



Is *in vitro* meat the solution for the future?

Jean-François Hocquette^{a,b,*}

^a INRA, UMR1213, Recherches sur les Herbivores, Theix, 63122, Saint-Genès-Champanelle, France

^b Clermont Université, VetAgro Sup, UMR1213, Recherches sur les Herbivores, 63122 Saint Genès Champanelle, France



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ABSTRACT

The production of *in vitro* meat regularly generates media interest because of the contribution it could, at first glance, make to the issue of feeding humankind while also protecting the environment and respecting animals. However, the majority of experts considers that there are still numerous technological obstacles that have to be overcome to produce *in vitro* meat. In addition, even if *in vitro* meat could eliminate the supposed lack of well-being of livestock and has the potential to free up cultivable land, other supposed advantages are questionable and not always agreed upon by the scientific community. However, another major problem for the commercialisation of *in vitro* meat would be its acceptance by consumers, even if some consumers are ready to taste it at least once. In particular, the artificial nature of the product goes against the growing demand for natural products in many countries. The consumption of *in vitro* meat will depend on a conflict of values at an individual or collective level. The reality is that a range of other complementary solutions already exist which meet the challenges of food supply in our society, but which are less saleable to the media.

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1. Introduction

The gathering or the production of food for human consumption has constantly evolved during history in order to meet the needs of humankind. The major stages in this evolution are well-known: while the first men were hunter-gatherers, the sedentarisation and the development of technology for farming livestock and crops changed the organisation of human societies and their way of life (Patou-Mathis, 2009). The regular increase in the human population has always been a source of concern about how to meet the food requirements of the population both in terms of quantity and quality so that the needs, particularly human physiological needs, are met. Agricultural and animal husbandry techniques were then modernised with a significant use of fertiliser and/or crop protection products and more technical complexity (irrigation, mechanisation, etc.) leading to a significant increase in crop and livestock yields (Vinnari and Tapio, 2009).

Today, we are again at a strategic crossroads owing to the co-occurrence of several factors: (i) a rapid, spectacular and unprecedented increase in the human population who need to be fed, (ii) a significant urbanisation of humans further and further away from a rural culture and contact with livestock, (iii) questions or new social expectations concerning for example the welfare and life of animals as well as the protection of our increasingly-threatened environment and consequences on human health of too high meat consumption (Vinnari and Tapio, 2009; Wu et al., 2014; Mathijs, 2015). The proposed solutions

for meeting these new challenges abound, which is indicative of the growing awareness of our citizens of the necessity of changing our dietary habits. But the proliferation of ideas which are more or less realistic can also be interpreted as a symptom of growing concern.

Among the meat substitutes to develop in light of these challenges is artificial meat from cultured cells and especially from stem cells (reviewed by Moritz et al., 2015). This technique was first described years ago, but has only recently been highly publicised when a cultured beef hamburger was tasted on August 5, 2013 in London (<http://culturedbeef.net/event/>, Post, 2014). From that point, artificial meat from stem cells has been considered by the media as a new type of meat with a great potential because, in theory, we can produce huge amounts of meat due to the tremendous potential of stem cells to multiply themselves. Consequently, compared to traditional meat, we would need far fewer farm animals (almost none) to produce huge quantities of cultured meat which would be supposed to solve the above mentioned problems: producing enough meat to feed the increasing human population, lowering carbon footprint from livestock, and reducing the need to breed and kill so many animals.

There is abundant information in the press and also in the scientific literature about the proposition to produce artificial meat. A symposium on artificial meat production was organised on October 18, 19 and 20, 2015 (<http://culturedbeef.net/about-the-symposium/>). The “*In vitro* meat cookbook” (van Mensvoort and Grievink, 2014) was launched in 2014 and suggests a wide range of new products from cultured meat. This article intends to review the possibility of cultured meat production in the future based on the recent literature. The first section of the article will present the key factors in meat consumption in human history until today including the driving forces behind the current interest in

* INRA, UMR1213, Recherches sur les Herbivores, Theix, 63122, Saint-Genès-Champanelle, France.

E-mail address: jfhocquette@clermont.inra.fr.

artificial meat. The second and third sections of the article will present the most up to date information, respectively, on the technical questions and on the ethical questions raised by the production of artificial meat. Finally, the advantages and drawbacks of artificial meat will be discussed compared with other alternative solutions which may be able to meet the challenges of food supply in our society.

2. Meat consumption in human history and current challenges

2.1. The development of key factors in meat consumption

Human beings are omnivores and, as such, have a long history of consuming meat among other types of food. The first human beings were scavengers and/or hunters (Speth, 1989), since their digestive systems were well equipped to make full use of animal foods, whereas herbivores have the specialised organs to digest cellulose. Consequently, it is well known that eating meat from herbivores is an efficient way for human beings to indirectly make the most of plants, grass and any type of natural pasture since the latter cannot use these natural sources of food. It has been shown that our pre-human ancestors were eating meat as early as 1.5 million years ago (Dominguez-Rodrigo et al., 2012). Since then, humanity has consumed meat from different types of animals and meat consumption is part of our culture. Since about 1–9% of human beings are vegetarians in many developed countries and 40% in India (Ruby, 2012), we can say that a large majority of the human population eat meat regularly or occasionally. Eating meat is often seen as a pleasure (Polkinghorne et al., 2008). In summary, humanity used to and still relies on meat.

Throughout history, the main problem for humanity has been to ensure enough food (mainly energy and proteins) and thus enough meat to satisfy nutritional needs. This has been the main driver of meat consumption. However, food in the same manner as language, beliefs, religion, lifestyle, etc. is one of the constituent elements of a culture and identity of social groups. In fact, groups of humans and civilisations build their identity, in particular, through their food customs by affirming their differences compared to other groups or cultures, which allows them to grow together and continue (reviewed by Font-i-Furnols and Guerrero, 2014 and Laisney, 2013). For example, the Japanese have a diet based on fish and in some African countries insects are eaten which is viewed negatively in the Western world. Therefore, cultural factors are also important drivers of meat consumption.

The primary social difference for food is usually linked to the standard of living of consumers and is therefore of a financial nature which nowadays has to do with purchasing power. Historically, meat consumption was, for a long time, reserved for wealthier social groups as meat was considered a rare product (at the beginning of human history, hunting was a difficult activity) and expensive (compared with plant products). During the last fifty years, meat consumption has increased a lot driven by economic development of many countries (Sans and Combris, 2015). Today, the democratisation of meat products (accessible to most) has led to an inversion of preferences in many developed countries such as France: the higher social classes consume less meat and have a tendency to prefer lamb and poultry while the least wealthy social classes continue to prefer beef and cured meats (Laisney, 2013). When different countries are compared, meat consumption differs among countries for similar degrees of economic development suggesting that historical, geographical, cultural and/or religious factors are also implicated in consumers' choices (Sans and Combris, 2015).

Following economic development in the developed countries, it is generally considered that the nutritional needs of populations are, on average, satisfied. On the basis of the hierarchy of needs according to Maslow (1943), five fundamental needs (or groups of needs) have been identified, and when a group of needs is satisfied, another will progressively take its place according to the following hierarchical order: physiological needs > safety needs > needs for belonging and

love > need for esteem > need for self-actualisation. Maslow's hierarchy of needs is a theory in psychology proposed by Abraham Maslow in his 1943 paper "A Theory of Human Motivation" in Psychological Review. Thus, according to this theory, it is logical to observe that when the physiological and nutritional needs have been, on average, satisfied, the other needs become progressively more important, in particular the safety needs (which includes for food products, the absence of health risks). Safety is indeed a very important issue for animal products (reviewed by Hocquette et al., 2005). The needs for love, esteem and self-actualisation (which includes in particular a commitment to noble causes such as the welfare of animals and protection of the environment) become important after safety. Therefore, in the future, the influence of income of consumers and of price of beef is likely to decline over time so that other factors will become more important (Henchion et al., 2014).

The FAO has published that the livestock sector is an important contributor to climate change (Steinfeld et al., 2006; Gerber et al., 2013), which is a major issue of our society. In industrialised countries, the highest preferences for meatless meals are observed in the most highly-educated people (Hoek et al., 2011), who are those who understand more easily the challenges for society and these people also belong to the wealthiest social classes (Rimal, 2002). The dissemination of eating habits from the top of the social ladder towards the bottom both for financial and moral reasons is therefore a driver for change in food practices. There are two mechanisms in this dissemination: the wealthier classes want to stand out by consuming the rarest products which conform to their ideals, and which are therefore more expensive, while the other social classes want to imitate the wealthiest. Other mechanisms are added to that such as, for example, economic constraints (crises, general lowering of buying power) and generational effects (younger generations also consume less meat in order to satisfy the ideals of animal and environmental protection) (reviewed by Laisney, 2013 and Ruby, 2012).

As a consequence of all these profound developments, the main factors which currently affect meat purchases and consumption are, in addition to sensory factors (mainly colour, tenderness, and flavour), psychological factors (including cultural factors and lifestyle), guarantees of hygiene and safety, as well as marketing factors such as price, brand, and labels based on origin, safety, local production and ethical production (reviewed by Hocquette et al. (2013a); Font-i-Furnols and Guerrero, 2014). Among psychological factors, moral issues relating to carbon footprint (Scolan et al., 2011) and animal welfare (De Backer and Hudders, 2015) are more and more important. Flexitarians (person whose diet is mostly vegetarian but sometimes includes meat, fish, or poultry) are more and more numerous but have different moral drivers than vegetarians: they are more concerned about animal welfare than full-time meat eaters but less concerned than vegetarians (De Backer and Hudders, 2015).

To summarise, our modern society needs to provide animal products (or substitutes to animal products) which are safe, affordable, and have a lower environmental footprint, while still meeting consumer and citizen demands for product quality and animal welfare. However, attributes are not of equal value to all consumers, which should favour consumer segmentation and production differentiation (Henchion et al., 2014).

2.2. The driving forces in the trend for artificial meat

Proponents of artificial meat have taken into account in their communication strategy all the social elements which determine nowadays the relationship of consumers to meat.

First of all, the communication campaign in favour of artificial meat plays on the new social drivers which tend to reduce the consumption of meat from animals (the necessity to improve human health, animal welfare and environmental protection). In fact, the producers of artificial meat propose a meat which, because artificial, has potentially an

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