Bonny, S.P.F., Gardner, G.E., Pethick, D.W. and Hocquette, J-F (2015) What is artificial meat and what does it mean for the future of the meat industry? Journal of Integrative Agriculture, 14 (2). pp. 255-263.

What Is ‘Artificial Meat’ and What Does It Mean for the Future of the Meat Industry

Abstract:

The meat industry cannot respond to increases in demand by ever increasing resource use, as had occurred during the industrial revolution. The industry must find solutions to issues regarding animal welfare, health and sustainability and will have to do so in the face of competition from emerging non-traditional meat and protein products in an increasingly complex regulatory environment. These novel meat and protein products, otherwise known as ’artificial meat’ are utilising ground breaking technologies designed to meet the issues facing the conventional meat industry. These artificial meats, *in vitro* or cultured meat and meat from genetically modified organisms have no real capacity to compete with conventional meat production in the present environment. However meat replacements manufactured from plant proteins and mycoproteins are currently the biggest competitors in the market and are gaining a small percentage of the market. Manufactured meats may push conventional meat into the premium end of the market, and supply the bulk, cheap end of the market if conventional meat products become more expensive and the palatability and versatility of manufactured meats improve. In time the technology for other artificial meats such as meat from genetic modified organisms or cultured meat may become sufficiently developed for these products to enter the market add to the complexity of the competition between meat products. Conventional meat producers can assimilate agroecology ecology concepts in order to develop sustainable animal production systems. The conventional meat industry can also benefit from assimilating biotechnologies such as cloning and genetic modification technologies, using the technology to adapt to the changing environment and respond to the increasing competition from artificial meats. Although it will depend at least in part on the evolution of conventional meat production, the future of artificial meat produced from stem cells appears uncertain at this time.

Key words:

Artificial meat; *In vitro* meat; Meat industry; consumer satisfaction; sustainable production

Introduction:

Since the appearance of agriculture meat production has gone through many different evolutions, the most recent being the industrial revolution of the 1800’s. A population explosion and the sudden influx of new technologies changed the face of agriculture into what we see today (McCurry-Schmidt 2012). The increasing demands of the growing population was met with the industrialisation and intensification of farming, along with increasing the amount of land farmed (McCurry-Schmidt 2012). Today, agriculture is once again facing a similar challenge of an increasing population coupled with the advent of new technologies. However, the challenge presented before us now is arguably far more complex. With estimates of the global population reaching a plateau at 9 billion in the year 2050 (Anon 2004), the meat industry would need to increase production by approximately 50-73% to maintain per person demand of the growing populace (FAO 2009; NIAA 2012).

Consumer demands are complex and multifactorial. Grunert *et al.* (2004) found that cost and a number of intrinsic quality and extrinsic quality factors influence the decision to purchase a product. Intrinsic factors relate directly to the product and include meat colour, fat, marbling and sensory qualities. Extrinsic factors, in contrast, are much more subjective and include cost, brand, origin, production methods, healthiness, animal welfare, safety and sustainability (Grunert *et al.* 2004). After purchase, variable eating quality is a major factor in customer repeat purchase intention. (Polkinghorne *et al.* 2008).

Controversies surrounding meat production in regard to health, safety, welfare and sustainability highlights that the industry is struggling to meet changing consumer demands (Vinnari *et al.* 2009). At the same time, it appears the current capacity of conventional meat production is reaching its limits. Projected meat production for 2050 would suffice for almost 8 billion people, falling short of projected population estimates by 1 billion (Gilland 2002). In response to the projected shortfall the meat industry, and the agricultural industry as a whole, must endeavour to utilise resources in the most effective manner in order to both fully supply the market place and satisfy consumer demands. One response by the conventional meat industry to these challenges is the development and implementation of agroecology, meaning to stimulate natural processes to reduce inputs, to reduce waste and to maximise efficiency (Dumont *et al.* 2013). Technologies, such as genetic modification and cloning are also being researched (Maga *et al.* 2010). Other products being researched and developed focussed at producing food external to the traditional meat industry, such as using mycoproteins and plant and insect based proteins as meat replacements and *in vitro* meat culturing techniques.

For the purposes of this review article we will be considering artificial meat defined within three broad categories encompassing both real and hypothetical products (Table1). The first, are meat substitutes manufactured from alternative protein sources, known as 'meat alternatives'. Commonly used alternative protein sources are plants and fungi (mycoproteins) (van der Spiegel 2013). The second is cultured meat, or *in vitro* meat; derived from tissue and cells grown in a laboratory setting rather than in a living organism (Post 2012). Genetically modified organisms can be considered as a third category of artificial meat. Despite the similarities with traditional meat production, animals that have had their genome artificially altered in the laboratory may be considered as artificial or man-made and are worthy in a discussion of artificial meats. Cloned animals are a fourth category of artificial meat. Meat from cloned animals could be considered a natural as it is simply a 'scientist assisted' form of producing identical offspring. However the cloning process is 'man made' and the clone is a copy of the 'parent' animal and thus the meat could be considered artificial.

This review will investigate how each of these broad categories of artificial meat have different advantages and limitations and have a varied approach to 4 major issues facing the meat industry; sustainability, health and safety, welfare and market acceptability, both today and in the future.

Sustainability

About 70% of all agricultural land is used for some aspect of livestock production. However the exact environmental impact is controversial. Some authors estimate that livestock produce approximately 18% of all greenhouse gas emissions including 37% of all methane emissions mainly associated with ruminants (FAO 2009). However other authors have delivered dramatically lower numbers (Pitesky *et al.* 2009) and there is yet to be general agreement. However as ruminant animals are the major sources of greenhouse gas emissions associated with meat production, any decrease in the total number of ruminant animals farmed for meat would better satisfy requirements for environmental sustainability. Artificial meat products may help to reduce the greenhouse gas emissions compared to conventional meat production; however a full lifecycle analysis will be needed to confirm this.

In vitro meat recently received a large amount of publicity in August 2013 following the production and tasting of the world's first 'burger' made from stem cells grown in tissue culture medium (Goodwin *et al.* 2013). In a superficial life cycle analysis Tuomisto *et al.*

(2011) calculated that, under specific production conditions, *in vitro* meat may reduce energy consumption and land usage by 99%, water usage by 90% and energy consumption by 40% when compared with conventional meat production. If realised, these reductions may lead to a large reduction in greenhouse gas emissions. However, it should be noted that the technology to produce *in vitro* meat on an industrial scale remains theoretical at this stage making any predicted reductions in greenhouse gas emissions purely speculative. Furthermore the development of such technology will be time consuming and costly. If the goals of research and development programs are rapid and guaranteed reductions in greenhouse gas emissions then resources might be better invested in technologies which are closer to being ready for commercial application.

The majority of meat replacement products on the market today are made from alternative protein sources such as soy, wheat proteins or mycoprotein. Depending on the animal species and various other conditions, between 2 to 15 kg of plant material is needed to produce 1 kg of meat. In 2008, 40% to 50% of the global grain harvest was used for animal feed (Grigg 1995). Accordingly many suggest that the direct consumption of plant proteins would have lower total carbon emissions than one including meat. However livestock, particularly ruminants can consume waste products from cropping have the ability to thrive on land unsuitable for cropping and thus be ideal for agroecological techniques.

Genetic modification is another tool that can be utilised to reduce the environmental impact associated with meat production. This tool appears best suited to the management of specific problems, for example phosphorous digestion in pigs. The addition of a single enzyme, phytase, which is secreted in the saliva, can markedly reduce phosphorous concentrations in effluent, eliminating this particular environmental hazard. Enviropigs are awaiting approval by the food and drug administration in the USA (Bruce *et al.* 2013). However attempts to progress efficiency in sheep by adding growth hormone genes with genetic modification technologies led to the development of sheep that were metabolically unstable and more prone to cardiac hypertrophy and metabolic diseases (Adams *et al.* 2006). At present there are no genetically modified livestock approved for human consumption.

Animal cloning allows the industry to further disseminate valuable, naturally occurring genetics by increasing the number of individuals in a population with a particular genotype, increasing efficiency, therefore reducing carbon emissions (Petetin 2012). This amplification of favourable genetics can be utilised to enhance other techniques such as genetic modification or agroecology.

Health and safety

Foodborne pathogens such as Salmonella, Campylobacter and E. coli are responsible for millions of episodes of illness each year in the USA. Though the most common source of food borne pathogens is fresh produce, 22% originate from meat products (CDC 2013). From an epidemiological point of view it is evident that these pathogens and emerging diseases, such as avian and swine influenza, are associated with the intensity of livestock farming and other developments in the agricultural industry.

Avian and swine influenza are important public health considerations. Vaccinating animals against these diseases is costly and time consuming, and difficult to achieve in some circumstances. Furthermore the scorched earth approach of slaughtering all exposed individuals is also becoming more and more unacceptable to the public. Poultry that have been genetically engineered to eliminate their susceptibility to avian influenza offer an alternative humane method of risk minimisation (McColl *et al.* 2013). These genetically modified birds are unlikely to become the dominant production animal, however they could provide valuable exclusion zones and create disease free boundaries slowing and restricting the transmission of avian influenza. They could also improve the safety and viability of combined pig/chicken production systems. Strains of pigs and poultry that are resistant to salmonella are also currently being developed (McColl *et al.* 2013). Livestock which provide significant public health benefits are more likely to be encouraged and subsidised by governments and regulating authorities than by consumer demand.

By contrast, cloning may heighten the risk of disease in intensive industries through a reduction in genetic diversity, and therefore a loss of the variation in susceptibility to pathogens that exists in genetically diverse groups. While there may be a slight increase in both communicable and individual disease risk, testing has yet to reveal any health problems related to food products from cloned animals (Petetin 2012).

The techniques for industrial *in vitro* meat production are yet to be developed and as such have the potential for both positive and negative consequences for public health and food safety. The highly controlled environment of the cell culture process may allow for improvements in health and safety, reducing the risk of food borne pathogens or contaminants. *In vitro* meat would also allow for a reduction in close quarter human–animal interactions, reducing the risks of epidemic zoonosis' and emerging diseases (Datar *et al.* 2010). Sterile environments and antimicrobials could remove pathogens such as salmonella and *E. coli* from the production process (Datar *et al.* 2010). However sterile environments are expensive, if not impossible to achieve on an industrial scale therefore the cultures would require chronic long term use of antimicrobials generating their own health and safety issues. Furthermore some authors argue that the process of cell culture is never perfectly controlled and that some unexpected biological mechanisms could occur. For instance, epigenetic modifications could occur during the culture process with unknown potential effects on the muscle structure and possibly on human metabolism and health when it is consumed (Hocquette *et al.* 2014).

Market acceptability

The different forms of artificial meat all inherently contain both barriers and advantages to commercial implementation that will affect the uptake of the technology (Table 2). Manufacturers and producers will only adopt new technologies and products if there is a potential of increasing turnover and profit. Products must have the capacity for mass production and be capable of supplying a significant proportion of the marketplace. Ideally products would be able to be produced with limited change to existing infrastructure, which acts to reduce set up costs and the initial risk for the industry. Consumers are also more likely to purchase a product that is similar to an existing product that they are familiar with. Therefore for a product to compete with conventional meat it should closely mimic or recreate the position conventional meat has in the minds of the consumers in terms of appearance nutrition, convenience and meal solutions (Verbeke *et al.* 2010).

Regulatory systems are among the most important influences in determining the course of technological innovation (Bruce *et al.* 2013). None-the-less they are still actively supporting conventional agriculture at a local level, including meat production. This support is tightly controlled and may be in the form of a quota system, or restricted to specific geographical regions with a low production capacity (Anon 2003). Meat substitutes based on plant proteins may be able to access this existing agriculture support structure, but other artificial meats will have to compete with a subsidised product. Specific artificial meat products or producers may also receive encouragement and subsidies from government and regulating bodies if they can prove definitive reductions in greenhouse gas emission and other environmental benefits (Dagevos *et al.* 2013).The support of government funds would greatly increase the likelihood of commercialisation of artificial meat technologies.

The largest challenge with the commercial uptake of genetically modified meat technology is the licensing requirements. The European Union has reacted to genetically modified organisms with a de-facto ban (Carlarne 2007). The USA has not banned genetically modified animals from entering the food chain, but is yet to approve any such products for human consumption (Carlarne 2007; Bruce *et al.* 2013). The regulatory hurdles for genetically modified livestock are, at present, negatively affecting the likelihood of investment return. If the regulatory hurdles are overcome genetic modification techniques are arguably quite suited to conventional production techniques and infrastructure. While no major infrastructure investment is necessary for the farming of most of the currently feasible genetically modified livestock, once the new organism is developed, the major cost involved in this form of artificial meat production is the dissemination of the new desired genetic material within the population. Artificially produced sires and dams are an expensive initial cost and the transfer rate of the new genetics and, more importantly, phenotypes to future generations is still low (McColl *et al.* 2013).

Several artificial meats made from plant based proteins and mycoproteins are currently available in the marketplace. These meat substitutes hold a small market share, which is estimated at only 1-2% (Hoek *et al.* 2004). The most important barrier for these products is consumer acceptability. Consumers are familiar with these types of products and classify the products in similar categories as processed meat (Hoek *et al.* 2011). This gives these products an advantage over completely novel products. However there are several negative stigmas attached to plant based meat substitutes associated with taste and texture (Hoek *et al.* 2011). As such these meat substitutes are not currently considered a real alternative for non-vegetarian consumers (Hoek *et al.* 2004; Hoek *et al.* 2011).

The cell culture approach for *in vitro* meat is in preliminary stages of development and the technology is at least 10-20 years away from being commercially available (Mattick *et al.* 2013). The realisation of this technology will require significant commitment and investments from both governments and industry. As an example, the first *in vitro* burger made for human consumption cost $335,000 USD to produce (Mattick *et al.* 2013).

Furthermore any *in vitro* meat enterprise would require the construction of an entirely new type of manufacturing facility with a number of untested technologies. This presents a significant risk for commercial organisations, however the vast majority of media coverage for *in vitro* meat has been positive, and consumers have expressed hypothetical interest in the product, were it to become available (Goodwin *et al.* 2013).

Food products derived from cloned animals are considered safe for human consumption in the USA, while they are still banned in the European Union. The cloning process has been commercialised and is available through a number of different companies (Brooks *et al.* 2011), however the process is still relatively expensive and has a lower success rate than other assisted reproductive technologies (Verzijden 2012). Agroecological techniques generally require minimal to no change to existing legislature and strive to decrease inputs through using waste products, and lowering costs for producers (Soussana *et al.* 2012). Certain types of agroecological methods will be difficult to implement as they may require a paradigm shift in the thought processes of producers and/or legislative change. These aspects are unlikely to see rapid uptake in the industry, particularly if a producer has to accept a decrease in efficiency and production with the promised decrease in costs.

Animal Welfare

Consumers, particularly from developed nations, are concerned about the treatment of livestock (Latvala *et al.* 2012). Some are questioning not just the treatment of livestock but the ethical justification for the use of any animals in human food production (Croney *et al.* 2012). The different forms of artificial meat addresses this issue in different ways and thus may be preferred by consumers when they are presented with the opportunity to buy products that closely resemble traditional meat (Richardson *et al.* 1994), but without an association with animal welfare problems.

Plant and fungal based meat alternatives and *in vitro* meat both have the capacity to vastly reduce the numbers of animas required to meet global demands for meat/protein, thereby improving animal welfare by reducing the numbers of animals farmed (Croney *et al.* 2012). However traditional meat production, especially from ruminants, functions best in an integrated agricultural system (Hou *et al.* 2008), which include animals as an essential element in broader agricultural system. Moreover at present all cultured meat techniques still require animal products such as the use of fetal calf serum as an essential component, and as such are unable to eliminate the use of animals entirely (Datar *et al.* 2010; Post 2012).

Eliminating livestock from food production is not the only way to address animal welfare problems. Other options involve redesigning husbandry systems and employing conventional breeding technologies. The now commercialised 'polled gene marker' test for beef cattle, for example, has the potential to eliminate the need for dehorning (Mariasegaram *et al.* 2012; Francis 2013), a significant animal welfare issue, through the application of targeted breeding programs. Cloning is another technology that is used to increase the genetic improvement of agricultural animal species. However this particular technique may have some negative impacts on animal welfare. There are higher juvenile mortality rates and the cloning process itself is not perfect, with some progeny acquiring defects, such as large offspring syndrome as a direct result of the cloning procedure (Verzijden 2012).

The European Union focus however is to develop agroecology and industrial ecology concepts for animal production in the 21st century (Dumont *et al.* 2013). This entails the utilisation of species and breeds that have already been selected, over hundreds of years, to better suited their particular environment and production systems enabling the welfare of the animals to be improved through decreased stress and disease (Anon 2003).

The future of the meat industry

Conventional meat production is reaching the limits of its production capacity and any further increases in output will require new technologies and techniques (FAO 2009). Currently only conventional meat and certain types of meat replacement products are present in the market place (figure 1). For the future agroecology, cloning, and artificial meat may provide technologies and techniques which would allow the meat industry to meet the increasing consumer demands. However it would be unrealistic to expect artificial meat to completely replace conventional meat (Hou *et al.* 2008) due to the complexity of the market place and the vast array of different consumer groups.

As climate change begins to have more and more of an influence on government policy (NIAA 2012), it is likely that the push for sustainable production methods may not come directly from the consumer, but through increasing government regulation. More and more regulatory bodies, including the European Union and the Food and drug administration in the

USA, are passing legislation requiring companies to act in a more environmentally sustainable fashion (Anon 2003; Carlarne 2007). In the year 2012 the world's largest coal exporter, Australia, implemented a carbon tax (Head *et al.* 2014) and the Swiss government has even discussed a possible 'meat tax' as a result of concerns regarding the greenhouse gas emissions of livestock (Lerner *et al.* 2013). These types of legislations will make greenhouse gas emissions, resource usage and waste disposal more difficult and costly in the future. Regulatory systems are among the most important influences in determining the course of technological innovation (Bruce *et al.* 2013) but they can also be unpredictable, for example the carbon tax in Australia is scheduled to be rescinded with a change in government in 2014. The changing regulatory environment will likely favour meat, artificial or not, and meat alternatives produced with lower greenhouse gas emissions and environmental impacts.

As the demand for meat increases, the resources available decrease and the regulatory environment becomes more complex conventional meat production is likely to incur greater costs, making meat more expensive (NIAA 2012). As the price of conventional meat increases the demand for cheap alternatives will also increase. The first products which are likely to generate strong competition for conventional meat are meat substitutes manufactured from plant or insect proteins. These products are the most attractive to manufactures and have the lowest barriers to commercialisation. They are likely to enter the market in the lower quality 'burger/sausage' sector where the division between 'real' and 'artificial' is already blurred for the consumer (Hoek *et al.* 2011). This may push meat, particularly red meat, into the premium end of the market.

Cloning technology, genetically modified livestock and cultured *in vitro* meats, still have significant technological and/or regulatory barriers to commercialisation. Genetic modification has to overcome some minor and some major technological issues and significant regulatory issues before it is a viable option. *In vitro* meat has significant technological barriers to overcome before it can enter the market. Some scientists argue that the product will never see commercialisation, while others argue that it will revolutionise the meat industry (Chiles 2013). Furthermore it remains to be seen if the majority of consumers will accept such a new technology.

Keeping the meat industry consumer focused, and delivering a consistent, quality product will be essential when faced with competition from artificial meat (Grunert *et al.* 2004;

Polkinghorne *et al.* 2008). The conventional meat industry has the capacity to adopt and harness accelerated genetic selection, cloning and genetic modification technologies in order to not only increase production capacity but to and improve its ability to satisfy consumer demands for quality animal welfare, sustainability and healthiness (Novoselova *et al.* 2007). It would also give the industry greater flexibility and a greater capacity to improve the quality of the product offered to the consumer and increase efficiency and production. However the strict regulatory barriers and the passionate activism of certain consumer groups would have to be addressed before this is successful (Bruce *et al.* 2013).

Alternatively or additionally conventional meat production can embrace agroecological techniques to increase production while simultaneously meeting consumer demands for quality, animal welfare and sustainability. Consumers which are attracted to agroecological produce are also likely to reduce their meat consumption and increase their intake of alternative protein sources, more closely matching the outputs of agroecological systems. This emergence of these products and techniques will lead to a complex marketplace with different products and groups of products all competing and appealing to different sectors of the consumer base (figure 1).

Feedback from the customer to the farmer in the conventional meat industry is poor and reactivity is slow at best. This is particularly evident in sectors of the industry which are comprised of many small to medium size enterprises, such as the beef and sheep industries. In contrast the large industrial enterprises that form vegetable and fungal based meat replacement products, and potentially *in vitro* meat products in the future, have the ability to respond much faster to consumer demands. Currently the major form of feedback to meat producers in Europe is carcass price, as determined by the European carcass classification score. These scores are at best an approximate assessment of lean meat yield and provide very little information to the producer. For all meat producers to have better connectivity to consumers there will need to be better investment in systems for efficiency and quality, overlaid with welfare, environmental and health standards.

A quality based grading system such as the USDA system in U.S.A. or the M.S.A. system in Australia provides the framework for increasing the connectivity between producers and consumers. These systems provide producers with direct feedback on eating quality and monetary incentives for improvements in both lean meat yield and eating quality. This type of system empowers farmers to choose to target their production system to either high yield, or high quality, or a combination of the two. Changing the focus of conventional meat producers from yield or arbitrary scales to consumer assessed quality will allow for consumers to have a greater influence over meat production and increase the adaptability of the industry.

Conclusion

The traditional meat industry is facing a changing market place. Different groups of consumers are demanding a variety of modifications to current meat producing practices and it would be detrimental to the industry to ignore any of these pressures. Regulating authorities are also introducing new, environmental legislation changing the economics of production. Artificial meat technologies are utilising ground breaking techniques and technologies to meet the evolving demands of consumers which include environmental sustainability, health concerns and animal welfare. However many barriers are in place before these products can enter the market on a large scale. Many products rely on untested technology, not ready for commercial application or are struggling with government regulations and thus have yet to find a place in the industry. The market place is large and varied with many different consumer groups demanding different products. The products that best fit these markets will out-compete other products and determine the future of the meat industry. Currently the only products that are widely available to consumers are meat replacement products manufactured from plant proteins and mycoproteins. While the conventional production of meat utilising animals is unlikely to ever be completely eliminated, not least due to ruminants' unique ability to digest cellulose, the industry will face a challenging market place and regulatory environment, leading to changes in the industry as a whole. The traditional more extensive livestock systems (pasture based beef and lamb) will need to develop improved systems for transparent monetary transaction and feedback so as to have 'market pull' improvements in efficiency and quality.

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Table 1 The different product categories of artificial meat

Types of artificial meat	
Meat substitutes	Plant and myco-proteins used as meat alternatives. E.g. quorn, tofu
Cultured meat	Produced though the *in vitro* culture of tissues or cells (stem cells, myocytes
Modified meat	Meat derived from genetically modified organisms

Table 2 The relative abilities of traditional meat production, types of artificial meats and alternative protein sources to meet the demands of the market place

		Traditional meat	Cultured meat	Manufactured meat	Insect proteins	Modified meat
				Plant and mycoproteins		Genetically modified and cloned organisms
Sustainability						
	Resources used	High	Significantly Reduced	Significantly Reduced	moderate reduction	Reduced, depending on the product
	waste	High	Potentially reduced	Reduced	Reduced	High
	Greenhouse gas emissions	high	Potentially reduced	Reduced	Reduced	Reduced
Health		Unchanged	Potential improved fatty acid profile and reduced iron content Untested product	High in protein	High in protein and minerals	Improved fatty acid profile, improved vitamin and mineral content
Safety		Unchanged	Untested product	Reduction of food borne diseases. Reduced cholesterol content	Safe with small scale production, untested with large scale production	Reduction or elimination of zoonotic disease
Market acceptability						
	Capacity for mass production	Yes, but reaching limitations	Marked technological barriers at present	yes	Yes	Moderate technological barriers at present
	Need for further research	Moderate	High	Low	Moderate	Moderate
	Cost	Increasing	Very Expensive	Cheap	Moderate	Expensive premium product
	Government regulation	Subsidies, but increasing regulation	untested	Subsidies, standard regulation	Standard regulation	Severe restrictive regulation

Addresses Welfare concerns	no	Yes	Yes	Yes	Moderate
Acceptability to consumers	demand increasing	Neophobia and technophobia	Palatability problems	Neophobia	Technophobia