issues of relevance to ethical debate can be identified. The first relates to whether investment in animal genomic technologies will deliver advantages to society, (including in terms of the welfare of the animals themselves), proportionate to the investment of resources, and production costs. The second relates to whether resource investment in genomic technologies in animal production systems at the expense of investment in other technological innovations will reduce future flexibilities in animal husbandry systems.

Within this context, it should be recognised that not all genomic technologies applied to animal production systems are associated with the same ethical implications for producers and other stakeholders, including consumers. While the ethical implications of *genetic modification* (GM) applied to animal production have been considered extensively (e.g. see, *inter alia*, Lassen et al. 2006; Verhoog 2003), genomic technologies which do not involve genetic transfers from one organism to another (see Rothschild and Plastow 2008), have less frequently been considered. Many genomic technologies do not involve GM, but map rapidly and accurately the genome of production animals, which may be applied to improve production efficiency or animal welfare through selective breeding (e.g. Van Tassel et al. 2008; Womack 2005). Examples include marker-assisted selection to develop production animals which deliver improved meat quality (Rothschild 2004; Gao et al. 2007), and single nucleotide polymorphism associations to assess traits such as behaviour, disease resistance, and structural and environmental adaptivity, which may identify genetic causes for differences related to behaviour and stress. This may, in turn, facilitate the breeding of healthier, more adaptable animals and promote animal welfare (Rothschild and Plastow 2008). Improved feed efficiencies developed through genomic research may also reduce production costs (Kim et al. 2000). Ethical concerns may vary between different stakeholder groups, including primary producers, representatives of the food industry, non-governmental organisations with interests in environmental protection, consumer and animal welfare and health, as well as consumers (see, *inter alia*, Bremer 2013; Marris 2001; Kaiser et al. 2007). It is the opinions and priorities of these stakeholders which will shape the success or otherwise of the implementation and commercialisation trajectories of genomic technologies applied to animal production systems applied within the agricultural and food sectors.

The aim of the current paper is to develop an analysis of the ethical positions of different stakeholders regarding the application of genomic technologies to animal production systems. To this end, GM, which has been identified as potentially one of the most controversial of genomic technologies applied within the animal production sector (Macnaughten 2004; Chapotin and Wolt, 2007; Frewer et al. 2013b), will be compared with genomic technologies which do not involve genetic modification.

Ethical Issues and Regulation

The literature suggests that societal responses to non-food applications of GM animals (for example, in relation to pharmaceutical production or as human or animal disease models) raise few societal objections assuming *animal welfare standards and safety assessments are adequate and addressed in regulatory procedures*; the latter is a *de minimis* requirement for societal acceptance of food-related applications od GM technologies to animals, although the purposes of the genetic manipulation, in particular in relation to specific benefits and beneficiaries, appear to be the decisive factor in determining consumer acceptance (Frewer et al. 2013b). While the ethical concerns of stakeholders (e.g., members of policy communities, industry representatives and environmental and consumer groups) have been examined in this context (e.g. see Mepham 2000; Kaiser et al. 2007; Novoselova et al. 2007), less is known about the opinions of such key stakeholders and end-users regarding genomic technologies which *do not* involve genetic modification. Understanding such concerns is important from the perspective of optimising ethical standards and animal welfare issues in animal production systems, and ensuring their economic viability, which in turn will affect all actors in the supply chain.

Important Stakeholders with Interests in Genomic Technologies Applied to Food Production

Animal health and animal welfare have been shown to be linked with the economic well-being of farmers (Scott et al. 2001). While there is a societal perception that farmers are primarily financially motivated, and concerned only with their livelihood (Hubbard and Scott 2011), there is a large degree of variability between farms, and farmers differ considerably in how they make decisions regarding formulation of farming strategies (Siebert et al. 2006). Most farmers are interested in supplying high-quality products, having a satisfying job and establishing a more positive image of agricultural and livestock production. Thus it is important to understand how farmers conceptualise the impacts of genomics on production animals in terms of product quality and animal welfare, as well as economic demands on the supply chain, and compare this with consumer perceptions.

Other ethical concerns may arise within the context of animal production systems. The need for improved food security (e.g. see, *inter alia*, Ericksen 2014; FAO 1996; Godfray et al. 2010; Godfray and Garnett 2014) is an important driver which influences the need for increased efficiency of animal production systems. The increased global demand for animal protein means that improved efficiencies need to be identified in animal production systems, unless demand reduces or substitutes are developed (GO-Science 2011). Arguably, both delivering access to secure nutrition, or at least secure food comprising of the range of nutritional requirements, equitably distributed across the needs of global populations, represents an important ethical issue, as does reducing overconsumption and food waste, particularly in affluent countries. In this context, concerns about negative impacts on human health associated with increased animal protein production (Wang and Beydoun 2009; Chao et al. 2005; Lutsey et al. 2008; Popkin et al. 2012) and increased consumer demand, (Fuller et al. 2002; Godfray et al. 2010), must also be addressed. An ethical issue therefore relates to whether increasing supply of animal proteins may have a detrimental effect on the environment and on human health, through changed accessibility if supply increases outstrip demand or vice versa. Thus health care professionals represent an important stakeholder in the debate about genomic technologies applied to animal production systems, in particular if supply is increased, which may then subsequently increase consumer demand. Developing healthier products (for example, meats which are lower in fat or higher in important nutrients for human health) may contribute to improved public health, but costs may be too high for these products to contribute to anything other than a niche consumer market; another ethical issue is therefore is equity of access to the benefits of genomics technologies applied to animal production systems. Genomic information could be applied to breeding animals that are more environmentally sustainable, that have different meat nutritional profiles, that are more efficient or economically sustainable or that are more disease resistant. From an ethical perspective it may also become possible to use genomic information to select animals that make raising and handling animals easier for farmers, transporters and processors (animals that can more easily handle the stress of long transport for example). All of these possibilities come with ethical considerations—which attributes should be encouraged (or data provided allowing farmers to choose attributes) and how the choice of particular strategies will affect animals, farms and farmers, consumers and the public. What differentiates the use of genomic information is the speed at which the particular genes can be identified and the genetics of domesticated animals changed in a particular direction—which may or may not be to the benefit of society.

Consumer Perceptions and Attitudes Towards Genomic Technologies Applied to Animal Production Systems

Consumer perceptions are potentially an important factor influencing the commercialisation trajectory of animals produced using genomic technologies. There has been considerable research directed towards understanding consumer perceptions associated with the acceptability of GM animals used for food production (e.g. see Costa-Font et al. 2008; Frewer et al. 2013a, 2014). The main conclusions can be summarised as follows. First, consumer perceptions or attitudes associated with GM animals applied in the agrifood sector are generally more negative than those associated with GM plants or other less advanced organisms, independent of in which region globally data are collected. In Europe, high levels of risk perception have lead to consumer rejection of GM animals applied to food production. In North America and Asia concerns focus on moral and ethical issues. However, consumer decision-making regarding the acceptability of different applications is contextualised by a case-by-case analysis of specific applications, including specific (perceived) risks and benefits, and other values, such as ethical concerns and values.

However, research into consumer perceptions of, and attitudes towards, genomic technologies applied to production animals has less frequently focused on technologies which do not involve GM per se. Genomic technologies have infrequently been examined in the context of plant-related applications, and empirical studies involving accelerated breeding of animals are less frequent again. There is limited evidence to suggest that consumer attitudes towards genomic technologies applied to plants which do not involve GM but rather involve other genomic technologies are viewed relatively positively by consumers (Schenk et al. 2011; Van den Heuvel et al. 2008).

A limitation of current knowledge related to genetic technologies applied to animals utilised in food production is whether genomic technologies raise different ethical issues according to:

1. Whether the technology applied is GM or other genomic technologies which do not involve GM.
2. Whether different stakeholders, including consumers and/or citizens, perceive differences in ethical issues.
3. Whether such differences in perception are linked to their membership of a specific stakeholder group (e.g. consumers, primary producers, industry).
4. Whether 1, 2 and 3 are influenced by the outcome of the genomic application (e.g. animal welfare or improved production efficiency).

Table 1 Search terms used

Search term 1 (AND)
(gm OR gmo OR "genetic modification" OR bioeng* OR biotech* OR transgene* OR cisgene* OR clon* OR genom*)
Search term 2 (AND)
("ethical analysis" OR moral*)
Search term 3 (AND)
(animal* OR cattle OR pig* OR hog*)

Building on the overall objective of the paper, genetic technologies applied to production animals in general from the perspectives of different stakeholders and end users, including consumers, will now be considered.

Literature Review Methodology

A review of the literature regarding ethical issues and genomics applied to production animals was conducted. The search terms are provided in Table 1. The purpose was to extract ethics literature focused on both GM production animals, and those developed using other forms of genomic technology.

The research questions were as follows:

1. What are the ethical issues associated with the application of genomic technologies to animals utilised in food production?
2. Do these vary between application of GM, and other forms of genomic technologies applied to selective breeding?
3. Do differences exist between applications used to improve animal welfare and feed efficiency?

Two data bases, "Scopus" and "Web of Knowledge", were searched.[1] The search terms were included in the topic section of the database, and in the keywords, title, or abstract of the article being searched. For quality control reasons, only peer reviewed articles published in English were included.

The review process first considered the GM and genomic technologies identified in the papers and the extent to which ethical aspects of the technology had been considered.

Impact of Ethical and Moral Considerations on Consumer Attitudes

The review process was then repeated with a particular focus on capturing stakeholder and citizen perceptions of use of both GM and genomics in agricultural animal production systems. The results were then combined and a critical analysis

[1] The first search was conducted on 16 August 2013 in Web of Science, which yielded 72 relevant papers, and on 15 August 2013 in Scopus which yielded 88 relevant papers. After these lists were combined and duplicates removed, 127 papers remained for review.

applied to map ethical priorities against the perspectives of specific stakeholder groups, as well as identify gaps in the existing literature. The information identified from the review was subject to ethical analysis through the use of an ethical matrix.

The concept of the ethical matrix is to consider for modern technologies used in food production, how the fundamental ethical principles of autonomy (self-determination), non-malfeasance (no harm), beneficence ("do good") and justice (fairness), are applied to, and perceived by, various interest groups (e.g., producers, consumers, and the biotic environment; Mepham 2000). While acknowledging that this approach has limitations in analysing and weighing the ethical issues associated with a technology, it is helpful in identifying the types of issues that may need to be considered (Coles and Frewer 2013). A *generic ethical matrix* regarding the application of genomic technologies to food production animals was developed. The interest groups identified are: scientists and developers, farmers, food manufacturers and distributors, workers, consumers, animals and the biotic environment. In addition, the study seeks to identify whether any distinction exists in ethical concerns (including ethical concerns as perceived by the public) between the use of GM technology or other genomic approaches which do not utilise GM per se but instead use genetic technology to inform more efficient genetic selection. Two other relevant areas of ethical consideration, which do not fit neatly into the four ethical principles described above, but which nevertheless do raise ethical concerns amongst many stakeholders are those of "*Unnaturalness*", and *"Enhancement"* or "*Disenhancement*".

Unnaturalness

The concept of *unnaturalness* has been an area of concern for many years in relation to GM organisms in general but more strongly felt in relation to GM animals (see e.g. Bredahl 1999; Tenbült et al. 2005). This can frequently be expressed as feelings that range from vague unease to disgust at the idea of creating animals that would not normally occur naturally, which may stem from religious beliefs, cultural or traditional norms and identity, perceptions of consumer health and environmental risks, animal welfare or simply the idea of changing the nature or affecting the dignity or telos of the animal. There is, for example, a feeling amongst some consumers that because it is "unnatural", GM technology should not be utilised in developing or improving animal species, particularly within the food chain (Frewer et al. 2013a). While for some individuals this will arise from deeply held religious convictions that GM technology is somehow "interfering" with creation, for others it may have more to do with concerns about risk such as fears that science does not have adequate understanding of genetics and the possible unseen impacts of manipulating genes that would not occur naturally in animals, with the objective of ensuring that we do not generate irreversible damaging effects on the environment and its biota. However, the same feelings of "unnaturalness" may not apply to the application of genomics to what might be considered natural.

Enhancement and Disenhancement

While feelings of unnaturalness may be associated with certain forms of GM applied to animals, it is also important to consider the ethical aspects of whether the use of such techniques for the enhancement of animals in order to improve their health and well-being is ethically problematic (Chan 2009). The objective may be to improve productivity through reducing the incidence of disease, simultaneously benefiting the animal itself in terms of reducing suffering and distress. Consideration as to whether it is appropriate to adopt an instrumentalist approach to animals is required. This approach affords them no rights but considers their well-being solely in relation to the extent to which it benefits humans. Alternatively animals can be ascribed "moral status" whereby humans have a responsibility to treat animals well for their own sake and thus also consider enhancement in relation to whether it benefits the animal itself (Chan and Harris 2011).

Disenhancement could involve changing the animal in order to make it more compliant with particular production methods. In other words the concept of disenhancement has arisen to some extent as a possible solution to issues of animal welfare during their incorporation into the human food chain (Ferrari 2012). Hence it has been suggested that if an animal's welfare can be improved by GM so that any suffering can be reduced by, for example, reducing the animal's ability to feel pain that is ethically acceptable (Thompson 2008). The animal does not suffer and is also compliant to more aggressive production methods. One example frequently quoted is that of "the blind chicken" (Thompson 2008). Chickens farmed intensively in battery conditions frequently attack each other, plucking the feathers from neighbouring chickens and so causing distress and suffering. However, chickens that are blind show little or no inclination to engage in this behaviour. It is therefore argued that to disenhance all chickens to make them blind will not only reduce the suffering of the chickens but also enhance the use of battery farming. However, from an ethical point of view, it is important to consider enhancement not only from a position of utility, or improvement of animal welfare. It is essential to also take into account the concepts of *telos* and dignity. Here, the dignity of the animal and of humans who represent moral agents are included (Weckert 2012). If human beings adopt the approach that improving animal welfare through disenhancement will reduce suffering and so facilitate more profitable production, we are simply commodifying the animal and according it no intrinsic value whatsoever, but rather treating it only as an object for maximising profit (Palmer 2011). Whilst animals may not be considered as moral agents, they certainly have particular states of being to which they aspire and which accord to them a certain dignity, including species-specific needs and possibilities (Kunzmann 2010). It has been argued that the extent to which we deny animals dignity and the ability to adopt states of being in which they would naturally choose to exist, reflects something of our own morality (Warkentin 2009). The ethical matrix analysing ethical issues against stakeholder interests and priorities is presented in Table 2.

Discussion

The ethical perspectives of different stakeholders regarding genomics applied to animal production systems will be discussed in turn.

Table 2 Ethical matrix analysisng ethical issues against stakeholder interests and priorities

	Beneficence		Non-malfeasance		Justice		Autonomy	
	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]
"Ethical Matrix" from applied ethics literature								
Scientists (including industry-based agricultural genetic breeders and others)	Increased profit from successful applications Advance scientific endeavour To improve animal health and welfare To enhance environmental sustainability	Increased profit from successful applications Advance scientific endeavour To improve animal health and welfare To enhance environmental sustainability Development of genomic databases to more accurately predict phenotype, disease, productivity etc.	Implement effective risk assessment to ensure minimal or no potential harm to other interest groups including animals and environment Avoid exploitation of the market and warn stakeholders of any risks Rigorous risk assessment of any new genes introduced into the gene pool If production of animals reduces variation (e.g. cloning), take steps to contribute to preservation of species gene pool	Implement effective risk assessment to ensure minimal or no potential harm to other Interest groups including animals and environment Avoid exploitation of the market and warn stakeholders of any risks Identification of any adverse welfare issues associated with new strains of animal Contribute to preservation of species gene pool	Clear and consistent regulatory framework, guidelines and risk assessment process to facilitate product development and marketing and to minimise uncertainties or risk of market failure Protection of IPR Assess impact of introduction of new and novel genes on the individual species and the environment	Clear and consistent regulatory framework, guidelines and risk assessment process to facilitate product development and marketing and to minimise uncertainties or risk of market failure Protection of IPR Assess impact of introduction of new varieties strains on the individual species and the environment	Freedom to develop new and novel varieties, in compliance with any applicable regulation	Freedom to develop new varieties, in compliance with any applicable regulation

Table 2 continued

	Beneficence		Non-malfeasance		Justice		Autonomy	
	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]
Primary producer (farmer)	Increased profit from improved products and yields Awareness of characteristics of modified genes Improved, safer and more efficient farming practice Improvement to animal health, disease resistance and welfare	Increased profit from improved products and yields Awareness of characteristics of selected genomes Improved, safer and more efficient farming practice Improvement to animal health, disease resistance and welfare	Responsible use of GM-products in accordance with regulations Avoid GM applications that harm animals or are detrimental to their welfare Adopt precautionary approach to release of GM organisms into the environment Contribute to preservation of species gene pool, particularly if utilising cloned animals to reduce variation	Avoid adoption of new strains which result in sub-optimal animal welfare Adopt precautionary approach to cross-breeding of new strains with more traditional stock Contribute to preservation of gene pool	Ability to change supplier or method of inputs Improve welfare of animals, maintenance of *Telos* and enhance environmental sustainability	Ability to change supplier or method of inputs Improve welfare of animals, maintenance of *Telos* and enhance environmental sustainability	Awareness of characteristics of modified genes Evidence-based freedom of choice as to whether to adopt GM technology without undue pressure from processors or distributors	To be provided with sufficient information on animal genome and its characteristics to make informed breeding choice Evidence-based freedom of choice as to whether to adopt new animal strains without undue pressure from processors or distributors
Industry (manufacturer or distributor)	Increased profitability from use of GM-based animals Better quality and greater reliability of supply	Increased profitability from use of genomic animals	Not using supplies that might have resulted in harm to animals and their welfare or to the environment	Not using supplies that might have resulted in harm to animals and their welfare or to the environment	Clear and consistent regulatory	Clear and consistent regulatory	Awareness of characteristics of modified genes	Awareness of characteristics of selected genomes

Table 2 continued

	Beneficence		Non-malfeasance		Justice		Autonomy	
	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]
		Better quality and greater consistency and reliability of supply	Ensure that products and processes are tested to avoid harms to consumer health or the environment Provide consumers with adequate information and labelling e.g. GM	Ensure that products and processes are tested to avoid harms to consumer health or the environment Provide consumers with adequate information and labelling to avoid any adverse health effects (e.g. allergies)	Framework including safety and labelling requirements Provision of adequate information and labelling to fully inform consumers	Framework including safety and labelling requirements Provision of adequate information and labelling to fully inform consumers	Freedom to choose whether or not to use GM-based raw materials and Processes	Freedom to choose whether or not to use genomic animals
Workers	Increased financial, health and environmental benefits	Increased financial, health and environmental benefits	A safe working environment Minimised exposure to hazardous substances and animal diseases (e.g. retroviruses)	A safe working environment Minimised exposure to disease vectors	A safe working environment Treating animals appropriately and customers fairly	A safe working environment Treating animals appropriately and customers fairly	Implementation of agreed codes of practice with employer	Implementation of agreed codes of practice with employer
Consumer	Ability to benefit from better quality food and greater health benefits at reasonable cost, without fear of unknown risks Adequate labelling information	Ability to benefit from better quality food and greater health benefits at reasonable cost, without fear of unknown risks Adequate labelling information	Ability to benefit from better quality food and greater health benefits without fear of unknown risks	Ability to benefit from better quality food and greater health benefits without fear of unknown risks	Adequate labelling provided so as to be able to avoid potential risks or exercise personal choice including moral choice	Adequate labelling provided so as to be able to avoid potential risks or exercise personal choice including moral choice	Ability to consider and/or make a judgement on the "naturalness" of the end product or processes used	Ability to consider and/or make a judgement on the "naturalness" of the end product or processes used

Table 2 continued

	Beneficence		Non-malfeasance		Justice		Autonomy	
	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]	GM[a]	Genomic[b]
					Adequate information provided on the nature of the GM process	Adequate information provided on the nature of the genomic process		
Animals and their welfare	Improved health and welfare Greater variation could increase genetic vigour	Improved health and welfare Elimination of debilitating diseases	Respect for animals Risks of unknown harms for animals through introduction of "foreign" genes Less variation (e.g. through cloning) could reduce variety and reproductive vigour	Respect for animals Risks of unknown harms to animals by focussing on expression of particular genes Standardisation of "good" breeds might reduce gene pool	Ability to express *Telos* Adequate regulation in place to safeguard animal health and welfare	Ability to express *Telos* Adequate regulation in place to safeguard animal health and welfare	Ability to express Telos	Ability to express Telos
The biotic environment	Improved food security through more sustainable Production of more nutritious foods reduces Impact on the environment	Improved food security through more sustainable Production of more nutritious foods reduces Impact on the environment	Adequate assessment of environmental risks from release of GM animals,	Assessment of impact of accelerated breeding of new strains on the gene pool	Regulatory measures and guidelines to protect and promote environmental sustainability	Regulatory measures and guidelines to protect and promote environmental sustainability	Respect for existing ecosystems and balance of nature	Respect for existing ecosystems and balance of nature

[a] GM refers to genetic modification

[b] Genomic refers to genomics technologies which do not utilise genetic modification per se

Scientists and Innovators

From an ethical perspective, scientists and innovators developing advances in both GM and genomics in animals in the food chain will see their role as not only pushing back the frontiers of scientific understanding, but also finding ways of improving food security and production efficiency through improving animal growth and resistance to disease and pests. Responsible researchers will aim to improve the welfare of the animal by reducing disease-related suffering. An environment in which scientists and innovators are free to investigate and pursue their scientific endeavours is considered to be extremely important by these stakeholders. However, while it is often argued that scientists should not be restricted in the way in which their research develops, it is clear that there are still limits of societal acceptability beyond which they should not go. The reality is that scientists not only have their work facilitated by the society within which they operate, but that society also embodies a moral, legal and regulatory framework to which scientists and innovators should comply. Scientific research operates within a framework of committees on, for example, ethics and animal welfare, legislation on data and environmental protection as well as a wide range of other regulatory bodies. Scientists are also often seeking to develop innovations which they hope that society will adopt. Therefore not only is it in their interests in terms of the acceptability of the science to develop applications which are ethically acceptable, but they also have a responsibility to carry out their research in a way that minimises risks of harms to themselves, other stakeholders and the environment. It is important for scientists to be able to recognise not only where potential risks or hazards may lie but also consider the interests and perspectives of other current or future stakeholders.

In comparing GM and genomic approaches for improving animal productivity, health and welfare, the sustainability of the species gene pool is an important consideration. GM applications, including large scale cloning of successful modifications, entail some risk that pre-existing genes, if modified or excised from the genome, may eventually be lost from the entire gene pool. At the same time, novel or modified genes may be introduced, resulting in a significant alteration to a gene pool that has developed over millennia to withstand a wide range of environmental changes. With genomic solutions, however, the focus is on more accurate identification of individual genes and their expression, and better understanding of their specific functions either individually or in concert with other genes. Therefore, while such innovations may alter the balance of the gene pool, they are unlikely to eradicate completely the presence of any individual gene and will only make use of pre-existing genes in developing strains that are more resistant to disease, more productive, more nutritious etc. However the speed at which the genetic selection could advance does necessitate some caution in order not to homogenize the domestic population of any livestock species. Measures to ensure preservation of the gene pool are essential for sustainability, and to minimise any risk of irreversible adverse effects. It is relatively easy to preserve the gene pool of plant species (e.g. see, for example, the Svalbard Global Seed Vault,[2] located in

[2] http://www.regjeringen.no/en/dep/lmd/campain/svalbard-global-seed-vault.html?id=462220, accessed 14th May 2014.

the permafrost in the mountains of Svalbard in Norway). It is much more costly and technically challenging to store animal genetic resources (see the National Center for Genetic Resources Preservation (NCGRP)[3] in the USA). Therefore it might be argued that where a genomics solution for animal productivity, health or welfare is feasible, this would be a preferable to pursuing a GM solution even if only on the grounds of sustainability.

Primary Producers (Farmers)

While farmers farm in order to make a living, for most there are also many other factors which motivate them, not least of which are genuine concerns for the health and welfare of their animals beyond the need to provide fit and healthy specimens for the food chain. Farmers have a strong interest in their ability to benefit from the introduction of a new technology through a positive impact on their productivity and hence profitability *and* the effect of the technology on the health and welfare of their livestock and the environment in which they live and work. It is important for those who are developing biotechnology applications for animals in the food chain to understand the factors which motivate farmers, and the relationship that they have with their livestock. This will enable them to identify those risks and benefits which are important to farmers and which influence their decision-making. These may include the quality of the product, their willingness to utilise less expensive, and/or lower quality feed and their priorities for animal health and welfare.

A further issue likely to be of great importance to farmers is the extent to which they have autonomy and flexibility in relation to selection of the animals they choose to breed. This will include the impact of IPR and patenting of specific breed lines on the flexibility they have to breed subsequent generations, or to modify the genome of their stock. Will they face restrictions on breeding of "genomically bred" animals, or of crossing them with other varieties? How much information will be made to farmers? Genetic information is extremely powerful and valuable knowledge. Asymmetric information in any 'market' allows for the possibility of control and exploitation. Breeding companies and breed societies have historically been heavily involved in the development of phenotypic databases and this is likely to continue and indeed increase with genomic databases. However the genomic databases will be more powerful and as all genes contain information, every bit of research adds more knowledge about different links between genes, disease, efficiency etc. Therefore the level of information provided to farmers about an animal's genome is particularly important and affects the amount of autonomy they have in breeding decisions. To a certain extent the provision of information directly to farmers will depend on who manages the databases and how those databases are linked to commercial transactions related to semen and animals to be used in breeding. If the decision rests purely with the owner of the databases, who may also be the suppliers of specific products (semen or animals), there can be asymmetric information and potential for market power. The ability to map the genome of domesticated animals ensures enormous amounts of data are available, which could

[3] http://www.ars.usda.gov/main/site_main.htm?modecode=54-02-05-00, accessed 14th May 2014.

be overwhelming if provided without filter to individual farmers. As understanding of the potential of the use of genomics grows the maximum social benefit from the technology will be achieved if data can be made available on demand for producers to optimize their own breeding decisions (Berry et al. 2014).

Manufacturers and Distributors

What ethical issues are relevant to the manufacturers and distributors responsible for processing, preparing, packaging and distributing animal food products to the consumer? Most obviously manufacturers and distributors should be provided with sufficient information to enable them to decide whether or not they wish to make use of suppliers using either GM or genomic technologies, and would expect to benefit from their trade in terms of profitability and promotion of brand identity. They will therefore be looking for an appropriate balance between quality and price that enables them to make a sustainable profit. This will be greatly enhanced by reliability of product quality and price. Acceptance of animal material produced from either GM or genomic technologies is therefore only likely if it can be demonstrated that there is a significant improvement in reliable quality over traditionally bred animals, particularly if the new technologies involve higher cost. A lower than normal cost might encourage adoption, assuming quality is equivalent. Ethically responsible members of the food industry will also wish to ensure that any animal products they utilise are produced using the highest possible welfare standards and involve production methods that minimise damage to the environment. This also impacts on their responsibility to the consumer where justice (fairness) requires that they are as open and transparent with consumers as possible, while at the same time preserving their own right to remain commercially competitive. Ensuring that their suppliers engage in good animal welfare and environmental protection standards is an ethical position for the food industry to adopt. It also makes commercial sense as utilising animal products from sources with poor animal welfare or environmental standards can seriously or even terminally damage brand image. Thus the industry will be acutely aware of the extent to which consumers are likely to accept or reject a new technology. The industry also has not only an obligation to meet regulatory requirements, but also an ethical responsibility in providing the consumer with adequate and appropriate information in order for them to exercise their autonomy in order to make informed choices about whether or not to purchase a particular product. This involves not only providing an accurate description of the product itself, (and any scientifically proven benefits), but also clear and understandable labelling to enable the consumer to identify what the product contains, from where it was sourced, details that may be relevant to the consumer about how the product was produced or sourced (e.g. free-range, caged, fair trade etc.) as well as any potential risks that may be associated with the product (such as and allergens that it may contain). Such labels often also benefit the manufacturer by acting as a means of advertising adherence to practices of which the consumer approves. As it would be ethically unacceptable for the food industry itself not to know whether its sources of animal material were utilising GM or genomic technologies, the same ethical principle applies in their responsibility to the consumer. It is important in relation to new and innovative technologies for consumers to be able to decide whether or not to purchase foods which involve the use of GM or genomic technologies in the food chain.

One difference between the use of genomic information and GM lies in the ability of processors and retailers to require genetic information on the animals they purchase (particularly attractive as the cost of genotyping comes down). Animals bred based on genomic information for particular traits such as feed efficiency or disease resistance, for example, could be verified with genetic tests on the meat. This significantly increases the potential of traceability (currently back to location of origin) to also provide verification of genetic attributes of particular meat products. It is possible to imagine a particular retailer suggesting that their meat (beef, for example) is all produced from cattle verified to have a feed efficiency gene and thus produced less feed and lower greenhouse gas emissions as a result. This could become a marketing edge for certain products and provide incentives for farmers to genotype more of their animals or select semen or breeding animals on the basis of specific genes.

Workers in Primary Production and the Food Industry

Those working in the food industry should expect the normal health and safety requirements to apply to their employment. This should include any additional measures in the case of GM to ensure that they are not exposed to any additional hazards such as retroviruses or zoonoses. They in turn have an ethical responsibility to ensure that they maintain high standards of animal welfare and environmental protection in their daily work and comply with all the relevant codes and regulations. No differences between GM and genomic technologies applied to animal production systems are identifiable in this regard. For farmers and employees in processing/distribution/retailing of food or meat products the use of GM animal products or the use of products from animals created using genomic information is likely not much different. However the use of genomic information can provide additional verification of attributes of animals or meat products. Genetic tests can verify the presence or absence of GM in the product. The use of genomic information in breeding decisions cannot be verified as easily but the presence/absence of specific genes can be ascertained by genetic testing on animals or meat products. The understanding of the genome of domestic animals can provide additional assurances for farmers and employees that the animals/products they are working with are safe to work with.

Consumers

Those involved in development, production and supply of food at all stages of the human food chain have particular ethical responsibilities towards the consumer as the end-user of the food product. It is not enough to simply provide food that meets legal and regulatory requirements on food safety, it is also important that the information provided is fair both to themselves and to the consumer and adequate to enable consumers to make an informed choice. Consumer choice is made within a complex framework of their appreciation and understanding of risks, both technical and perceived, and influenced by the interaction of a wide range of values which may be derived from moral, societal, cultural, religious or personal preferences and perspectives including dietary choice. Therefore labelling of foodstuffs is essential for more than just safety reasons. In order to exercise autonomy of decision, consumers also need information on the geographical and biological source of the food together with the process by which it is produced and quantities of constituents. They will, in most cases, also require certain assurances about the food, such as welfare standards, how an animal is slaughtered, "naturalness", whether it is produced organically and possibly factors relating to pay and working conditions of those involved in production.

In many countries, there is a requirement to label all GM products or indeed products produced using GM technology at some stage in the process. Other regulatory regimes have adopted the approach that it is not necessary to label GM products, based largely on the principle of *substantial equivalence,* and as a result GM food materials may be freely mixed with their non-GM equivalents. This approach however does deny choice to those consumers who do not wish to consume GM produce and could be criticised by some as ranking scientific opinion and commercial interest above consumer values and autonomy. Genomic technologies currently have no regulatory requirements for labelling or other identification or acknowledgement of use of this technology in the production of food, whether plant or animal. In most cases this is understandable as the animal product would be actually equivalent to produce from an animal bred by natural processes without the use of sophisticated genomic technology. However, it can be argued that consumers should be informed if the process involved any form of disenhancement or other animal welfare issue or indeed results in the use of any practices or processes that might be damaging to the environment such as increased use of pesticides, hormones, non-veterinary use of antibiotics, or other pharmaceutical products, or to the genetic diversity of domesticated animals. Traditional livestock breeding using quantitative genetics has never been an issue communicated to the public. On that basis the 'equivalence' of genomic selective breeding might not need to be communicated. The question of whether this will continue to be satisfactory to a public increasingly concerned about production technology remains open.

Most consumers are unlikely to choose a food product resulting from novel technology unless they perceive that it provides some additional benefit to them compared to an equivalent "natural" product. They are even less likely to choose it if they perceive that there is any additional risk involved and are likely to be concerned if they perceive that any benefits accrue to others particularly commercial interests, while they bear any risk. Hence those seeking to introduce a new technology must to enter into dialogue about consumer concerns and priorities. This may apply to novel genomic technologies, but research is needed to determine whether this is indeed a consumer priority in the area of animal production systems.

Issues for the Environment

Indeed the environment can be, and is, considered by many to be a system or "entity" consisting of all the interactions between all forms of life and the nonliving materials that surround them. It may refer to a localised system or "ecosystem", or be considered as encompassing all life on earth. The environment is a stable system which can be disrupted by, and will, respond to the introduction of new factors whether living or not. All life on earth interacts with, and depends upon, a stable environment such that changes to that environment which can affect its balance. Thus the ethical principles that apply to other stakeholders can also be analysed in relation to the environment, and similar regulatory controls implemented. On one hand, it is arguable that non-naturally occurring genomic technology may militate against the interests of the environment. However, in terms of societal responses to the implementation of different genomic technologies, it may be that societal stakeholders will argue that the environment is better equipped to "adapt" to genomic technologies which have the potential occur naturally, as opposed to those which can only occur through human intervention.

The following two cases identify some of the ethical implications identified in relation to the different biotechnology approaches in relation to, first, animal health and welfare and, second, feed efficiency.

GM Versus Genomic Selection of Pigs to Improve Health and Welfare Through Improved Disease Resistance[4]

The ethical aspects of GM *versus* genomic selection in pigs for improving health and welfare through improved disease resistance need to take into account the motivation of scientists, breeders and primary producers for seeking to improve porcine health and welfare. A question arises as to whether the objective is to improve productivity by reducing disease incidence, suffering and stress in the animals, or to enhance the quality of life of the animal and farmers or both. The perspective on the moral status of the animals concerned will affect how the risks, benefits and ethical concerns associated with each technology are balanced.

Other GM approaches which involve manipulation or alteration of genes may enable the development of new lines which are more productive, able to digest lower quality foods without adverse effects, resistant to common pests and diseases, or have specific genetic disorders or predispositions removed entirely from the genome. However GM technology still carries considerable risks in that the process of insertion of genes is not perfect and the outcome often uncertain (as demonstrated by the case of the Beltsville pigs in the US in 1985), which can result in further adverse welfare issues for the animal as well as incurring additional costs (Christiansen and Sandøe 2000; Pascalev 2006). The impact of alteration of the

[4] An example research project is the Application of genomics to improve swine health and welfare project (http://www.swineimprovement.com/). The international project aimed at identifying genes related to disease susceptibility for two major global diseases in pigs has numerous objectives such as the potential for reducing antibiotic use in pigs, enhanced quality of pig life through disease resistance and reduced emotional and economic costs for producers. The possibilities for identifying the specific combinations of genes that identify disease susceptibility are limited, due to complexity and issues related to heritability. In this project an international multidisciplinary consortium of researchers is attempting to combine information and analytical tools to identify specific areas of the genetic code to focus on for these diseases. As the research advances it may become possible to select animals with higher levels of disease resistance in breeding reducing the incidence of the diseases globally.

gene pool through removal or addition of specific genes also has to be considered as a sustainability issue. The commercial viability of GM animals in the food chain is also questionable as there is considerable evidence that even some consumers that accept GM technology in plants still have concerns of morality or unnaturalness about use of GM technologies, particularly in the food chain. Even if the technology is applied primarily to improve porcine health and welfare, it is unlikely to be acceptable to consumers if they see no benefit to themselves from the technology.

However, genomic technologies, informed by state of the art gene sequencing and genomic analysis of gene function and interaction, can use natural breeding processes and selection to rapidly develop better strains of pig with greater resistance to disease, reduce suffering and improve welfare (allowing artificial insemination to be considered as natural in this context). This avoids many of the actual or perceived disadvantages and uncertainties associated with GM technologies, including issues of morality, unnaturalness and sustainability. However, some current "natural" breeding programmes have resulted in negative outcomes in terms of animal welfare (e.g. breeding for productive efficiency in milk yield has resulted in reduced fertility in dairy cows (Oltenacu and Broom 2010) and breeding programmes in poultry have resulted in musculoskeletal problems in poultry (Hocking 1994). Therefore as use of advanced genomics is expected to rapidly speed up the process, it may be that there should be some mechanism to ensure positive animal welfare outcomes alongside development of other characteristics. As Hocking (1994) points out there is a lag between the development of breeding animals with optimal combinations of production, welfare and fitness traits and the adoption of such birds in commercial flocks, as for other livestock industries. The question of the moral status of the animal, and hence the motivation for use of genomic technology would still need to be considered. Hocking suggests the understanding of the genome of domesticated animals and the use of multiple indicators for selection possible through genomics may make the development of animals with production, welfare and fitness attributes easier than in the past when selection was based on single traits. However, it is worth noting that in domestic animals such as cats and dogs, breeding has for generations focussed on producing animals with characteristics which humans find pleasing, even when this results in breeds which have increased susceptibility to serious health issues. A greater awareness of the moral status of the animal for its own sake might therefore come to have implications beyond agriculture.

Production Efficiency and Improved Food Security: GM Versus Genomic Selection of Cattle for Feed Efficiency[5]

As in the previous example, consideration has first to be given to the moral status of the animals (cattle in this case). Here the objective is overtly about increasing

[5] An example research project is "Whole genome selection though genome imputation of beef cattle". (http://www.genomecanada.ca/medias/pdf/en/whole-genome-selection.pdf). The research involves the development of low cost tests which will allow the inferences of an entire genome from a relatively small number of genetic markers in cattle, providing breeding information at an early age. The research aims to improve production efficiency in cattle through improved feed efficiency.

production efficiency and the wider aim of improving food security. Hence a more utilitarian approach might be taken as ethical justification for altering the genome of the cattle in this case, as the outcome, even if it results in little health and welfare benefit for the cattle themselves, could be considered to not only provide greater profitability for the food industry through animals increasing in muscle mass and less fat and/or utilising lower quality feed more efficiently, better quality food for the consumer and greater food security for human society. It could therefore be argued that the overall net benefit is a greater good, even if there are less positive consequences for the cattle themselves in terms of animal health and welfare. So although GM technologies may involve higher costs and also carry greater risks both to the animals and in terms of gene pool sustainability, they might be considered as being appropriate in this case if the overall benefits are sufficient. However, as the overriding objective is to increase the quantity and possibly quality of meat entering the food chain, attempting to do this through the application of GM technologies would be completely negated unless consumer perceptions of unnaturalness and the idea of interfering with nature are allayed. A crucial factor in this would be for consumers to be able to identify clear and substantial societal and preferably personal, benefits in consuming food from GM animals and to be enabled to choose whether or not to consume GM food.

It would still appear that the ethical case is stronger for the application of genomics to improve production efficiency and food security, particularly if it is found that public concerns about unnaturalness do not apply to this technology as they do to GM. The risk issues to the animals would also appear to be less, and issues of gene pool sustainability are avoided. However, as for the previous case, some safeguards need to be in place to prevent adverse animal welfare effect and promote positive outcomes. There would then appear to be a better balance of risks and benefit between producers, consumers and the animals themselves. So a utilitarian ethical analysis might conclude that the net benefit of improving production efficiency and food security is greater using genomic technology than it would be using GM, assuming the same benefits can be delivered.

Conclusions

It is evident that increasing concerns over food security and animal welfare require solutions that improve production efficiency and also address issues of animal health and welfare within the human food chain. Gene technologies have developed to the point where they have the possibility to provide solutions. Important considerations that have to be taken into account are those of effective assessment of risks (to human health, animal health and welfare, the environment and economic viability), public acceptability and perceptions including moral values, as well as an awareness of the ethical basis of our treatment and usage of animals in the food chain. Research has indicated that while there is little evidence that food derived from GM animals would provide any additional risks to human health, there are still significant unknowns as well as potential risks to the health and well-being of the animals involved. In addition, there remains considerable consumer unease about the application of GM technology to animals used in the human food chain. There are, however, very few studies carried out on stakeholder (including consumer) attitudes regarding the application of genomics to animal production in the human food chain and it may be that this technology is perceived as no more than an extension of traditional breeding techniques. While this is an area which needs more research, it would appear from this study that genomics, because it avoids many of the disadvantages and consumer perceptions associated with GM, is likely to prove a more publicly acceptable route than is GM for the development of healthier and more productive animals. It is also important that all stakeholders in the use of animals in the food chain have a better understanding not only of how they address the ethical issues that apply to their own area of activity but are also aware of those affecting other stakeholders. They also need to have an approach to the moral status of the animals involved that finds credibility and acceptability with civil society.

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