Bioengineered Meat and it's Potential Contributions to Food Security in the Future- A Literature Review

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Abstract

The theoretical possibility of bioengineering meat grown in an industrial setting has long captured scientists' imagination. Almost a century after Churchill wrote that we should be growing separate parts of a chicken in a suitable medium, we still grow the whole animal to consume roughly 68% of it. Animal farming is responsible for 15% of the global GHG emissions, but also provides income and food security for farmers in developing countries. With a predicted rise in consumption of meat, reaching 374MT in 2030, due to developing countries increased access to animal-sourced foods, the environmental impact of livestock follows an ascending trend. The question is if bioengineered meat can break the trend while proving to be a viable product for mass consumption.

We aim to evaluate the possible beneficial contributions of bioengineered animal products to ensuring food security for a growing population, through reducing the environmental cost of animal farming for food purposes.

An extensive review of the existing scientific literature reveals that currently, a thorough life cycle analysis for bioengineered meat is still based on incomplete data, although said data is gathered directly from the industry, and has some degree of uncertainty regarding the levels of environmental impact and potential for development.

Keywords: bioengineered meat, environmental impact, food security

1. Introduction

Cultured meat for human consumption is a relatively recent endeavour, gaining increased popularity after Jason Matheny co-authored a seminal paper on the subject in early 2000s, and created New Harvest, the world's first nonprofit organization dedicated to supporting *in vitro* meat research. [1] Before that, the theoretical possibility of growing meat outside of an animal was addressed by Winston Churchill in his 1931 essay, where he wrote "We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium.". [2] The discovery of cell lines in 1948, coupled with a passion about food production and food security, led the Dutch scientist William Van Eelen to come up with the idea for cultured meat in the 1950s. He is now considered "the godfather of cultured meat". [6] In 2001, together with Wiete Westerhof (Amsterdam), Willem Van Kooten (Hilversum) and Christine Mummery (Bilthoven), William Van Eelen filed for a worldwide patent, on "Industrial production of meat using cell culture methods", granted in 2007. [3, 4] Ten years earlier, in 1991, Jon F. Vein filed for a patent on "Method for producing tissue engineered meat for consumption", granted in 2004. [5] All these patents rely on the same background information: ever increasing human population, low food security in underdeveloped and developing nations, environmental risks associated with animal agriculture, inefficient use of land (for feed rather than food), food safety concerns (growth hormones, bacterial infestation, antibiotic resistance). In their opinion a great contribution to

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food security may come from the field of bioengineering, by greatly reducing the risk of contamination in the processing of animal foods, especially meat. [6, 7, 8] As Jon Vein states in his patent, except for *E.coli*, there are some harmful bacteria that are considered “inherent” to raw meat. [9] Among them, campylobacter and salmonella are the two most common in Europe, causing zoonotic diseases. Salmonellosis was in 2019 in EU the second most reported zoonotic disease, with around 88,000 people affected, the first being campylobacteriosis, with over 246,000 human cases reported annually. [10] In order to prevent food-born diseases, the products suspected of posing a threat are often destroyed or recalled from the market. The emergency control of animal diseases often requires large scale euthanasia or depopulation of livestock, as was the case for pigs infected with African Swine Fever (ASF). Although ASF does not affect human health, it can be transmitted from humans, infecting other pigs. Between 2016 and 2020, 1.3 million pigs were killed in the EU, to control the spreading of the disease. [11] All these safety measures, although necessary, lead to food loss derived from livestock and contradict the purpose of raising animals for meat, thus posing a great threat to food security. [12] According to the patent files for bioengineered meat products, the sterile medium in which they are produced neutralizes the risk of bacterial or viral contamination, ensuring that all the quantity produced is fit for human consumption, thus nullifying food loss and greatly contributing to an increase in food security. [7, 8, 9] But can bioengineered meat fully replace meat from livestock? Is cultivating meat in industrial settings a more sustainable way of ensuring the global supply of meat products to a growing population? Has cultured meat a greater potential of ensuring food security and safety for a growing population? The next sections of the research papers are focused on analysing existing data, in order to determine if a positive correlation exists indeed between the practice of bioengineering animal meat destined for human consumption and a potential increase in global food security, while considering both economic and social costs associated with the practice.

2. Materials and methods

In order to understand the process of bioengineering meat, the roots of the practice and the level of knowledge available at this moment in the industry, we analysed technical documentation, patent applications and reports available for open access. In order to determine the potential of bioengineered meat to increase food security and food safety trough less damage to the environment, fewer threats for human health and less intensive use of limited resources, we have analysed numerous studies and reports provided by the scientific community, some of them in partnership with the industry. All the data available from external sources was analysed and synthesized, to determine if a potential positive correlation exists between growing specific cuts of meat from cells, instead of growing the whole animal, and food security of present and future generations.

3. Results and discussion

Life Cycle Analysis (LCA)

Early days studies on the subject of cellular agriculture in general and lab-grown meat in particular revolved around the great potential of culture meat to eradicate the existent problems of the animal agriculture supply chain: land use; water use; environmental damages due to GHG emissions, manure management, loss of terrestrial and marine ecosystems’ biodiversity; food loss due to bacterial and viral infection, contamination in the production processes, food safety concerns and many other “sins” of the animal agriculture. The potential of cellular agriculture, and especially bioengineered meat, to increase food security for present and future generation derives mainly form it’s presumed lower impact on the environment (lower GHG emissions, lower impact on ecosystems), the capacity to free land presently used for growing animal feed to be repurposed for direct human consumption and a higher degree of food safety, given that the meat is grown and processed in a controlled environment. [7, 8, 13, 14]

The life cycle analyses existing until 2021 (Tuomisto 2011 and 2014; Mattick 2015; Smetana 2015) [14, 15, 16, 17] were based mostly on assumptions, as the industry was not developed enough to provide sufficient data for analysis. The scenarios regarding energy requirements, area needed for the bioreactors and production processes, raw material cost and their environmental footprint, the outputs generated – both quantity of main product and nature of residues, and upstream processes were based on associations and assumption of similarity with parallel production processes from different industries:

- size of bioreactors and area needed for a production facility were assumed based on the size of a brewery;
- energy requirements of the building – lightning, HVAC system and other needs were assumed by equivalence with the energy needs of a warehouse;
- energy inputs for the process were simulated based on the technological requirements of different cell cultivation industries, by mathematical modelling;
- water inputs were calculated based on scientific literature that addresses the production process and the steps indicated for the procedure;
- raw material needed for the growth medium and their environmental costs were assumed based on scientific literature and existing information from the industry. [14, 15, 16, 17]

Based on these early attempt at analysing the life cycle requirements and impacts of bioengineered meat, for the development stage at that moment, the comparative analysis reveals the following:

Land use

All LCA performed before 2021, the last being in 2015, reveal that *in vitro* meat cultivation requires less land per unit of final product (m^2/kg meat) than conventional agriculture. The difference in land requirements is smaller between lab-grown meat and poultry, due to the fact that poultry can be farmed in tiered batteries systems, but significantly higher when compared with land requirements for cattle herds. In estimating land use for *in vitro* meat cultivation, a high proportion of land use is attributed to the production of the feedstock for the growth medium. [14, 15, 16, 17]

Energy use

The energy demands of *in vitro* meat cultivation are significantly higher compared with poultry and pork production requirements, but not much higher than beef production. The differences in energy use are higher considering the downstream industries (processing of feedstock) and the internal processes (cultivation phases and post-harvest cleaning). Also, there are significant differences in energy use between LCA, derived from differences in considered inputs. As such, Mattick's LCA (2015) [16] reveal an energy demand of more than 100 MJ/kg of cultured meat, compiled both for energy demands by stage of production and by input, while Tuomisto's (2014) [15] study considered two scenarios, based on feedstock origin, one with cyanobacteria, resulting in roughly 40 MJ/kg of meat, and one with wheat, resulting in almost 60 MJ/kg of meat.

Environmental impact

The main indices considered when computing the environmental impact of bioengineered meat were the level of GHG emissions, water use, waste product, provenance of energy (fossil fuel or renewable). [14, 15, 16, 17] The LCA carried by Smetana (2015) [16] also considered post-production stages (processing stage and distribution phase), potential resource depletion, eutrophication, ecotoxicity and acidification potentially resulting from the industry. The environmental impact was determined as the potential of cultured meat to cause global warming effects. As by Mattick (2015) and Tuomisto (2011, 2014), [14, 15, 16] the industry of cell-based meat products releases between 2.4 and 7.5 $kgCO_2eq/kg$ of product, the highest level (7.5 $kgCO_2eq/kg$ of product) being estimated by Mattick, [16] and the lower level being estimated by Tuomisto: 2.4 $kgCO_2eq/kg$ of product for optimist scenario (cyanobacteria as feedstock) and 4.4 $kgCO_2eq/kg$ of product for worst case (wheat as source of feedstock). [14, 15] When correlating all the LCA data, the global warming potential of cultured meat is higher than that of poultry and pork production, but comparatively lower than that of beef. [14, 15, 16, 17]

When analysing the conclusions derived from the aforementioned life cycle analyses, [14, 15, 16, 17] there are some aspects that must me taken into account:

- by 2015 no production facility managed to deliver significant results for the industry (big scale operating facility, large production) most of the data being estimated;

- LCA studies conducted during incipient phases (experimental, development, modeling) generally deliver results showing higher environmental costs compared with processes of industrial scale, due to high level of variability in data and experimental production optimization operations;
- the results of early LCA studies are anticipatory, and generally change towards lower environmental impacts as the industry develops, increasing the quantity and quality of information and decreasing the level of uncertainty.

In February 2021, CE Delft, an independent research and consultancy company specialised on environmental topics, from Netherlands, published a LCA based on the latest data provided by companies activating in the field. [18] Their LCA is the first study based on primary data delivered by more than 15 companies from production and also from the bioengineered meat supply chain, being further cross-checked by independent experts. The results of the LCA present a scenario modelled on a ground-meat final product, in a commercial-scale production facility, in 2030. The results are presented using the ReCiPe single score method, and is compared with the performance of conventional protein production of meat and meat alternative, using a high-aimed benchmark, to ensure the robustness of the results. The footprint of animal agriculture used for comparison is based on an optimised intensive production, from circular agriculture systems, projected for 2030 in developed European countries. Although some level of uncertainty is still present, the current LCA presents more reliable outcomes, due to large quantity of data used for modelling, acquired directly from the industry. The analysis is compiled for two different scenarios:

- sustainable production based on a mix of conventional sources of energy and energy from renewable sources (wind turbines, solar PV panels) in 50% ratio, with geothermal heating sources;
- conventional production scenario using energy based on a predicted mix of sources for 2030 and natural gas as source of heating.

A summary of the 2021 LCA results reveal that the carbon footprint- expressed in kgCO_2eq/kg product- is lower for cultured meat than any other animal protein source if the model is based on sustainable production, but higher than that of poultry and pork if the model is based on conventional production scenario. When compared with plant based protein sources, including tofu, both scenarios for bioengineered meat reveal a higher carbon footprint than plant based protein sources. [18]

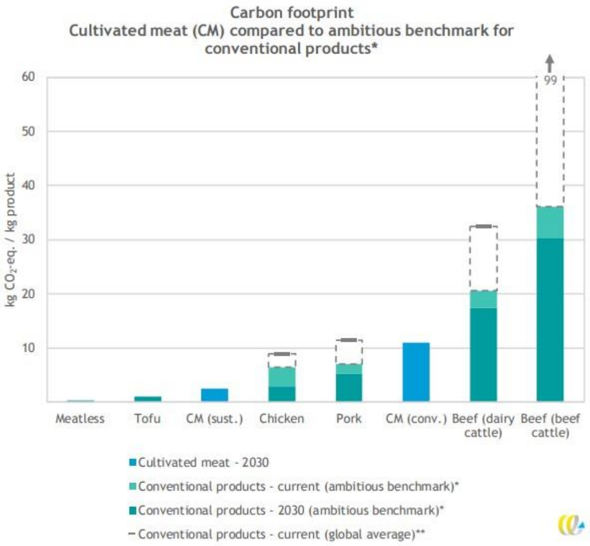

Figure 1. Carbon footprint of cultivated meat (CM) and conventional protein products

*Intensive, West-European, circular agriculture

**Taken from Poore and Nemecek (2018)

Source: LCA of cultivated meat Future projections for different scenarios (2021)

When using the ReCiPe single score for computing the environmental impact (global warming, water consumption, land use, fine particulate matter formation, human toxicity and other indices) of bioengineered meat, expressed in mPt/kg of product (million points), cultured meat situates lower on the impact scale than all conventional animal protein sources in the sustainable scenario, and above poultry ad pork in the conventional scenario. [18]

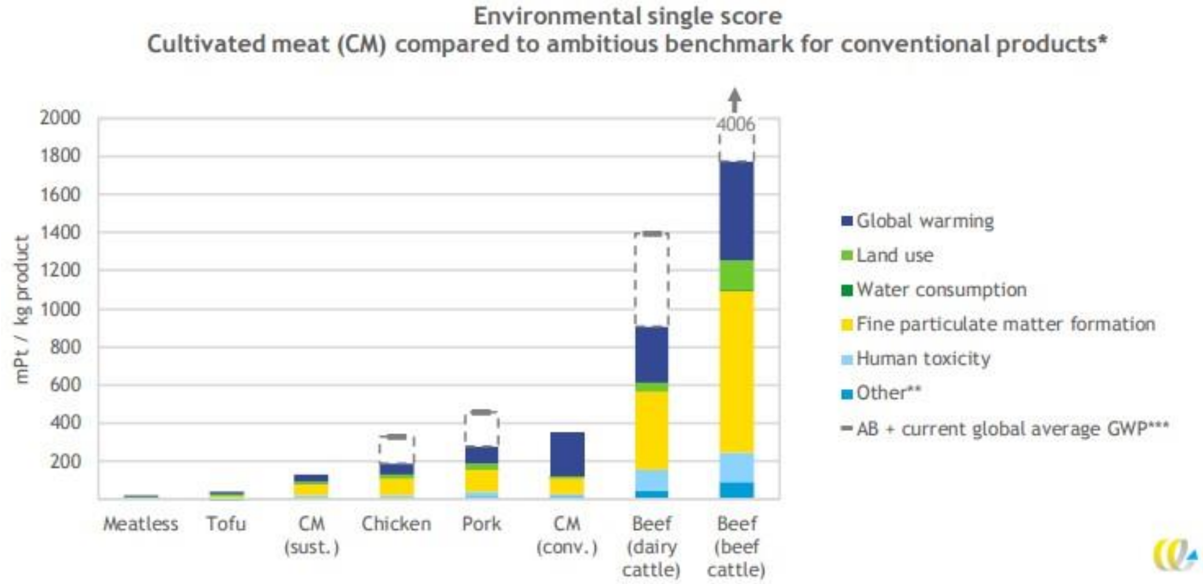

Figure 2. Environmental impact of cultivated meat (CM) using ReCiPe single score and conventional protein products

*Intensive, West-European, circular agriculture
** 'Other' includes 14 impact categories (resource depletion, acidification). A complete list can be found at https://www.rivm.nl/en/life-cycle-assessment-lca/recipe
*** Global Warming Potential taken from Poore and Nemecek (2018)
Source: LCA of cultivated meat Future projections for different scenarios (2021)

When compared with the previous LCA [14, 15, 16], the 2021 results indicate higher carbon footprint than previous studies, due to inclusion of upstream industries in the system boundaries considered for analysis. [18] Energy use was also higher in the 2021 LCA, for the same reason CFP (Carbon Footprint of Product) is higher, but additionally because of considering within the internal processes energy requirement for cleaning-in-place and steam-in-place (CIP/SIP) of bioreactors post-harvest. [18]

Table 1. Comparison of carbon footprint and energy use values between aforementioned LCA

Life Cycle Analysis	**Carbon Footprint (kgCO2eq/kg product)**	**Energy use (MJ/kg of product)**
CE Delft (2021)	2.5 – 13.5	147 – 266
Mattick (2015)	7.5	106
Tuomisto (2014)	2.3 – 4.4	35 – 61
Tuomisto (2011)	1.9 – 2.2	25 – 32

Source: LCA of cultivated meat Future projections for different scenarios (2021)

Techno-economic Assessment (TEA)

Regarding the feasibility of cultured meat compared with conventional protein sources form animal agriculture, according to a techno-economic assessment (TEA) compiled by CE Delft in 2021, at the moment the production costs associated with bioengineered meat are 100 to 10,000 times higher than the values for comparable conventional meat products. [19] Production costs are highly dependent and determined by the components of culture medium, specifically recombinant proteins, the next drivers of high production cost being the growth factors.

An analysis of the prices for different elements needed for the culture reveals wide variations between prices, for example, the lowest price for albumin, one of the recombinant proteins used in the culture media is 41 $/g of product while the highest price is 400$/ g of product. The price of recombinant proteins represent 80% of the cost, while together with growth factors determine more than 99% of the cost for cultured meat production.

The TEA conducted by CE Delft [19] analyses the costs of CM by production process and by raw material needed in the process, developing multiple scenarios for cost reduction. The most cost efficient scenario for 2030 results in a Cost of Goods Sold (COGS) of 6.43$/kg of product, the higher driver of cost in this scenario being the process of large-scale proliferation, with a value of 2.30$/kg of product. This COGS can be achieved by:

- selecting the medium components from the lower end of prices,
- growth factors and recombinant proteins selected by the same criteria (low price/g of product),
- investment costs are distributed not only to investors interested in profit, but between governmental funds and subsidies, non-profit funders driven by social interest (animal welfare, environmental footprint) and an extension of the required payback time to a maximum of 30 years,
- a feasible reduction in production run time of 25% for proliferation, differentiation and maturation stages, resulting in a reduction of energy and medium demands,
- larger cell volume per bioreactor, lowering the energy and medium needs, and also equipment costs.

To be noted that the COGS of 6.43$/kg of product is calculated for the year 2030, when production is realised in a full-scale production plant, with a production capacity of 10 kton/year, realised in a semi-continuous process. The final product is a non-specific meat, with a pasty consistency resembling very fine ground meat, that can be further processed.

A COGS of 6.43$/kg is still higher than the median price for conventional meat products, but is close to benchmark prices estimated for conventional meat in 2030. [19]

Consumers perception

It is unnecessary to mention that in order for a food product to be part of a diet and contribute to food security, individual or global, said product needs to be accepted for consumption by the potential consumers.

Numerous studies analysed the way consumers perceive cultured meat, and their willingness to consume such a product in the future.

A recent segmentation study on the area of South Africa reveals a high degree of openness of consumers to bioengineered meat products, with 60% of participants stating they are highly willing to try and 53% of participant being very likely to purchase. [20]

Another study from August 2021, on the Australian continent, carried on six consumers clusters reveal that 49% of them have some degree of willingness to consume CM, and 12%, refereed at as “prospective” consumers declare a high degree of willingness in consumption. [21]

A UK study from 2020 of the consumers acceptance regarding bioengineered meat reveal some key elements that contribute to the perception of consumers:

- lab-cultured meat has a higher degree of acceptance when compared with other foods derived from GMO practices;
- bioengineered meat is preferable compared with alternative protein sources, like insects;
- CM is less appealing for general consumers when compared with plant based alternatives but more appealing to meat-lovers, who refuse to consume alternative proteins;
- recognition of benefits of CM for the environment and animal welfare are potential drivers for consumers;
- consumers tend to attribute a high degree of risk to lab-grown meat due to “unnaturalness” and violation of biological laws;
- being able to try free of charge before buying might increase the willingness to consume cultured meat;
- the taste and price of bioengineered meat are the main determinants for the decision to buy and consume – while some are willing to lower their expectation on taste for a price comparable to meat products, a narrow segment of potential consumers are willing to pay more for cultivated meat than conventional meat. [22]

Some general conclusions can be found across multiple studies addressing consumers perception and openness to bioengineered meat: [20, 21, 22, 23, 24, 25,26]

- the highest levels of positive perception and willingness to include in the diet are registered in consumers with a median age of maximum 35 years;
- the level of education influences perception towards CM – consumers with higher education tend to be more open to try and consume bioengineered meat;

- the degree of environmental consciousness and concerns to animal welfare correlate positively with willingness to consume CM
- the way in which information regarding bioengineered meat is delivered influences the perception of consumers – a highly technical approach tends to have a negative impact, increasing the perception of unnaturalness, while informing on the potential environmental and societal benefits results in a higher degree of openness and willingness to try.

4. Conclusions

The LCA reviewed in the previous section reveal that when correlating food security with environmental issues – land use, deforestation, water eutrophication, climate change, and others – bioengineered meat has a lower environmental impact that beef in any scenario, and lower than any animal sourced proteins if obtained trough sustainable processes. The low environmental impact is correlated with high degree of sustainability and can indicate a potential of positively contributing to all pillars of food security in the future.

The TEA analysed reveals that although current COGS are extremely higher than ambitious benchmark prices of animal protein (sourced from intensive, West-European, circular agriculture), there are multiple applicable scenarios that have the capability of lowering the prices in the future, to comparable values of animal protein. Price is an important driver of consumption, therefore, comparable prices between bioengineered meat and conventional meat can prove beneficial for a shift in consumption towards inclusion of cell-based meat in diet. If we consider the increase in consumption of lab-grown meat and a decrease in consumption of conventional meat based on comparable prices, it can be further extended to a beneficial impact on the environment, with increased global food security. To be noted that according to results of TEA, a decrease in COGS is also correlated with a decreased environmental impact (considering energy consumption reduction associated with production processes and sustainable energy procurement).

Consumers perception and level of acceptance and willingness to consume are ultimately the main factor to positively or negatively impact the potential of bioengineered meat on food security. Even if LCA and TEA reveal great potential of reduction in environmental damages and high degree of sustainability correlated with a favourable shift in consumption of bioengineered meat, if the final consumers refuses to accept and adopt the final product, all the potential benefits for global food security derived from cultured meat production are nullified.

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