

Is “cultured meat” a viable alternative to slaughtering animals and a good compromise between animal welfare and human expectations?

Sghaier Chriki,[†] Marie-Pierre Ellies-Oury,^{‡,||} and Jean-François Hocquette^{||}

[†]ISARA, Agroecology and Environment Unit, Lyon, France

[‡]Bordeaux Sciences Agro, Gradignan, France

^{||}INRAE, University of Clermont Auvergne, Vetagro Sup, UMR Herbivores, Saint-Genès-Champanelle, France

Implications

- We need a holistic, multi-criteria, and independent assessment of the so-called “cultured meat.”
- The balance of all potential arguments in favor or against “cultured meat” is likely to be negative because all arguments from a human or an animal perspective are weak.
- Even the idea that “cultured meat” is a viable alternative to slaughtering animals and is good for animal welfare are still uncertain.

Key words: animal slaughter, animal welfare, cultured muscle fibers, meat

Introduction

The image of meat products has been undermined by some consumer groups due to increasing environmental, ethical, and health concerns. In this context, the relevance of meat substitutes and expectations in terms of labeling (welfare, environmental, or other) has increased. However, it is not certain that these substitutes really live up to consumers’ expectations and are more virtuous than meat in ethical, health, nutritional, or environmental terms (Onwezen et al., 2021). In recent years, alternatives to animal products have evolved and diversified to meet the expectations of certain consumers and could take a significant share of the meat market within a decade.

© Chriki, Ellies-Oury, Hocquette

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial License (<https://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact journals.permissions@oup.com
<https://doi.org/10.1093/af/vfac002>

Among these alternatives, “cultured meat” would, according to its promoters, perform significantly better in a life cycle analysis than meat as reviewed (Chriki and Hocquette, 2020). It is presented as a way to reduce the use and abuse of animals as well as health risks. The technology related to “cultured meat” has been continuously developed and improved and its potential market is expanding rapidly to meet consumer demands according to Zhang et al. (2021).

The aim of this review is, therefore, to take stock of the current knowledge on the benefits of this “cultured meat,” for which the term “meat” does not seem to be relevant. This review will be divided into two parts: the first will describe the “cultured meat” process and its potential benefits and weaknesses for humans, and the second will focus on the potential ethical issues for animals arising from this new technology, based on principles described in the first part.

Process, Potential Benefits, and Weaknesses

a) Is “cultured meat” really meat? What are the legal issues?

The principle of the “cultured meat” process is to produce a large amount of muscle from a few living cells. In practice, a biopsy is taken from a live animal. When cultured, this piece of muscle will liberate stem cells, which have the ability to proliferate and then transform into different types of cells, such as muscle cells and fat cells. Another option is to work with established cell lines, which implies that animals are not needed after an initial biopsy (Figure 1). In both cases, a very important point is the culture medium that should provide the nutrients, hormones, and growth factors necessary for cell proliferation and differentiation in mature tissue. A major potential benefit will, therefore, be to produce huge amounts of muscle from very few animals or even without any animals, therefore avoiding the potential cruelty of slaughter.

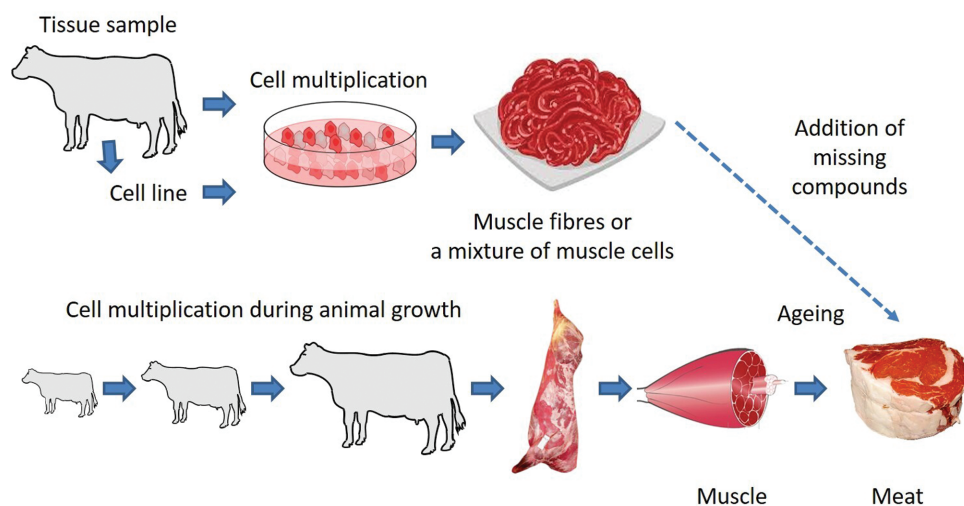


Figure 1. The process of “cultured meat” compared with conventional meat production.

A first important ethical and legal question refers to the nature of the product: is it meat? According to the definition of the American Meat Science Association (Boler and Woerner, 2017), not only for biological or technical reasons but also for semantic and commercial reasons (Ong et al., 2020), “cultured meat” is not really meat. Indeed, meat is defined as “edible tissues from an animal consumed as food” and “to be considered meat, *in vitro* meat must be originally sourced from an animal cell, be inspected and considered safe for consumption, and be comparable in composition and sensory characteristics to meat derived naturally from animals” according to Boler and Woerner (2017). Consequently, according to the authors of this article, the use of the word “meat” has induced an ambiguity favorable to the advocates of “cultured meat,” who are seeking to get rid of the negative aspects associated with meat (environmental degradation and animal suffering), while taking advantage of the positive values of meat for consumers (strength, vitality, healthiness, etc.). In this way, the start-ups have succeeded in imposing the name “meat” for these cultivated muscle fibers into the everyday language. Indeed, the main keywords used in press articles are “meat” and, to a lesser extent, “food” (Chriki et al., 2020).

In the European Union, meat is defined in Annex I of Regulation No. 853/2004 of the European Parliament and the Council as “skeletal muscle of mammalian and avian species recognized as fit for human consumption, with naturally embedded or adhering tissues.” According to the European Commission, meat is formed from different tissues, among them skeletal muscle, bone, connective tissue, blood vessels, adipocytes, or even nerves. Thus, meat industry stakeholders are increasingly trying to ban the use of the term “meat” in the labeling of “cultured meat” products. In addition, it appears that the American legislation is moving toward the recognition of “cultured meat” as “meat” and thus eligible for this designation, but this is not yet decided (Boler and Woerner, 2017).

As long as no genetic modification is involved, the approval of the European Commission on the advice of the European

Food Safety Authority (EFSA) under the Novel Foods Regulation is required before “cultured meat” can be marketed in Europe. The main purpose of this regulation is to ensure that novel foods are safe to eat, which is not fully demonstrated at this stage for “cultured meat.” There is, therefore, a need for them to be correctly labeled (so as not to mislead consumers) and not to be nutritionally disadvantageous compared with the foods they seek to replace. Similar food regulations related to “cultured meat” in other parts of the world are under discussion (Chen et al., 2022). In addition, “cultured meat” products with a genetically modified component are currently unlikely to be approved in Europe due to the heavy restrictions on genetically modified foods already in place and the general poor public perception of this technology.

Finally, unlike America and Oceania, it is very important to remember that the use of hormones is prohibited for meat production in Europe (Directive 96/22/EU; April 29, 1996). Adding exogenous hormones to the hormones naturally present in a growing animal is forbidden in Europe on the grounds of the precautionary principle, even if these man-made hormones are identical to natural hormones. Hence, it can hardly be anticipated that the European legislator would authorize the use of synthetic hormones for the production of “cultured meat.” However, one could consider that things are different since the meat culture is not done on a living animal.

So far, “cultured meat” has only been allowed in Singapore. The regulation of this state clearly indicates that “alternative proteins that do not have a history of being consumed as food will only be allowed for sale after they have been found to be safe for consumption.” To ensure that the safety assessments are rigorously reviewed, the Singapore Safety Agency formed a Novel Food Safety Expert Working Group in March 2020 to provide scientific advice (<https://www.sfa.gov.sg/food-information/risk-at-a-glance/safety-of-alternative-protein>). No food safety concerns were found for the “cultured chicken” produced by Eat Just and it was approved for sale in Singapore in December 2020, as an ingredient in nuggets. However,

although the process was science based, the authorization of “cultured meat” was relatively informal and accelerated in Singapore compared with the process in the EU (as indicated in <http://foodhealthlegal.eu/?p=1081>).

b) Is “cultured meat” really safe?

Produced in a fully controlled environment and without any potential contamination from the digestive organs of neighboring animals, “cultured meat” is presented by its advocates as safer than “conventional meat.” The strategic choice to name this novel food “clean meat” refers to this concept of a sterile product, free from any health hazard (Chriki et al., 2020). Indeed, because the production processes are not comparable between conventional meat and “cultured meat,” and without any potential contamination at slaughter, cultured muscle cells have much less opportunity to encounter intestinal pathogens such as *Shiga* toxin-producing *Escherichia coli*, *Salmonella*, or *Campylobacter*, three pathogens that are responsible for millions of episodes of illness each year (Bonny et al., 2015).

However, as for any innovation, scientists or manufacturers are never in a position to control everything and care should be taken to avoid mistakes, which may lead to negative consequences in terms of health for the consumer (Ong et al., 2021). This occurs frequently nowadays in the industrial production of minced meat (Chriki and Hocquette, 2020). Consumers do worry about the safety of “cultured meat” (Liu et al., 2021) although consumer attitude toward “cultured meat” varies across demographics and cultures (Zhang et al., 2021). A major issue with culturing cells is indeed its potential contamination by pathogenic bacteria, viruses, or fungi (Tomiyama et al., 2020). Regardless of the industry, it is important that Hazard Analysis and Critical Control Points (HACCP) measures are implemented.

Despite many substantial efforts made by farmers to reduce antimicrobial use, antibiotic resistance still remains one of the major problems facing livestock, leading to huge costs (He et al., 2020). According to “cultured meat” advocates, cultured cells are kept in a controlled environment and close monitoring can easily stop any signs of infection by any type of microorganisms such as bacteria. Thus, the majority of “cultured meat” companies have stated that they will not use antibiotics in their process. Nevertheless, if antibiotics are added to prevent contamination, or even occasionally to stop early contamination and disease, this argument is less convincing.

Due to all these uncertainties and the limited scientific literature on the safety of “cultured meat,” some authors such as Ketelings et al. (2021) have highlighted the fact that “the lack of in-depth research related to the hazard and risk characterization of cultured meat is considered to be the biggest barrier in introducing a safe product to the market.”

c) Is “cultured meat” really healthy and tasty?

With a composition similar to “traditional meat,” “cultured meat” can, according to its advocates, meet both the nutritional and sensory preferences of consumers (Lee et al., 2020).

However, it is not clear how close the levels of macro- (such as proteins) and micronutrients and the composition of cultured meat are to those of “traditional meat” (Fraeye et al., 2020). Furthermore, it is well known that dietary ingredients affect the healthiness and flavor of red meat depending on the type of animal diet and, to a large extent, on the species. For instance, increased unsaturation of dietary fatty acids results in a greater flavor change in lamb or beef than in pork. Several dietary ingredients (fish products, raw soybeans, canola oil and meal, pasture grasses, etc.) can cause undesirable flavors in red meat. In general, the type of feed given to farm animals affects the concentration of many volatile flavor compounds (Melton, 1990).

However, various strategies have recently been developed by start-ups, for example, adjusting ingredients (such as polyunsaturated fatty acids) in the production environment to provide more health, taste, and sensory benefits. Highly digestible proteins with optimum concentrations of amino acids or micronutrients (iron, zinc, and vitamin B₁₂) are key issues because these nutrients are also known to be beneficial to human health. According to Fraeye et al. (2020), it is likely that “cultured meat” lacks or is at least deficient in some of them. Conversely, the biomaterial mentioned above could modify the composition of cultured muscle by, for example, providing some specific amino acids that are abundant in collagen and thus reducing the relative contents of essential amino acids (Fraeye et al., 2020). Nevertheless, the sensory quality of “cultured meat” remains to be studied in order to avoid any problem linked to the rancidity of fatty acids. Finally, any ingredient (trace element or micronutrient) added in vitro to “cultured meat” is likely to have reduced nutritional qualities, as it is not provided in its original matrix and, therefore, potentially less absorbed. Indeed, the (artificial) chemical components of the culture medium or the biomaterials of “cultured meat” could have an inhibitory effect on the health benefits of some micronutrients such as iron.

Otherwise, mimicking the appearance, structure, and texture of conventional meat is a major difficulty for start-ups working on “cultured meat.” One of the problems is the pale color of this synthetic product due to the lack of myoglobin, a muscle pigment that is essential for the color of meat, especially for ruminant meat. The first solution consists in modifying the cell culture conditions in order to promote the expression of the myoglobin gene. The second solution is to add the myoglobin produced upstream directly into the medium (Fraeye et al., 2020).

In reality, given the complexity of the biological process, it is difficult to conceive synthesizing muscle fibers whose composition and structure would be close to those observed in vivo. It would be even more unrealistic to imagine being able to reproduce the diversity of meats, for instance, either white or red depending on the species (poultry, pigs, and ruminants), or to reproduce the suitability to grill, roast, or boil depending on the anatomical position of the muscles in living animals. This natural diversity of meats is explained both by the variability in the contents and characteristics of collagenous proteins and intramuscular fats and also by the diversity of muscle fiber metabolism according to animal breeds, species, and muscles.

Reproducing this diversity means, first of all, that researchers are able to carry out co-cultures of the different cell populations that make up the muscle, namely fibroblasts that produce collagen, adipocytes that store intramuscular fat, and myoblasts that transform into muscle fibers, etc. This also implies perfect control of this co-culture to reproduce the diversity of meat types. On the one hand, this is not feasible today, even though start-up scientists are working in this direction. On the other hand, this is not so important since more than half of the meat consumed is in minced form and/or incorporated into processed products which are also booming.

In addition, the second crucial point is that meat results from the *postmortem* transformation of muscle tissue. Indeed, after the slaughter of animals, their muscles contract and become tough (this is a process known as *rigor mortis*). The absence of oxygen leads to the transformation of residual glycogen into lactate, inducing a decrease in pH. During this process, different enzymes are activated and break down the muscle proteins leading to tenderizing of the meat. This is the aging process of the meat, which is well known to every butcher. During this phase, the aromas of the meat develop, also leading to an increase in its flavor, in particular, due to the Maillard reaction between the amino acids and the sugars, which is essentially generated during cooking and which is the origin of different flavor compounds. All these complex phenomena (especially aging) were, initially, not considered by start-ups producing “meat” by cell culture (Fraeye et al., 2020). This is why many ingredients (breadcrumbs, beetroot juice, saffron, egg powder, etc.) were added to the first in vitro “steak” to mimic the sensory quality of meat in terms of taste and color.

d) Is “cultured meat” as environmentally friendly as “conventional meat?”

According to its proponents, “cultured meat” is likely to be environmentally sustainable and supposed to produce less greenhouse gas (GHG) emissions (which is controversial), consume less water, and use less land (this being obvious) compared with “traditional meat production,” especially from ruminants (Lee et al., 2020). However, according to the authors of this article, this type of comparison is incomplete and sometimes biased or at least partial as previously explained (Chriki and Hocquette, 2020) and discussed below.

It is commonly accepted that livestock (especially cattle) are responsible for a significant share of global GHG emissions (14.5%). These GHG emissions, originating from the digestive tract of herbivores (60%), are largely due to not only methane emissions (40%) but also carbon dioxide (CO₂) and nitrous oxide (N₂O) (Gerber et al., 2015). As such, the reduction of methane (CH₄) emissions is presented as one of the most important potential benefits of “cultured meat” compared with conventional livestock farming. However, it is important to add that comparisons are currently contradictory and incomplete because 1) the various life cycle assessments currently available are based on hypothetical data and not really evaluated (as “cultured meat” is not yet produced on an industrial scale) and 2) a comparison based solely on quantitative data (only based

on CO₂ equivalent) is not relevant because we should consider for instance the differences between CH₄ and CO₂. Indeed, in a recent study, Lynch and Pierrehumbert (2019) concluded that global warming would be less with “cultured meat” than with cattle in the short term, but that in the long term, the impact of “cultured meat” would be more deleterious, as CH₄ accumulates less time in the atmosphere than CO₂. It can, therefore, be assumed that the effect of livestock farming on warming will decrease over the years and stabilize, while the warming due to the long-lived CO₂ gas from farmed “meat” will persist. Thus, Lynch and Pierrehumbert (2019) concluded that the potential advantage of cultivated “meat” over livestock in terms of global GHG emissions is not clear.

Regarding water consumption, it is now accepted that the production of 1 kg of beef requires on average 550 liters of freshwater (459 liters per kilogram of pork; 313 liters per kilogram of chicken). As “cultured meat” has been presented by its advocates as consuming about 367 to 521 liters per kilogram, the water footprint can thus be considered similar to that of “conventional” meat (Chriki and Hocquette, 2020).

While it is true that the production of feed for farm animals requires deforestation and the use of 2.5 billion ha of land (i.e., about 50% of the global agricultural area), 1.3 billion ha (of land used for feed production) corresponds to non-arable grasslands that can only be used for livestock (Mottet et al., 2017).

Regarding land, it is obvious that “cultured meat” will need less land than “conventional meat production.” However, this does not mean an advantage for “cultured meat.” Indeed, animal husbandry plays a key role by valorizing flows of non-consumable plant biomass, producing high nutritional value feed from them, and maintaining the carbon content and fertility of soils, as manure from livestock is a source of organic matter, nitrogen, and phosphorus. Land use is a distorted and unfair comparison between “cultured meat” and conventional meat. Indeed, in this type of comparison, the authors do not take into account the diversity of environmental services and impacts of livestock farming systems (not only GHG emissions and water use but also carbon storage and plant and animal biodiversity). Furthermore, to reduce and even avoid deforestation for the production of feed for farm animals, revising livestock farming systems using the principles of agroecology should be encouraged (Dumont et al., 2020).

Issues regarding Animal Welfare

a) Is “cultured meat” really produced without slaughtering animals?

The main potential benefit of “cultured meat” is theoretically to produce huge amounts of muscle from a small number of animal cells, either from farm animals or from cell lines, which proliferate in giant incubators. Thus, this process is likely to use much fewer animals to produce a lot of meat.

Based on these arguments, some authors indicate that the production of “cultured meat” would be more “animal-friendly,” as conventional meat may be considered “cruel” to

animals by some consumers (Ong et al., 2020). Some animal advocates would thus be able to accept the concept of “cultured meat” or even describe this product as “victimless meat,” “cruelty-free meat,” or “slaughter-free meat” (Chriki et al., 2020). Communication through the “animal welfare” argument thus seems to be an alternative that is favorable to the development, appropriation, and acceptability of “cultured meat” by consumers (Rolland et al., 2020).

Despite the potential to dramatically reduce animal use, there are a number of animal ethics-based objections to the development of “cultured meat.”

The first objection is that, when the process is based on biopsies from living animals to extract stem cells, some animals will still be needed. The living conditions of these animals should be questioned because they will be regularly subjected to biopsies to provide stem cells continuously (Figure 2). Therefore, specific welfare issues will appear for these animals. Some people may have moral problems with this process of regular biopsies as they did with genetic modifications of livestock. The selection of donor animals and the details of biopsy processes must be optimized, as this is a key bottleneck in the “cultured meat” production process (Melzener et al., 2021).

The development of pluripotent stem cell lines from livestock species has seen progress in recent years with a view to avoiding regular sampling of living animals and by working with immortal cell lines with infinite proliferative capacity. The starting cell lines can come from 1) a recently slaughtered animal from which the muscle satellite cells would be isolated or 2) an embryo or umbilical cord from which the embryonic stem cells and mesenchymal stem cells would be isolated, respectively (Ketelings et al., 2021). This implies genetic engineering techniques that will target the genes involved in proliferation. This also requires genetic modification for the cells to be able to differentiate into the desired tissue. From a theoretical point of view, this will avoid using animals. However, further evaluation is required to screen the (unexpected) effects of different cell reprogramming approaches on cell phenotype and biological functions. Many of these approaches have not been explored in livestock species (Reiss et al., 2021).

Whichever the starting point, the cell culture process requires the use of a growth medium rich in suitable nutrients for cell proliferation and differentiation. One of the most commonly

used components at present is fetal bovine serum (used by Post to produce the first cultured burger and more recently used by Eat Just to produce “cultured nuggets” in Singapore). This is taken from the fetus of pregnant cows at slaughter. Thus, there appears to be a need to 1) maintain farm animals to allow for the development of the production of fetal bovine serum and 2) slaughter pregnant cows to allow for the collection of this serum. Many companies have committed to eliminating the use of fetal bovine serum in their “cultured meat” production (Chen et al., 2022), and some have reported that they have already done so. These fetal bovine serum-free media would be based on 1) microbial fermentations to synthesize recombinant growth proteins or 2) nonanimal extracts (e.g., developing proteins and amino acids derived from plant hydrolysates). However, at the present time, we do not have any details on the artificial serum likely to replace fetal bovine serum that will probably not be considered as natural by consumers.

Otherwise, one of the difficulties in this “meat culture” process is to determine the exact concentrations of each component of the serum, which must be suitable for each type of cell or at least be well adapted to each stage of cell development. So, for example, the needs of a myoblast or a mature muscle fiber are not the same in terms of hormones and growth factors. In addition, for co-cultures of several cell populations, it will be difficult to find the most suitable medium for both cell populations at the same time. The fetal bovine serum has the advantage of enabling the efficient culture of a large number of cell types. However, in the case of a synthetic medium, for maximum efficiency, and above all, to minimize the costs of its ingredients which will be manufactured upstream, it will be necessary to seek the optimum compositions of these media according to the type of cells (Post and Hocquette, 2017).

b) What will be the future of animals if we do not need them?

At this stage, it is important to add that if livestock were to be replaced by cells producing “cultured meat,” a number of ecosystem services (i.e., the beneficial impacts of livestock) as well as production of byproducts from farm animals (hide, blood, and viscera) would be lost (Dumont et al., 2020). Indeed, inedible fats are used as raw material for the generation of biodiesel, and protein hydrolysis generates added-value products (i.e., bioactive peptides) with relevant applications in food, feed, health, pharmaceuticals, and cosmetics.

Moreover, there are still a large number of small family farms that depend on livestock for their survival, particularly in developing countries, and it is likely that the development of “cultured meat” by FoodTech companies would jeopardize the economic and food survival of these farmers.

In the long term, we would need technical strategies to reduce the number of farm animal numbers in case of “cultured meat” success. According to the authors of this article, this is likely to be a controversial problem and likely to reduce animal biodiversity. Indeed, a drastic reduction in the number of farm animals may not be without consequences for animal biodiversity because potentially less breeds and less genotypes would survive within each animal species.

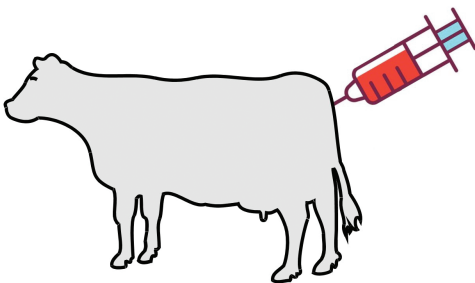


Figure 2. Are regular biopsies good for animal welfare?

c) What is the future for meat?

A key narrative in social networks such as Twitter is the shift toward ethical or sustainable livestock systems. From a food system perspective, consumers would rather agree with a future with less meat than with no meat (Maye et al., 2021). However, the authors point out that the number of tweets is not necessarily a good indicator of sentiment. It is likely that discussions on Twitter will only become more important when they are more developed as viable alternatives and, therefore, more represented in other online and offline media. As the use of Twitter and social media continues to grow and is used to promote particular discourses and interests, these media are likely to play a role in the future in articulating and amplifying public concerns. “Cultured meat,” “lab-grown meat,” “in vitro meat,” and “humane meat” are all names that the average consumer is probably not very familiar with. The benefits of this technique have attracted the interest of many citizens because of its potential to solve the issues of animal cruelty and environmental problems that can sometimes be seen in conventional agriculture (Webster and Talarczyk, 2021). Because of this reduced use of farm animals throughout the process, this fake meat seems to be more readily acceptable than conventional meat, by vegetarians

and vegans (Chauvet, 2018). The reduction in cruelty in the case of “cultured meat” seems to appeal to these consumers, as it requires little interaction with the animals through cell collection (Webster and Talarczyk, 2021).

However, generally speaking, meat products should meet the definition of sustainable food products based on the (FAO, 2010; FAO and WHO, 2019) definition of a sustainable diet. With “cultured meat,” it is not yet the case, at least, because the product is still expensive and its healthiness, safety, and low environmental impacts are still a matter of controversy as described above. The product may be also perceived as not natural (Figure 3). Furthermore, while it is advertised as a solution to solve animal ethical issues, it brings with it new ethical issues for both animals and humans (Table 1). Religious authorities are also debating on whether “cultured meat” is Kosher (i.e., compliant with Jewish dietary laws), Halal (i.e., compliant with Islamic laws), or what to do if there are no more animals available for ritual practices (a concern for Hindu consumers). However, this debate seems to be less present or absent in Christianity (Chriki and Hocquette, 2020).

In any case, the potential benefits of cultured meat should be compared with the potential benefits of other solutions such as other new technologies including meat from genetically modified livestock or improving our current livestock systems in the direction of agroecology to take advantage of the potential benefits of natural ecosystems. On the consumer side, reducing food waste and loss would not only make more food available to satisfy the increasing human population but also reduce the carbon footprint associated with food production and consumption. Finally, shifting our consumption habits to the healthiest and most environmentally friendly diets will be a win-win strategy.

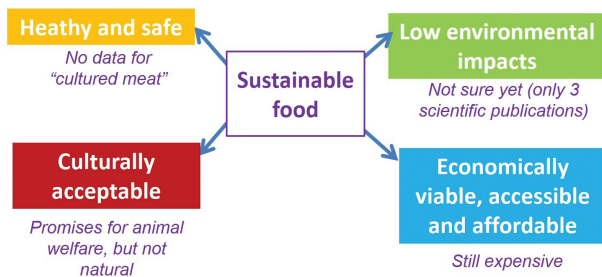


Figure 3. Does “cultured meat” meet the definition of a sustainable food product? The four branches of sustainable food are based on the definition of sustainable diets by FAO (2010).

Conclusion

This review shows that the “cultured meat” strategy cannot be analyzed solely through animal welfare criteria.

Table 1. Some potential weaknesses and advantages associated with “cultured meat”

Questions related to:	Ethical and other societal issues
The technology	Is there any potential ethical drift in this new technology? For instance, are there any unpredictable genetic modifications in these meat cells, especially when using cell lines?
Farm animals	The number of slaughtered animals may be reduced. What will be the life and the future of the remaining farm animals? These animals will be biopsied regularly and this raises new welfare issues. Alternatively, if cell lines are used, farm animals will no longer be needed. At least for a transition period, the number of farm animals should be decreased by slaughtering them and/or limiting their reproduction. Animal biodiversity will be reduced with fewer farm animals.
Environment	Emissions of GHG emissions are hypothesized to be lower but this has to be confirmed (in addition, CH ₄ emissions will probably be replaced by CO ₂ emissions). What will be the future of pastures, agriculture, landscapes, and the countryside with fewer farm animals? This will be associated with a decline in plant biodiversity, rural life, etc...
Farmers	What will be the future of farmers, especially in poor and developed countries if there are fewer farm animals?
The agro-food system	Vegan people may have access to animal proteins, thanks to “cultured meat.” How and by whom will our food production be managed and controlled? Do we want FoodTech companies to manage the production and quality of our food instead of local farmers? What will be the potential benefits and weaknesses of this potential major change?

There are different considerations to be analyzed together. The first point is that we may still need animal products (especially fetal bovine serum) for the culture process, despite the proliferation of muscle cells to produce a large amount of “meat” from fewer animals. Indeed, the first “cultured meat” currently marketed in Singapore is produced using fetal bovine serum, despite ongoing research to find another solution. The second point is that “cultured meat” technology is not mature enough to ensure the production of real meat. Only muscle fibers (similar to minced meat) are produced. Consequently, we should not call it “meat.” The third point is that only a few studies related to its environmental impact have been published so far in peer-reviewed scientific journals, with no unanimity on this point. In addition, there is a lack of knowledge of the real environmental impact of livestock with a lot of misunderstanding in the public media, particularly. Therefore, claims that “cultured meat” will be more environmentally friendly than conventional meat are not robust enough. The fourth point is that, because the technology is still in its infancy, it is impossible to prove that it will generate safe, healthy, and tasty products. Indeed, no nutritional data are available. Safety is subject to controversy based on various either positive or negative hypotheses. Taste has not been studied using rigorous approaches and is highly dependent on the ingredients added at the end of the process. Positive claims about the potential benefits of “cultured meat” are driven by private companies motivated by financial gain or by activists motivated by animal welfare or environmental issues. As a result, the current debate is more emotional than rational and unfortunately, in the public media, not based on sound and objective scientific arguments. To be brief, all the alleged benefits of “cultured meat” should be confirmed as they are not yet demonstrated. The accumulation of several potential benefits may not convince the scientific community that “cultured meat” is the best way forward because scientists rely more on facts than on hypotheses. Even the claim that “cultured meat” will avoid slaughtering so many animals is not so simple. Even if it is true, it raises other complex issues, which will need to be explored before deciding on the ethical status of this new technology.

Dr Marie-Pierre Ellies-Oury is a Professor in Animal Science at the National Higher School of Agronomy called Bordeaux Sciences Agro. She is also an associate scientist at INRAE in the Ruminant Unit (Biomarkers team). She studies the sensorial and nutritional quality of meat, bovine carcass quality, muscle biology, and consumer expectations related to beef quality.



Dr Jean-François Hocquette is a scientist at INRAE (a public research institute working for the coherent and sustainable development of agriculture, food, and the environment) studying muscle biology, genomics, and consumer expectations related to beef eating quality. He was the leader of the “Muscle Growth and Metabolism” research team (1999–2006) and the Herbivore Research Unit (172 people, 2006–2010). He was also a member of the French High Council for Evaluation of Research and Higher Education. He works for the International Meat Research 3G Foundation

and the European Federation of Animal Science (EAAP). He is the editor of the French Meat R&D journal and several books. He has been awarded by the French Meat Academy and received the 2014 Animal Growth and Development Award and the 2021 Meats Award from the ASAS (American Society of Animal Science). He will organize the World Congress of Animal Science in Lyon in 2023 as the President of the French Association for Animal Production.

Together, S.C., M.-P.E.-O., and J.-F.H. coordinated in 2020 the scientific handbook entitled: *Livestock for agro-ecology and sustainable food*, which is recently published by France Agricole Editions: https://www.editions-france-agricole.fr/site/gfaed/AGRO_gfaed.4464.42722_/fr/boutique/produit.html.

About the Authors



Dr Sghaier Chriki is a Professor in Animal Science at the Higher School of Agronomy called Isara. He is a biochemist and has a PhD in “Nutrition and Food Sciences.” In the last 10 yr, his research has been particularly focused on meat quality and consumer expectations related to beef quality. He also deals with consumer attitudes and potential acceptance toward “cultured meat.” **Corresponding author:** schriki@isara.fr

Literature Cited

- Boler, D.D., and D.R. Woerner. 2017. What is meat? A perspective from the American Meat Science Association. *Anim. Front.* 7:8–11. doi:[10.2527/af.2017.0436](https://doi.org/10.2527/af.2017.0436)
- Bonny, S.P.F., G.E. Gardner, D.W. Pethick, and J.-F. Hocquette. 2015. What is artificial meat and what does it mean for the future of the meat industry? *J. Integr. Agric.* 14:255–263. doi:[10.1016/S2095-3119\(14\)60888-1](https://doi.org/10.1016/S2095-3119(14)60888-1)
- Chauvet, D.J. 2018. Should cultured meat be refused in the name of animal dignity? *Ethic. Theory Moral Pract.* 21:387–411. doi:[10.1007/s10677-018-9888-4](https://doi.org/10.1007/s10677-018-9888-4)
- Chen, L., D. Guttieres, A. Koenigsberg, P.W. Barone, A.J. Sinskey, and S.L. Springs. 2022. Large-scale cultured meat production: trends, challenges and promising biomanufacturing technologies. *Biomaterials* 280:121274. doi:[10.1016/j.biomaterials.2021.121274](https://doi.org/10.1016/j.biomaterials.2021.121274)
- Chriki, S., M.P. Ellies-Oury, D. Fournier, J. Liu, and J.F. Hocquette. 2020. Analysis of scientific and press articles related to cultured meat for a better understanding of its perception. *Front. Psychol.* 11:1845. doi:[10.3389/fpsyg.2020.01845](https://doi.org/10.3389/fpsyg.2020.01845)

- Chriki, S., and J.F. Hocquette. 2020. The myth of cultured meat: a review. *Front. Nutr.* 7:7. doi:10.3389/fnut.2020.00007
- Dumont, B., P. Modernel, M. Benoit, A. Ruggia, P. Soca, S. Dernat, H. Tournadre, S. Dogliotti, and W.A.H. Rossing. 2020. Mobilizing ecological processes for herbivore production: farmers and researchers learning together. *Front. Sustain. Food Syst.* 4:544828. doi:10.3389/fsufs.2020.544828
- FAO. 2010. Dietary guidelines and sustainability. Food Agric. Organ. U. N. Available from <http://www.fao.org/nutrition/education/food-dietary-guidelines/background/sustainable-dietary-guidelines/en/> [accessed February 1, 2022].
- FAO and WHO. 2019. Sustainable healthy diets – guiding principles. Rome (Italy): FAO. Available from <http://www.fao.org/3/ca6640en/CA6640EN.pdf> [accessed September 27, 2021].
- Fraeye, I., M. Kratka, H. Vandeburgh, and L. Thorrez. 2020. Sensorial and nutritional aspects of cultured meat in comparison to traditional meat: much to be inferred. *Front. Nutr.* 7:35. doi:10.3389/fnut.2020.00035
- Gerber, P.J., A. Mottet, C.I. Opio, A. Falcucci, and F. Teillard. 2015. Environmental impacts of beef production: review of challenges and perspectives for durability. *Meat Sci.* 109:2–12. doi:10.1016/j.meatsci.2015.05.013
- He, Y., Q. Yuan, J. Mathieu, L. Stadler, N. Senehi, R. Sun, and P.J.J. Alvarez. 2020. Antibiotic resistance genes from livestock waste: occurrence, dissemination, and treatment. *NPJ Clean Water* 3:1–11. doi:10.1038/s41545-020-0051-0
- Ketelings, L., S. Kremers, and A. de Boer. 2021. The barriers and drivers of a safe market introduction of cultured meat: a qualitative study. *Food Control* 130:108299. doi:10.1016/j.foodcont.2021.108299
- Lee, H.J., H.I. Yong, M. Kim, Y.-S. Choi, and C. Jo. 2020. Status of meat alternatives and their potential role in the future meat market – a review. *Asian-Australas. J. Anim. Sci.* 33:1533–1543. doi:10.5713/ajas.20.0419
- Liu, J., É. Hocquette, M.-P. Ellies-Oury, S. Chriki, and J.-F. Hocquette. 2021. Chinese consumers' attitudes and potential acceptance toward artificial meat. *Foods* 10:353. doi:10.3390/foods10020353
- Lynch, J., and R. Pierrehumbert. 2019. Climate impacts of cultured meat and beef cattle. *Front. Sustain. Food Syst.* 3:1–11. doi:10.3389/fsufs.2019.00005
- Maye, D., J. Fellenor, C. Potter, J. Urquhart, and J. Barnett. 2021. What's the beef?: debating meat, matters of concern and the emergence of online issue publics. *J. Rural Stud.* 84:134–146. doi:10.1016/j.jrurstud.2021.03.008
- Melton, S.L. 1990. Effects of feeds on flavor of red meat: a review. *J. Anim. Sci.* 68:4421–4435. doi:10.2527/1990.68124421x
- Melzener, L., K.E. Verzijden, A.J. Buijs, M.J. Post, and J.E. Flack. 2021. Cultured beef: from small biopsy to substantial quantity. *J. Sci. Food Agric.* 101:7–14. doi:10.1002/jsfa.10663
- Mottet, A., C. De Haan, A. Falcucci, G. Tempio, C. Opio, and P. Gerber. 2017. Livestock: on our plates or eating at our table? A new analysis of the feed/food debate. *Glob. Food Secur.* 14:1–8. doi:10.1016/j.gfs.2017.01.001
- Ong, S., D. Choudhury, and M.W. Naing. 2020. Cell-based meat: current ambiguities with nomenclature. *Trends Food Sci. Technol.* 102:223–231. doi:10.1016/j.tifs.2020.02.010
- Ong, K.J., J. Johnston, I. Datar, V. Sewalt, D. Holmes, and J.A. Shatkin. 2021. Food safety considerations and research priorities for the cultured meat and seafood industry. *Compr. Rev. Food Sci. Food Saf.* 20:5421–5448. doi:10.1111/1541-4337.12853
- Onwezen, M.C., E.P. Bouwman, M.J. Reinders, and H. Dagevos. 2021. A systematic review on consumer acceptance of alternative proteins: pulses, algae, insects, plant-based meat alternatives, and cultured meat. *Appetite* 159:105058. doi:10.1016/j.appet.2020.105058
- Post, M.J., and J.-F. Hocquette. 2017. Chapter 16 – New sources of animal proteins: cultured meat. In: Purslow P.P., editor. *New aspects of meat quality*. Cambridge (MA): Woodhead Publishing, p. 425–441. doi:10.1016/B978-0-08-100593-4.00017-5
- Reiss, J., S. Robertson, and M. Suzuki. 2021. Cell sources for cultivated meat: applications and considerations throughout the production workflow. *Int. J. Mol. Sci.* 22:7513. doi:10.3390/ijms22147513
- Rolland, N.C.M., C.R. Markus, and M.J. Post. 2020. The effect of information content on acceptance of cultured meat in a tasting context. *PLoS One* 15:e0231176. doi:10.1371/journal.pone.0231176
- Tomiyama, A.J., N.S. Kawecki, D.L. Rosenfeld, J.A. Jay, D. Rajagopal, and A.C. Rowat. 2020. Bridging the gap between the science of cultured meat and public perceptions. *Trends Food Sci. Technol.* 104:144–152. doi:10.1016/j.tifs.2020.07.019
- Webster, J., and P. Talarczyk. 2021. Public perceptions of cultured meat pseudonyms. *J. Stud. Res.* 10:1–12. doi:10.47611/jsrshs.v10i2.1788
- Zhang, L., Y. Hu, I. H. Badar, X. Xia, B. Kong, and Q. Chen. 2021. Prospects of artificial meat: Opportunities and challenges around consumer acceptance. *Trends Food Sci. Technol.* 116:434–444. doi:10.1016/j.tifs.2021.07.010