

THE FUTURE OF THE WESTERN CAPE AGRICULTURAL SECTOR IN THE CONTEXT OF THE 4TH INDUSTRIAL REVOLUTION

Review: Protein Transition

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Table of Contents

1.	Technology Overview and Detailed Description	3
	Technologies applied	3
2.	Application Examples and Case Studies	4
3.	Technology or Application Life Cycle: Current Status and Expected Development in 2020 and 2050	5
4.	Business Eco-System View	5
5.	Benefits and Risks	6
	Benefits	6
	Risks	6
6.	Potential Economic, Social, Ecological (Environmental) and Political Developments and Impacts	7
	Economic Developments and Impacts	7
	Social Developments and Impacts	8
	Ecological (Environmental) Developments and Impacts	9
	Political Developments and Impacts	9
7.	Conclusions	10
8.	Synthesis and key trends from the literature	10

1. Technology Overview and Detailed Description

Protein transition has become synonymous with meat substitutes, in response to population explosions, environmental concerns around global warming due to, amongst other methane gas production by animals and the prediction of a global population of 9.5 billion people by 2015¹.

The current average meat consumption is 42 kg per person per year globally², indicating that the meat production sector has expanded 3-fold since 1960, and is expected to reach a demand of 300 million metric tons in 2020³. According to the World Bank⁴, the demand for meat around the globe is projected to increase by 56% between 1997 and 2020⁵.

Meat demand in the developing world is projected to rise from 65 million tons in 1995 to 170-200 million tons in the year 2020⁶. According to a prediction by the FAO⁷, the consumption of meat in the year 2030 could be as high as 100 kg per person per year in developed countries⁸. It was also projected⁹ that the total amount of meat consumption around the world may be 72% higher in 2030 than consumed in 2000 following current consumption patterns¹⁰.

There are three broad categories of alternatives to meat:

- I. Meat alternatives – protein sources identified and used as meat alternatives include plants and fungi (mycoproteins)¹¹.
- II. Cultured meat, or *in vitro* meat – meat derived from tissue and cells grown in a laboratory setting^{12,13}.
- III. Genetically modified organisms - animals that have had their genome artificially altered in the laboratory

Cloned animals are possibly a fourth category of artificial meat. This report will focus on cultured meat, or *in vitro* meat.

Replacing meat from livestock with meat cultures in laboratories involves growing protein cells from a culture of animal stem cells, or the whole muscle is synthesised *de novo* in a laboratory. The principles of tissue engineering are applied.

Technologies applied

Self-organizing technique

This technique involves the use of tissue muscle of a donor animal which is then proliferated in a nutrient medium under specified or controlled conditions. The tissue formed most closely resembles meat, containing muscle cells, fat and other cells in familiar proportions. This self-organising technique helps to create structured meat i.e. meat produced will have a well-

defined 3-D structure, like natural meat¹⁴. The same can be achieved using the principles of tissue engineering for de novo synthesis of muscle tissue¹⁵. This technique is best for producing structured muscle tissue such as steaks¹⁶.

Scaffold-based technique

The second method of culturing meat involves suitable stem cells which can be obtained from several types of different tissues. Embryo cells or adult skeletal muscle satellite cells are proliferated, attached to a scaffold or a carrier and then perfused with a culture medium in a suitable bioreactor¹⁷. The resulting myofibres can be harvested, processed and consumed as meat or its products¹⁸. The scaffold-based technique is suitable for processed ground meat products, and not structured meats, such as steaks.

Tissue engineering of muscle fibres

Another approach, namely tissue engineering of muscle fibres, is the creation of an artificial muscle completely, using tissue engineering techniques. In addition to using the polymer for nutrient perfusion and cell attachment, co-culturing the myoblasts with other types of cells to mimic the actual structure of muscle is conducted¹⁹. However, this technique has technical limitations (discussed below in this document).

Figure 1 below shows the general steps in the production of cultured meat product

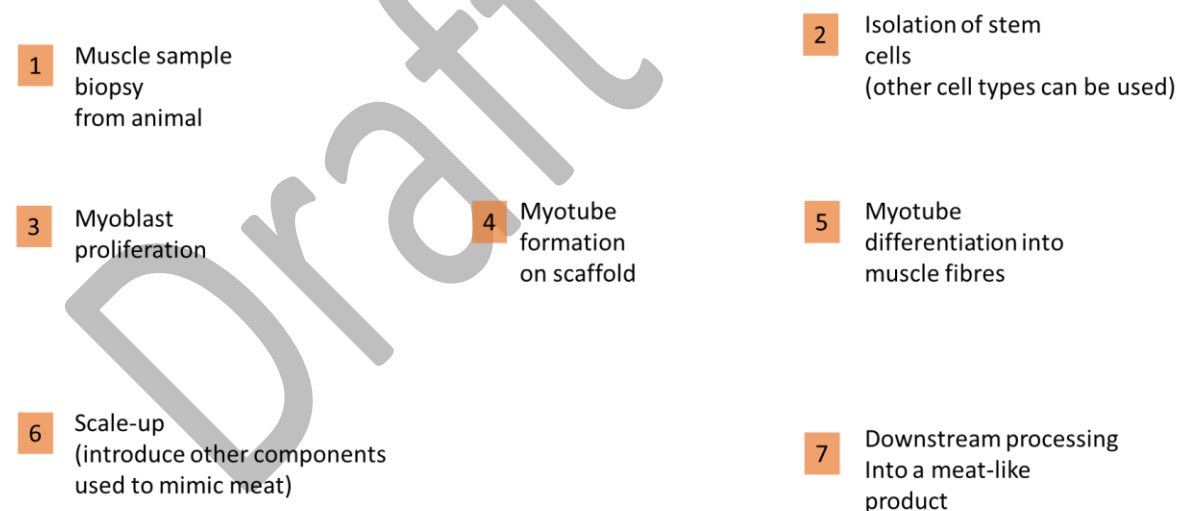


Figure 1: Steps in the production of cultured meat product (Adapted from the literature²⁰)

2. Application Examples and Case Studies

The literature gives examples of made meat replacers and hybrid meats, already in the market²¹. These are listed here for reference.

- The first cultured hamburger was created by Mark Post of Maastricht University in 2013, cost £200,000 and took two years to create²²
- Ready-made (vegetarian) meat replacers (Netherlands) - Tivall, Vivera, GoodBite, Quorn, and Valess) - contain combinations of wheat, soy, egg proteins, contain cow's milk proteins.
- Quorn is a fungal protein (mycoprotein) extracted from *Fusarium venenatum*.
- increased use of lupin and different types of legumes for a meat-like 'bite' of the product (www.devegetarischelager.nl; <http://www.likemeat.eu/>)
- Beeter® (www.eetbeeter.nl) is a 100% plant-derived basic product for replacement of meat and fish that focuses on an attractive 'bite'. Another example is Meatless (www.meatless.nl)
- Insects (Netherlands) - mealworms, buffalo worms and locusts.

3. Technology or Application Life Cycle: Current Status and Expected Development in 2020 and 2050

Table 1: Life Cycle

Technology Area	Current application in agriculture	Expected applications in agriculture by 2020	Expected applications in agriculture by 2050
Protein transition	<p>Currently at research stage. Insect burgers and vegetarian 'butcher' meat already on the market (these products look like meat, but are made from the proteins of mushrooms, soya or dairy products. Chicken nuggets and croquettes - contain a mix of meat and 'alternative proteins'. Meat Substitutes from plants and mycoproteins</p>	<p>GMO cloning of meat (animals that are genetically modified to produce food and feed)</p>	<p>Diet makeovers, i.e. insect-based protein diets. Artificial meat based on cell and tissue culture cells produced at commercial scale</p>

4. Business Eco-System View

Protein transition overlaps with the following technologies:

- 3D printing
- Genetics
- Synthetic biology

- Aquaculture
- Renewable energy

5. Benefits and Risks

The benefits, challenges and prospects of cultured meat may be summarised as in the list below.

Benefits^{23, 24,25}

- A shorter turnaround time to manufacture the product
- Better control over meat composition and quality by manipulating the flavour, fatty acid composition, fat content and ratio of saturated to poly-unsaturated fatty acids
- Health aspects of the meat can be enhanced during production (and not during post production modification, which may be difficult, expensive and unattainable) by adding factors like certain types of vitamins to the culture medium which might have an advantageous effect on the health of consumers, especially in less developed countries
- Meat contamination and incidence of food borne (zoonotic) diseases could be significantly reduced
- The production of exotic cultured meats becomes possible.
- Reduction of animal use in the meat production system, as well as nutrients and energy use
- Bioreactors can be stacked for scalability
- Cultured meat involves 7–45% less energy than conventionally produced meat (only poultry has lower energy use), 78–96% lower emissions of greenhouse gases, 99% lower land use, and 82–96% lower water use compared to conventional meat production methods
- Less slaughtering of animals (pain and suffering)
- Minimal harm to animals by collection of stem cells for culturing, through biopsies
- Due to the aseptic and strictly controlled environment required for its production, producing meat from cell cultures is safer than conventional production through animal husbandry
- Antibiotics are not required

Risks

- Funding for basic research: Much of the basic biotechnology research needed to mass produce cultured meat has yet to be done, including studies on optimal cell lines and culture media²⁶

- Few researchers: entirely devoted researchers at about 5 individuals worldwide, with another 50-100 known researchers in related fields expressing varying degrees of interest in working on cellular agriculture
- Lack of regulatory preparedness: relative infancy of the science behind it means that current food industry regulations are generally not prepared for commercial production at any significant scale.
- Significant improvements are needed to overcome these challenges in reproducing the taste and texture of natural meat²⁷
- Culture medium: progress in this area is severely hindered by the fact that optimal cell lines have not yet been found, as individual cell lines often require distinct medium formulations to proliferate. Furthermore, some bioactives and growth factors are still obtained from animals
- Energy requirements: One recent life cycle analysis (LCA) of cultured meat production found that, while land and water use are expected to be far lower than all other forms of meat production, its energy requirements would be extremely high compared with previous estimates²⁸
- Cost: The only private company currently making cultured beef reports a production cost of about €36,200/kg,²⁹ which is roughly 18 times cheaper than the €650,000/kg burger unveiled in 2013.
- Consumers, however, may be cautious or even negative about cultured meat such products due to perceptions of “unnaturalness” and “artificialness.”

6. Potential Economic, Social, Ecological (Environmental) and Political Developments and Impacts

Economic Developments and Impacts

It is predicted that the global cost savings achievable by replacing traditional (natural) meat with *in vitro* (cultured) meat could be more than \$130 billion per year³⁰. By using the appropriate stem cells, proliferating them under optimum conditions and providing them with the right stimulatory signals and co-factors in a 3D environment, industrial meat production seems feasible³¹. However, certain technical challenges would need to be overcome, as mentioned elsewhere in this document, including the development of cost-effective growth media developed, the selection of appropriate (compatible and edible substrates and scaffolds for muscle cell attachment, growth and maturation) which will aid in the definition of the correct texture of the cultured meat, the achievement of scalability for industrial production. the attainment of high nutritional value and taste (over the 1000 different water soluble and fat-derived components are necessary to obtain strain specific taste of meat)^{32,33}.

As the price of conventional meat increases the demand for cheap alternatives is predicted will also increase, with the first such products being meat substitutes manufactured from plant or insect proteins, since they the most attractive to manufacture and have the lowest barriers to commercialization.^{34, 35}.

The cell culture approach for *in vitro meat* is 10-20 years away from being commercially available. Commercial application will require significant commitment (possibly including regulation) and investments from both government and industry, to cover research costs, as well as funding for new infrastructure costs in production³⁶.

Social Developments and Impacts

Large-scale of cultured meat may result in employment dynamics - production could move into cities to exploit lower transport costs, to the disadvantage of rural production sites such as conventional farms. Certain infrastructure and skills such as abattoirs and slaughtering may no longer be important.

It has been proposed that the rise of artificial meat will result in the decline of traditional livestock-rearing practices in rural areas, in particular the decline of livelihoods based on livestock-farming. This is more relevant for developing countries³⁷.

The production process requires the use of hormones and certain food grade chemical nutrients, which may be unattractive to consumers value natural production systems.

Consumer attitudes will influence the level of adoption of cultured meat. For example, vegetarians may not be the best target for novel products as the original source is still animals. Price and sensory perceptions were reported as the major obstacles to accepting cultured meat in diets³⁸. More than 50% of French consumers in survey accepted the concept, but doubted taste and health aspects³⁹. In the US, respondents in a survey were willing to taste *in vitro* meat, but were not willing to incorporate it into their regular diet⁴⁰.

Consumers are more likely to purchase a new product that is like an existing product already in use, and so for such a product to compete with conventional meat it should closely resemble conventional meat in appearance, taste, texture, convenience of acquisition, price, and nutritional value⁴¹.

Manufacturers and producers will adopt new technologies and products if there is a potential of turnover and profit has been demonstrated, meeting criteria of mass production, and minimal changes to existing, product demand.

Meat has significant cultural significance, as an aspirational food. The reduction in poverty is closely-linked to the ability to eat meat. In addition, the inability to eat meat suggests lower economic standing. It has been argued that meal without meat will drive changes in eating habits. Other nutrient sources such as whole-grain products, fruits and vegetables, or other processed foods in the diet would escalate in prominence⁴².

Cardiovascular disease, diabetes, and colorectal cancer are associated with red meat consumption, and alternatives to conventional red meat may drive research efforts. Meat is a carrier for several foodborne pathogens that are responsible for many illnesses per annum. Low hygiene levels on some farms results in the development of animal diseases such as swine influenza, avian influenza, foot-and-mouth disease, and mad cow disease, which have economic and human health implications^{43,44}.

Ecological (Environmental) Developments and Impacts

Cultured meat production could potentially have substantially lower greenhouse gas (GHG) emissions, land use and water use compared to conventionally produced meat – 7 to 45% less energy than conventionally produced meat, 78 to 96% lower emissions of greenhouse gases, 99% lower land use, and 82 to 96% lower water use (if cyanobacteria can be used as the source of nutrients and energy). If cultured meat was produced at large scale, more land would be released from meat production for other agricultural uses.⁴⁵

Political Developments and Impacts

The meat industry of the US has very powerful political lobbying capacity, and will defend its market from meat alternatives. The same could be said for the South African meat industry. In the US, the meat industry has successfully lobbied and financially supported politicians and the USDA to prevent changes in how the meat production facilities are inspected, and has objected to changes to the food pyramid that could reduce the recommended daily allowances of meat⁴⁶.

According to the EU Directive 258/97 on “Novel foods and novel food ingredients” (1997), novel foods and novel ingredients are defined as those foods or ingredients which have not been consumed to any significant degree in the EU before May 1997, such as foods produced by new production processes like genetic modification, but also foods or ingredients isolated from plants or animals using new techniques. In this directive, novel foods and ingredients must undergo a safety assessment before being marketed, as part of the authorisation procedure⁴⁷. The South African regulatory landscape will be interrogated to determine what regulation is present, and if recommendations for similar legislation can be made for cultured meat.

Several policies and strategies exist in South Africa to support cultured meat development. These are underpinned by the following:

- New Growth Path
- Industrial Policy Action Plan (IPAP)
- National Development Plan (NDP).

Annexure 1 illustrates the alignment of *in vitro* meat production (cultured meat production) with the key policy mandates of DAFF, articulated in the NDP, and APAP, and illustrates where *in vitro* meat production (cultured meat production) and possibly technologies of the future may be used to support the delivery of the South African governments proposed interventions as articulated in the APAP.

The development of cultured meat as an industry would speak directly to the Western Cape Department of Agriculture's strategic plan, most notably Strategic Goal 6, Programme 4 (Sub-Programme 4.3), as well as its risk mitigation/management plans.

7. Conclusions

Published recommendations⁴⁸ in support of the development of cultured meats are the following:

- Funding and promotion of academic interest in cellular agriculture is important to develop cultured meat technology from the laboratory to the market
- Increased public awareness about the benefits of cultured meat is crucial to facilitate technology and product adoption, as well as acceptance by manufacturers, who are driven by profits
- Cultured meat development is to be facilitated through policy changes and appropriate legislation
- It is possible that cultured meat products could play a useful complementary role alongside conventional meat products in meeting predicted increases in the global demand for meat.

8. Synthesis and key trends from the literature

- Whilst the merits of cultured meat are appreciated, the process development is not at a level where it can be commercially viable, and it may be a while before commercial scale-up is attained;
- Significant government funding in the form of subsidies, as for other agricultural sectors will drive development to commercialization, and affordability for the consumer.

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- ¹ United Nations. 2015. *Revision of world population prospects*. [Online] Available: <https://esa.un.org/unpd/wpp/publications/files/keyfindingswpp2015.pdf> [Accessed: 1 October 2017].
- ² UNEP Global Environment Alert Services (GEAS). 2012. [Online] Available: <http://www.unep.org/pdf/unep-geas.pdf> [Accessed: 1 October 2017].
- ³ Alexandratos, N. & Bruinsma, J. 2012. *World agriculture towards 2030/2050*. [Online] Available: http://www.fao.org/fileadmin/templates/esa/Global_perspectives/world_ag_2030_50_2012_rev.pdf [Accessed: 2 November 2017].
- ⁴ De Haan, C., Van Veen, T.S., Brandenburg, B., Gauthier, J., Le Gall, F. & Mearns, R. 2001. *Livestock development: Implications for rural poverty, the environment, and global food security*. Washington, DC: World Bank.
- ⁵ Vinnari, M. 2008. The future of meat consumption: Expert views from Finland. *Technological Forecasting and Social Change*, **75**(6), 893-904.
- ⁶ Cinar, M.U. 2015. *Impact of livestock genomics on food security and sustainability*. Paper presented at the Regional Workshop on Sustainable Management of Food Security, Istanbul, 9-10 April.
- ⁷ Food and Agriculture Organization of the United Nations (FAO). 2003. *World agriculture: Towards 2015/2030. An FAO perspective*. Rome: FAO.
- ⁸ Grunert, K.G. 2006. Future trends and consumer lifestyles with regard to meat consumption. *Meat Science*, **74**(1), 149-160.
- ⁹ Fiala, N. 2008. Meeting the demand: An estimation of potential future greenhouse gas emissions from meat production. *Ecological Economics*, **67**(3), 412-419.
- ¹⁰ Datar, I. & Betti, M. 2010. Possibilities for an in vitro meat production system. *Innovative Food Science & Emerging Technologies*, **11**(1), 13-22.
- ¹¹ van der Spiegel, M., Noordam, M.Y. & van der Fels-Klerx, H.J. 2013. Safety of novel protein sources (insects, microalgae, seaweed, duckweed, and rapeseed) and legislative aspects for their application in food and feed production. *Comprehensive Reviews in Food Science and Food Safety*, **12**, 662-678.
- ¹² Post, M.J. 2012. Cultured meat from stem cells: Challenges and prospects. *Meat Science*, **92**, 297-301.
- ¹³ Stephens, N., Kramer, C., Denfeld, Z. & Strand, R. 2015. *What is in vitro meat?* [Online] Available: http://www.foodphreaking.com/FP02_WhatIsInVitroMeat.pdf [Accessed: 1 November 2017].
- ¹⁴ Sharma, S., Thind, S.S. & Kaur, A. 2015. In vitro meat production system: Why and how? *Journal of Food Science and Technology*, **52**(12), 7599-7607.
- ¹⁵ Edelman, P.D. 2003. *In vitro meat production*. [Online] Available: <http://new-harvest.org/wpcontent/uploads/2013/03/Edelman.pdf> [Accessed: 30 October 2017].
- ¹⁶ Edelman, P.D., McFarland, D.C., Mironov V.A. & Matheny, J.G. 2005. Commentary in vitro cultured meat production. *Tissue Engineering*, **11**, 659-662.
- ¹⁷ Kosnik, P.E., Dennis, R.G. & Vandenburgh, H.H. 2003. Tissue engineering skeletal muscle. In Guilak, F. (ed.), *Functional tissue engineering*, 377-392. New York, NY: Springer-Verlag.
- ¹⁸ Bhat, Z.F. & Bhat, H. 2011. Tissue engineered meat-future meat. *Journal of Stored Products and Postharvest Research*, **2**, 1-10.
- ¹⁹ Fox, S.I. 1996. *Human physiology*. Dubuque, IA: W.C. Brown Publishers.
- ²⁰ Kadim, I.T., Mahgoub, O., Baqir, S., Bernard Faye, B. & Purchas, R. 2015. Cultured meat from muscle stem cells: A review of challenges and prospects. *Journal of Integrative Agriculture*, **14**(2), 222-233.
- ²¹ Tijhuis, M.J., Ezendam, J., Westenbrink, S., van Rossum, C. & Temme, L. 2011. *Replacement of meat and dairy by more sustainable protein sources in the Netherlands: Quality of the diet*. [Online] Available: <http://www.rivm.nl/bibliotheek/rapporten/350123001.pdf> [Accessed: 23 October 2017].
- ²² WRAP. 2017. *Food futures: From business as usual to business unusual*. [Online] Available: <http://www.wrap.org.uk/content/food-futures> [Accessed: 4 November 2017].
- ²³ Bhat, Z.F. & Bhat, H. 2011. Tissue engineered meat-future meat. *Journal of Stored Products and Postharvest Research*, **2**, 1-10.
- ²⁴ Tuomisto, H.L. & de Mattos, M.J.T. 2011. Environmental impacts of cultured meat production. *Environmental Science & Technology*, **45**(14), 6117-6123.
- ²⁵ Genovese, N. & Notaro, K. 2011. *The crusade for a cultured alternative to animal meat: An interview with Nicholas Genovese, PhD PETA*. [Online] Available: <https://ieet.org/index.php/IEET2/more/notaro20111005> [Accessed: 4 November 2017].
- ²⁶ Online communication between New Harvest CEO Isha Datar, New Harvest research strategist Daan Luining, and Effective Altruism Foundation research associate Adrian Rørheim. 2016, March 7.

- ²⁷ New Harvest. 2016. *3D vascularized tissue: The cultured steak*. [Online] Available: http://www.new-harvest.org/cultured_steam [Accessed: 5 October 2017].
- ²⁸ Mattick, C.S., Landis, A.E., Braden, R., Allenby, B.R. & Genovese, N.J. 2015. Anticipatory life cycle analysis of in vitro biomass cultivation for cultured meat production in the United States. *Environmental Science & Technology*, **49**(19), 11941-11949.
- ²⁹ Harris, S. & Valeti, U. 2016. *Meat without misery*. [Online] Available: <https://www.samharris.org/podcast/item/meat-without-murder/> [Accessed: 31 October 2017].
- ³⁰ Young, J.F., Therkildsen, M., Ekstrand, B., Che, B.N., Larsen, M.K., *et al.* 2013. Novel aspects of health promoting compounds in meat. *Meat Science*, **95**(4), 904-911.
- ³¹ Langelaan, M.L., Boonen, K.J., Polak, R.B., Baaijens, F.P., Post, M.J., *et al.* 2010. Meet the new meat: Tissue engineered skeletal muscle. *Trends in Food Science & Technology*, **21**(2), 59-66.
- ³² Young, J.F., Therkildsen, M., Ekstrand, B., Che, B.N., Larsen, M.K., *et al.* 2013. Novel aspects of health promoting compounds in meat. *Meat Science*, **95**(4), 904-911.
- ³³ Post, M.J. 2012. Cultured meat from stem cells: Challenges and prospects. *Meat Science*, **92**(3), 297-301.
- ³⁴ Hoek, A.C., Luning, P.A., Weijzen, P., Engels, W., Kok, F.J. & de Graaf, C. 2011. Replacement of meat by meat substitutes. A survey on person- and product-related factors in consumer acceptance. *Appetite*, **56**, 662-673.
- ³⁵ Hoek, A.C., van Boekel, M.A.J.S., Voordouw, J. & Luning, P.A. 2011. Identification of new food alternatives: How do consumers categorize meat and meat substitutes? *Food Quality and Preference*, **22**, 371-383.
- ³⁶ Mattick, C. & Allenby, B. 2013. The future of meat. *Issues in Science and Technology*, **30**, 64-67.
- ³⁷ Thornton, P. 2010. Livestock production: Recent trends, future prospects. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences*, **365**(1554), 2853-2867.
- ³⁸ Verbeke, W., Sans, P. & Van Loo, E.J. 2015. Challenges and prospects for consumer acceptance of cultured meat. *Journal of Integrative Agriculture*, **14**, 285-294.
- ³⁹ Hocquette, J.F. 2016. Is in vitro meat the solution for the future? *Meat Science*, **120**, 167-176.
- ⁴⁰ Wilks, M. & Phillips, C.J.C., 2017. Attitudes to in vitro meat: A survey of potential consumers in the United States. *PLoS ONE*, **12**, e0171904.
- ⁴¹ Verbeke, W., Pérez-Cueto, F.J.A., de Barcellos, M.D. & Krystallis, A. 2010. European citizen and consumer attitudes and preferences regarding beef and pork. *Meat Science*, **84**, 284-292.
- ⁴² Tijhuis, M.J., Ezendam, J., Westenbrink, S., van Rossum, C. & Temme, L. 2011. *Replacement of meat and dairy by more sustainable protein sources in the Netherlands: Quality of the diet*. [Online] Available: <http://www.rivm.nl/bibliotheek/rapporten/350123001.pdf> [Accessed: 23 October 2017].
- ⁴³ McColl, K.A., Clarke, B. & Doran, T.J. 2013. Role of genetically engineered animals in future food production. *Australian Veterinary Journal*, **91**, 113-117.
- ⁴⁴ Datar, I., Datar, I. & Betti, M. 2010. Possibilities for an in vitro meat production system. *Innovative Food Science and Emerging Technologies*, **11**, 13-22.
- ⁴⁵ Tuomisto, H.L. & Teixeira de Mattos, M.J. 2011. Environmental impacts of cultured meat production. *Environmental Science & Technology*, **45**, 6117-6123.
- ⁴⁶ Johnson, S. 2016. *The politics of meat*. [Online] Available: <http://www.pbs.org/wgbh/pages/frontline/shows/meat/politics/> [Accessed: 31 October 2017].
- ⁴⁷ Tijhuis, M.J., Ezendam, J., Westenbrink, S., van Rossum, C. & Temme, L. 2011. *Replacement of meat and dairy by more sustainable protein sources in the Netherlands: Quality of the diet*. [Online] Available: <http://www.rivm.nl/bibliotheek/rapporten/350123001.pdf> [Accessed: 23 October 2017].
- ⁴⁸ Rorheim, A., Mannino, A., Baumann, T. & Caviola, L. 2016. *Cultured meat: A pragmatic solution to the problems posed by industrial animal farming*. [Online] Available: <https://sentience-politics.org/wp-content/uploads/2016/02/Cultured-Meat.pdf> [Accessed: 28 October 2017].