Chapter 19

The future of cultured meat between sustainability expectations and socio-economic challenges

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1 Introduction

In August 2013, the first cultured beef burger was presented to the London press by Professor Mark Post. This appeared as a fantasy fulfilled, some decades after Churchill (1932) prediction: "…Fifty years hence, we shall escape the absurdity of growing a whole chicken to eat the breast or wing, by growing these parts separately under a suitable medium…".[a] Nevertheless, as for any disruptive innovation, a plethora of doubts and questions has quickly replaced the incipient enthusiasm.

Cultured meat[b] production refers to the practice of using muscle-specific stem cells taken from a living animal, growing sufficient numbers of cells in a nutrient serum, and then letting them differentiate into muscle tissue via bioreactors (Post, 2014). The growing social implications concerning animal welfare and environmental sustainability (Jairath et al., 2021; Salter and Lopez-Viso, 2021; Sanchez-Sabate and Sabaté, 2019) are elements fostering the acceptance of cultured meat, accelerating its technical development. Furthermore, in the light of food security analysis, clean meat seems to provide a sure protein source coping with an increasing worldwide population and protein demand (Bryant, 2020; Fernandes et al., 2021; Jairath et al., 2021). On the other side, low as well as medium-income countries, often net meat exporters towards peers and higher-income states, could be negatively influenced by the cultured meat entry as it would make the conventional meat demand weaker on the international market. Middle and high-income countries might feature economic disruptions as well, especially in terms of inequality between rural and urban spaces. As noted by some authors (e.g., Newton and Blaustein-Rejto, 2021; Rubio et al., 2020), the upscaling of this alternative meat system may alter within-country equilibria, with industrialized and highly-skilled regions up-taking the majority of production facilities, damaging the livelihood and income levels of rural territories, which traditionally rely on animal farming (Bryant, 2020; Treich, 2021). Furthermore, given the high entry investment and the increasing economies of scale of cultured meat production, the not-yet-born supply chain seems already suffering from unbalanced bargaining power, with big agri-food industrial players driving the whole sector.

As of today, cultured meat is not available on the market, but it could be soon in Singapore as the Singapore Food Agency approved it for sale. The Guardian[c] hailed such a decision "as a landmark moment across the meat industry".

In other countries worldwide, regulators are assessing cultured meat for its potential market entry (Bryant, 2020; Post et al., 2020). In the US, the USDA and FDA opened the discussion in July 2020 concerning their roles and responsibilities for cultivated meat regulation; in India, the government has been funding research in cellular agriculture intending to make the country a hub for alternative proteins production; whereas, on the EU side, the Commission referred to alternative protein sources as potential contributors to deliver a climate-neutral European food system by 2050 (Kurrer and Lawrie, 2018) and funded a cultured meat research program under the European Union's Horizon 2020 framework. As for now, however, no request for authorization of lab-grown meat production has been presented for approval to the European Food Safety Authority (EFSA) stance.[d]

a. See Fernandes et al. (2020) and Jairath et al. (2021) for a chronological journey through the development of the cultured meat.

b. Several names are used for cultured meat in the literature: lab-grown meat, in vitro meat, cell-based meat, artificial meat, synthetic meat, clean meat, etc. (see also Section 5). They are used alternatively in this chapter.

c. https://www.theguardian.com/environment/2020/dec/02/no-kill-lab-grown-meat-to-go-on-sale-for-first-time.

d. https://gfi.org/cultivated-meat-regulation/.

Future Foods. https://doi.org/10.1016/B978-0-323-91001-9.00024-4

In recent years, literature on cultured meat has rapidly grown (Fernandes et al., 2020, 2021; Treich, 2021), analyzing each time particular facets. With no claim to be exhaustive, this chapter aims to offer a review of the most debated issues, from the environmental benefits and consumers' perception to some less analyzed sides, like legislation, nomenclature, and some expected supply chain impacts which may derive from the scaling up of cultured meat production. A critical assessment of the available literature will be provided as well. The technology and engineering of cultured meat are out of the scope of this chapter.

2 Positive externalities of cultured meat

The present section describes the most recent findings achieved by the scientists in evaluating the potential impacts of such disruptive innovation on the environment, animal welfare, food safety, and security.

2.1 Environmental benefits

The mainstreamed claims regarding the environmental performance of cultured meat concern less Greenhouse Gas (hereafter GHG) emissions, which is also the main controversial point, and to be more resource-parsimonious, especially regarding water and land uses when compared to the conventional meat production process (Chriki and Hocquette, 2020; Lynch and Pierrehumbert, 2019; Santo et al., 2020; Stephens et al., 2018).

Scientific studies well document how livestock, especially ruminants such as cattle, are responsible for a large share of the air pollution: methane CH_4, the most potent GHG, and nitrous oxide N_2O, both directly produced by manure and the enteric fermentation in ruminants, and carbon dioxide CO_2, indirectly produced by the land converted to pasture or feed production. Advocates of cultured meat suggest that lower emissions per unit of meat will result from bypassing biological processes, eliminating CH_4 and N_2O emissions, while CO_2 will remain due to energy used for cell culturing (i.e., the warming phase of cells). However, many unknowns remain related to large-scale lab-grown meat production (Mattick et al., 2015a,b; Tuomisto et al., 2014; Tuomisto and Teixeira De Mattos, 2011).

The major share of the investigations concerning the environmental implications of cultured meat production relies on the Life Cycle Assessment (LCA) methodology, with some results suggesting the carbon footprint of cultured meat even higher than conventional meat (Mattick et al., 2015a,b; Tuomisto et al., 2014; Tuomisto and Teixeira De Mattos, 2011). Other findings show a parsimonious GHG footprint for cultured compared to conventional beef production, while the opposite is true in regards to conventional poultry and pig production systems (Santo et al., 2020; Stephens et al., 2018).

Tuomisto and Teixeira De Mattos (2011) compare cultured to conventional beef, pork, sheep, and poultry meat production systems, finding a very promising reduction of GHG emissions (in the range of 78%–96%), land (99%), water (82%–96%), and energy (7%–45%) use by the former (exception made for the poultry production in terms of energy use). More recently, by assuming a different medium and including a cleaning phase, Mattick et al. (2015a,b) find significantly higher energy consumption for the lab-grown meat when compared to conventional pork and poultry production systems; nevertheless, when conventional beef production is concerned, the lab-grown meat results more parsimonious. However, results are again controversial, with studies concluding on a significantly higher amount of energy required by cultured meat production compared to any conventional meat production scenario (4 times higher than poultry) (Alexander et al., 2017).

Comparing the whole production process (i.e., "cradle-to-plate") of lab-grown meat with other meat systems (i.e., dairy-based, mycoprotein-based, plant-based, and conventional poultry sector), the energy requirements make the in-vitro meat the least environmentally-friendly system, albeit eliciting positive impacts on land and freshwater ecotoxicity (Smetana et al., 2015). Nonetheless, if one considers the potential impact on global warming of conventional and lab-meat production systems, the advantages of the latter in terms of GHG emissions may not be that obvious. Lynch and Pierrehumbert (2019) spot a relevant drawback in previous studies regarding the comparison method: based on CO_2e (carbon dioxide equivalent), which relates different GHG pollutants to CO_2, conclusions seem flawed by the fact that different gases "differ both in the amount they change the atmospheric energy balance (radiative forcing) and […] how long they persist in the atmosphere" (Lynch and Pierrehumbert, 2019, p.2). Indeed, carbon dioxide persists for millennials in the atmosphere, contrary to methane and nitrous dioxide, which last about 12 and 100 years, respectively. In light of this, the cumulative nature of CO_2 emissions has not been captured, leading to an overestimation of the warming impact of short-living gases as methane, which constitutes a significant portion of the conventional beef production system. Lynch and Pierrehumbert (2019) thus offer new insights on the issue, shading light on the climate impacts of switching from farmed to laboratory meat. Relying upon an atmospheric model and three consumption pathways to 1000 years,[e] the footprints of four different cultured meat production systems retrieved from the current literature (Mattick et al., 2015a,b; Tuomisto et al., 2014; Tuomisto and Teixeira De Mattos, 2011) are tested. The authors conclude that cultured meat is not the most sustainable alternative to the farmed meat: even for the most optimistic scenario, lab-grown hamburgers would compete with the conventional beef in terms of CO_2 in the long term, while avoiding completely other gas emissions (representing a climate advantage of the cultured meat). However, one has to recall the four cultured meat footprints used in the study are merely speculative since no real data on emissions produced by cultured meat plants is available. Moreover, several steps and ingredients in the processing of lab-grown meat are left out of the impact assessment, conveying a potentially biased estimation. This is also true for the current conventional meat production paradigm: for instance, the biodiversity loss due to the deforestation stemming from the livestock sector expansion, groundwater pollution, and eutrophication are side effects that have to be included in the overall assessment (Santo et al., 2020). That is to say, the by-products of both systems should be entirely analyzed. This is particularly true when relying upon the LCA method, massively applied by scholars when studying and comparing the environmental impact of lab-grown meat.

Concerning the use of land, in vitro meat would reasonably spare surfaces currently devoted to livestock, especially for pastures and feed production, and increase carbon sequestration (Albanito et al., 2016). On the other hand, the maintenance of soil fertility and soil carbon content is a positive externality generated by livestock activities (e.g., manure generates organic matter, nitrogen, and phosphorus). Moreover, of the approximately 2.5 billion ha devoted to livestock production, more than one-half is non-arable land, hence "useable" just for livestock (for further details, see Mottet et al., 2017). Thus, since these estimated unsuitable 1.3 billion hectares could not serve other destinations, reducing consumption and production of farmed meat would not necessarily increase the offer of land. Moreover, ruminants can convert non-edible plants into protein, reinforcing protein security, albeit the grain-fed system, which represents the vast majority of the current livestock production management, requires more inputs (for feed production) than plant foods for the same amount of protein and calories (Marlow et al., 2009; Santo et al., 2020; Wilkinson, 2011). Hence, a major criticism is neglecting positive externalities, such as eco-system services, the livestock activity generates (Martin et al., 2020; Ryschawy et al., 2019).

Other findings suggest a lower land footprint for cultured meat than conventional beef, although similar to poultry. However, it is also emphasized how, in terms of land use, results widely vary, mainly depending on inputs choice for cultured meat and feedstocks. Indeed, the cultured meat production system will use land to produce inputs, mainly to provide energy or nutrients to the cell medium. Whereas blue-green algae and hydrolysate would result in smaller land requirements, soy and corn-derived inputs would result in a similar amount of land as conventional poultry livestock, considering the protein content (Santo et al., 2020).

Concerning water use, a recent study raises an interesting and yet controversial point (Chriki and Hocquette, 2020): so far, the comparison between the lab and farmed meat relied on the assumption that 1 kg of conventional beef needs 1500 L of water when recent studies firmly estimate a water need within the range of 550–700 L (95% of such water requirements are devoted to crops and forages for animal feeding), inflating the advantage of cultured meat production. Some concerns over the water contamination are raised by the authors since chemical waste and spillage from cultured meat factories may contaminate the environment via water discharges of meat incubators. However, they eventually infer that such circumstances are unlikely to happen in a highly controlled production environment. Concerning the blue water footprint (i.e., the amount of freshwater from ground or surface sources used for the production process), all but the conventional pig meat production system results in using less water than cultured meat (Santo et al., 2020). In the same study, it is claimed that eutrophication would be just slightly lower for the in vitro meat compared to conventional poultry production when based on soy and corn-derived inputs. However, such eutrophication drawback would be limited by using cyanobacteria instead of corn and soy inputs, hence the nitrogen-fixing species. The same conclusions are drawn when referred to pesticides: if land and inputs used for in-vitro meat and poultry system are similar, the same applies to pesticides.

Hence, depending on the inputs used, the environmental consequences are different, and conclusions are still speculative, given the yet undisclosed technology. All in all, cultured meat seems to bring in more negligible environmental impacts when referred to beef and (to a lesser extent) pork, but not when conventional poultry and plant-based produce are concerned.

While some scholars (e.g., Hocquette, 2016) argue that an improved conventional cattle production system may bring environmental results similar to cultured meat production, some others (Dolgin, 2019; Pieper et al., 2020; Rubio et al.,

e. Scenario 1: very high and constant levels of meat consumption; Scenario 2: high consumption levels for the first 100 years followed by an exponential decline; and Scenario 3: a starting rate of meat consumption equal to the current situation, followed by an exponential increase of both consumption and population reaching a peak after 100 years for exponential decline afterward, shrinking to 75% of current consumption. See the cited research for further details.

2020; Singh et al., 2020) recently fueled skepticism over the higher environmental performance of organic livestock management. They also criticize some environmental impact projections concerning cultured meat production by arguing that their theoretical basis is biased by lacking information on large-scale processes that have not been validated by the industry yet. Therefore, the environmental assessment related to cultured meat production needs more data, particularly related to material inputs and the industrial-scale production schemes. More generally, they call for a detailed LCA of in-vitro meat plants and more transparent assessments of potential environmental benefits, since these can be null, as witnessed by higher energy demand, higher blue water footprint, and even higher GHG footprint than conventional meat production systems. They argue against cultured meat as an environmental panacea (Chriki and Hocquette, 2020; Lynch and Pierrehumbert, 2019; Santo et al., 2020; Stephens et al., 2018), suggesting a non-impartial nature of environmental studies so far, with the bulk of scientific research around the topic often funded by cell-based meat companies (Santo et al., 2020).

Finally, neither societal nor scientific consensus is being reached concerning the cultured meat's impact on natural resources and environmental contamination, calling for independent and less conjectural assumptions.

2.2 Animal welfare

Animal suffering in farming activities has been "normalized" for a long time, interpreted as necessary to prevent behavioral and economic problems, especially in high-density livestock (e.g., piglets castration) (Heidemann et al., 2020; Lundmark et al., 2014; Mancini et al., 2018). Recently, society has shown an increasing awareness regarding animal welfare, with cultured meat labeled as "victimless meat" because of its potential to avoid or at least tremendously reduce animal slaughtering (Bhat et al., 2015).

Cell-based meat has the potential of uncoupling slaughtering and meat production. It would modify the longstanding relationship between humans and animals, domesticating cells rather than animals, and it would prevent animal suffering and slaughtering, causing none to minor disruptions in meat consumption patterns and volumes (Heidemann et al., 2020). Cultured meat enthusiasts claim that this product will completely detach animal deaths from meat production (Heidemann et al., 2020) and represent an appealing option for "vegans, vegetarians and to those conscientious omnivores interested in reducing their meat intake on ethical grounds" (Bryant et al., 2019; Jairath et al., 2021, p.705). Cultured meat would represent a solution to animal welfare issues not only in industrial and intensive systems but in small, organic and pasture-based farms (Chriki and Hocquette, 2020; Santo et al., 2020).

For producing in vitro meat, a biopsy is needed to collect the muscle cells from the animal. What represents a very problematic facet of this novel food is that the fetal bovine serum is still often used as cell growth medium (hereafter FBS), collected during the animal slaughtering (Chauvet, 2018; Heidemann et al., 2020). The Canadian Council on Animal Care[f] grades the biopsy on animals as minor stress or short-lasting pain (Reis et al., 2020a), suggesting an improvement regarding animal welfare. However, so far, no comprehensive animal welfare assessment has been conducted regarding animals biopsy for the cultured meat environment (Santo et al., 2020). Concerning the inputs used in the cultured meat production process, many still relate to animals: the FBS as a growth supplement for cell and tissue culture, scaffolds used to grow muscle tissues, and hydrogels of animal nature used to obtain near-natural tissue (Stephens et al., 2018). Indeed, albeit FBS is a 'natural' by-product of the meat industry since bovine heads are not slaughtered to produce FBS only, this would imply the cell-based meat industry relying on the farmed meat, weakening the claimed advantages regarding animal welfare. To this extent, more empirical investigations are crucial to compare the number of animals involved in both the cultured and conventional systems (Santo et al., 2020).

Nonetheless, FBS-free growth media already exist (Zhang et al., 2020), but their cost is still prohibitive (Santo et al., 2020; Thorrez and Vandenburgh, 2019). Indeed, the OECD recently published a guide for good in vitro method practices, encouraging animal-free serum media or even serum-free media alternatives (OECD, 2018). However, for the complete removal of animals from the cultured meat supply chain, technological challenges are yet to be solved, especially concerning the source of animal cell line and the inputs entering the process (Bhat et al., 2019; Kadim et al., 2015; Santo et al., 2020).

It has also been pointed out that, despite a dramatic decrease in the number of slaughtered heads (Schaefer and Savulescu, 2014), the average animal welfare may decrease due to competitiveness issues: indeed, the remaining conventional meat farmers might want to compete on price, intensifying their agricultural activity to be more cost-efficient and lower the price, with negative consequences on the animal welfare, environmental and public health (Heidemann et al., 2020; Tubb and Seba, 2019).

f. http://www.ccac.ca/Documents/Standards/Policies/Categories_of_invasiveness.pdf (access date: 21-01-2021).

By considering animal welfare in a broader context, some authors (Newton and Blaustein-Rejto, 2021; Rubio et al., 2020) suggest that cultured meat would bring in some opportunities and positive externalities; indeed, the genetic diversity would be even more preserved than nowadays, as conventional meat may turn into a niche and high-priced market, whereas others (Jairath et al., 2021; Treich, 2021) alert on the potential loss of animal genetic resources.

2.3 Food safety

As much as meat provides humans with a valuable amount of micronutrients and proteins, western dietary habits, too high in animal produces, are significantly related to deadly diseases (e.g., heart diseases, diabetes type 2, strokes, cancers, cardiovascular diseases) (Godfray et al., 2018; Lam et al., 2019; Pan et al., 2012). Moreover, bacterial pathogens such as Salmonella, Listeria, Campylobacter, and *Escherichia coli*, even though not exclusively related to meat production, originate from animal guts and can enter the food chain via diverse channels (e.g., contamination of water sources, manure transportation, meat contamination via animals' severed digestive tracts, among others) (Santo et al., 2020; Solomon et al., 2002; Waters et al., 2011). Antibiotic-resistant pathogens also represent a serious and significant concern in the meat industry (Haskell et al., 2018; Santo et al., 2020).

Due to avoiding contact with other digestive organs during the slaughtering process, cultivated meat is claimed to be safer than conventional meat (Bonny et al., 2015; Shapiro, 2018). The highly controlled environment would make outbreaks very unlikely to occur, avoid costly vaccinations, and reduce antibiotics use (Chriki and Hocquette, 2020). However, as far as the cultured meat process does not involve any carcass, reducing the potential for contamination, a fully sterile process environment is impossible to achieve, hence antibiotics may be used as inputs for the medium to curb the growth of bacterial pathogens. Albeit the quantity and quality of such antibiotics are unknown yet, the quantity will be much smaller than that of conventional meat (Heidemann et al., 2020).

Moreover, whereas food workers in conventional meat production are exposed to foodborne illness at the workplace (one out of four workers suffers from some respiratory illness) (Santo et al., 2020), the production environment of cultured meat would allow for a null risk of zoonotic diseases, due to the absence of pathogens. This would lead to reduced health-related costs: bacterial diseases would be avoided, hence reducing financial pressure on the public health systems and shrinking costs related to monitoring, prevention, and treatment of the meat product during the production process (Chriki and Hocquette, 2020; Heidemann et al., 2020). However, this is yet conjectural since the lab-specific code of practice, and the overall regulatory landscape, are yet to be disclosed.

Cultured meat is commercially unavailable, and little can be inferred on its nutritional aspects: quality and composition of proteins, amino acids, vitamins, minerals, fatty acids, and compounds, such as taurine and creatine, are unknown. However, the composition of cultured meat will be customizable by controlling the ratio of saturated/unsaturated fatty acids (substituting saturated with, for example, omega-3) aimed at reducing the risk of high cholesterol (Chriki and Hocquette, 2020; Heidemann et al., 2020), and by adding some functional ingredients and components (Bhat et al., 2019; Post, 2012; Santo et al., 2020) aimed at enhancing the nutritional value of the product and decreasing the risk of rancidity of the product (Chriki and Hocquette, 2020; Heidemann et al., 2020). Finally, it is not clear whether cultured meat will be provided with those micronutrients specific to animal products; hence, health benefits deriving from micronutrients may be reduced depending on the composition of the culture medium. In this regard, the potential addition of chemicals to the medium would result in a "chemical" meat (Chriki and Hocquette, 2020), with potential negative consequences on consumer acceptance. Indeed, as much as cultured meat has been portrayed as "healthier, safer, and disease-free" (Santo et al., 2020), dysregulation of cell lines may happen (as in cancer cells), with unknown effects on human health (Chriki and Hocquette, 2020; Hocquette, 2016). All in all, health benefits are yet purely conjectural (Santo et al., 2020).

2.4 Food security

Whereas the envisaged increase in protein demand (Singh et al., 2019) would put further stress and criticism on the environmental consequences of livestock farming, besides involving an agricultural sector that has already reached its maximum capacity (FAO, 2018), the fully controlled production environment for lab-grown meat has the potential of positively impacting food security. Indeed, area-depending factors such as land quality and availability and climate would not be of concern anymore, and more significant shares of the global population might have access to protein sources (Jairath et al., 2021). Cultured meat would reduce the inputs per kilogram of product and is likely to increase the number of people fed from the agricultural land base (Heidemann et al., 2020; Röös et al., 2017). Indeed, as a single cell line may be sufficient to feed the world, cultured meat would provide communities with a potent instrument for enriching global food security (Bhat et al., 2015).

Significant socio-economic effects are expected worldwide. However, studies are mainly speculative yet, with no empirical applications mimicking the impacts of lab-grown meat on the agricultural sector. Jairath et al. (2021) and Treich (2021) suggest that cultured meat may entail negative consequences on developing countries' agricultural sector; indeed, nearly 30% of developing countries' agricultural GDP originates from livestock (World Bank, 2009), constituting the economic backbone of many states via food, employment, income, and even transportation provisioning (FAO, 2012). Fig. 1 shows an overview of the geographical distribution of cultured meat start-ups and companies involved in cultured meat research & development so far, as well as the main data related to the present global conventional bovine production and trade system and consumption.

As one may quickly notice, the largest bovine meat exporters, Argentina or Brazil, or significant producers as Pakistan or Mexico, which can be categorized as medium and low-income countries, respectively, do not yet feature any initiative on cultured meat; on the other hand, Israel and Norway – whose impact on the global trade is negligible but embed highly-skilled workforce, financial resources, and advanced infrastructures, show to be interested in joining what may become a new lucrative production sector. Therefore, if, on the one hand, cultured meat may be a some-kind-of panacea for food insecurity by (potentially) producing proteins land and environmental resources needless, on the other hand, it is likely to reduce meat exports from developing and middle-income countries, harming the economic sustainability of farmers rearing animals for meat production (Jairath et al., 2021). However, the geographical expansion of cultured meat may bring in some benefits to developing countries as well, such as enhancing high-tech skills in employees (Godfray et al., 2019).

To the best of the authors' knowledge, there is a paucity of empirical works in this regard, and no empirical assessment is available estimating the potential impact on food security. Indeed, given that the price of cultured meat is not yet disclosed, little can be said about its affordability by the low-income population or the government's capacity to produce it domestically.

Anyhow, the most profitable activities concerning cultured meat design and production are likely to take place in developed countries, where staunch energy infrastructures and the supply of highly educated employees with specific skill sets are available (Rubio et al., 2020; Treich, 2021). Therefore, international policy instruments need to be applied to dilute the negative effects on developing countries, particularly in the light of previously established preferential meat trade agreements. However, this appears to be a non-trivial and exceptionally sensible policy process.

3 The potential impact of cultured meat on conventional meat supply chains

Since the proof of concept provided in 2013, the number of food industry professionals, entrepreneurs, and investors involved in artificial meat has dramatically risen. Thirty-two in vitro meat companies are listed nowadays, of which one-fourth focuses on beef production, 22% on cultured poultry, and pork and seafood represent 19% each (the residual companies are investing in mouse for pet food, kangaroo and horse cultured meat). North America is the cradle of these companies, hosting 40%, followed by Asia (31%), and Europe (25%), and, for the period 2015–2020, 320 million dollars have been (at least those publicly disclosed) invested in the business of which 75% destined to the beef and pork production.[g] Public funding is also on the rise, with India, Singapore, Japan, Belgium, and the EU already funding some cultured meat-related initiatives (Choudhury et al., 2020). The development of this new industry would ultimately create further market opportunities within the chain, boosting intermediate input industries such as suppliers/producers of cell culture media, growth factors, generators of cell lines, cell manufactures, and fats as ingredients for the cultured meat (Choudhury et al., 2020). However, despite the presence of start-ups engaged in these new food products, cell-based meat is primarily funded by venture-capital-backed companies, sometimes receiving investment from large meat processing companies (e.g., the US-based Tyson Foods that invested in the Beyond Meat)[h] (Santo et al., 2020). Indeed, as recalled by Bryant (2020) and Treich (2021), worries are relevant when the market structure is discussed. Companies producing cultured meat need sturdy investments for covering high entry costs and constant or even increasing returns to scale (Rubio et al., 2020; Treich, 2021) and skilled workers that (already) multinationals catalyze. In such a scenario, the hypothetical supply chain will suffer from power concentration from the very beginning, with few producers able to pressuring suppliers, consumers, and driving industrialization.

g. According to Choudhury et al. (2020), the companies interested in cultured meat are: Atemys Foods, Balletic Foods, Just, New Age Meats, Wild Type, Because Animals, Fork & Goode); Canada (Seafuture); Europe (Macanta Meats, higher Steaks, Biotech Foods, GOURMEY, Peace of Meat, Innocent Meat, Mosa Meat, Meatable); Asia (BioFood Systems, Future Meat technologies, Mea Tech, Aleph Farms, SuperMeat, ArtMeat, Clear Meat, Shiok Meats, IntegriCulture, Avant Meats, VOW). See also Fig. 1.

h. https://www.beyondmeat.com/whats-new/why-i-am-welcoming-tyson-foods-as-an-investor-to-beyond-meat/.

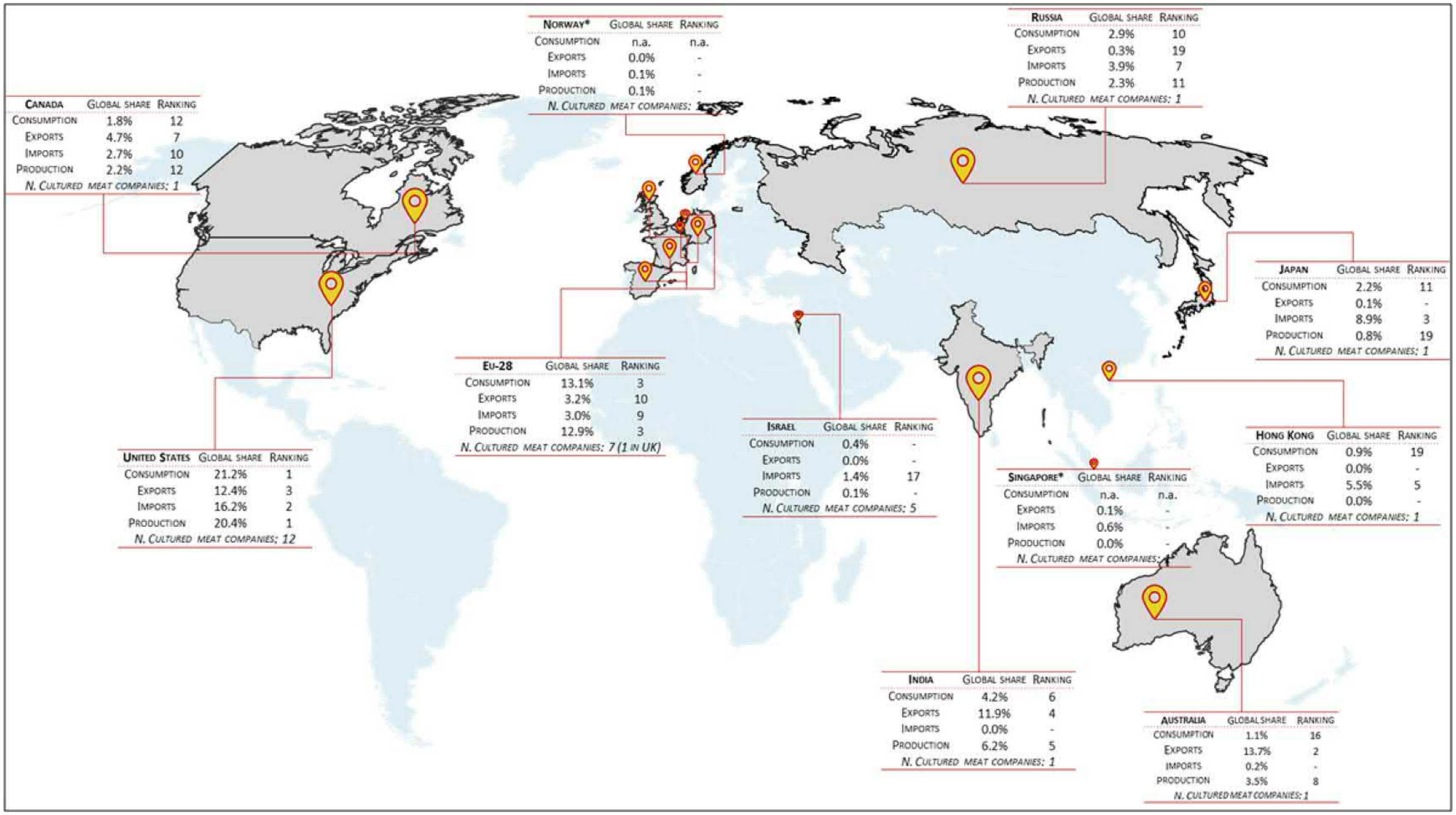

FIG. 1 Start-ups and companies involved in cultured meat R&D versus current conventional bovine meat production, trade, and consumption statistics, 2020. *(Source: Authors' elaboration on USDA data, 2020; *Data retrieved from FAOSTAT, last available year 2018.)*

Thus, the governance of cultured meat value chain represents the first challenge for the future of agri-food systems. In answering the question “who would benefit from the scale-up of cultured meat?”, some scholars (van der Weele and Driessen, 2013; van der Weele and Tramper, 2014) see opportunities for small businesses on the line of micro-brewery labs, while some others (Stephens et al., 2018) cast doubts on such hypothesis questioning the ability of small agribusinesses to collect governmental subsidies and gain access to highly technical information to produce cultured meat, especially after tremendous (private) financial capital investments in such technology. Therefore, large-scale and multinational groups might witness a further increase in their bargaining power along food chains (van der Weele and Driessen, 2013). Indeed, given the location of the majority of start-ups in industrialized countries, scaling up cultured meat production might further enhance the disparity North-South (Hocquette, 2016; Mouat and Prince, 2018; Reis et al., 2020a; Santo et al., 2020).

Relying on the Global Value Chain (GVC) perspective,[i] cultured meat is classified as disruptive innovation, and its value chain is expected to be vertically integrated (Reis et al., 2020a). This is the case of the partnership between Impossible Foods and Burger King in the US market. The former, a US plant-based producer, directly supplies the fast-food chain by vertically integrating some commercial activities such as packaging and distribution, thus bypassing large multinational companies.[j] Further examples are offered by the same fast-food chain that is purchasing a plant-based production plant from Marfrig to supply the Brazilian market,[k] or by Future Meat Technologies, the Israeli start-up, claiming to be developing a new manufacturing and distribution model, consisting in producing and marketing starter packs (i.e., starter tissues) grown in farms equipped with infrastructures able to produce the cultured meat.[l] This, in turn, would be sold to meat processing companies or directly to the point of sale.

The current envisaged industrial strategy, entailing vertical integration, is mainly taking place in developed countries, while protein demand growth is related to emerging developing countries (Godfray et al., 2019; Reis et al., 2020a). Thus, the authors speculate that the current multinational business models might be extended to the cultured meat value chain, with the research and development of the product, design, marketing, and services to be concentrated in developed countries, while low-adding activities in emerging ones, i.e., the production phase (Reis et al., 2020a).

The scaling up of cultured meat production might negatively impact the conventionally farmed meat value chains in developed countries too. Indeed, the EU GDP relies on around 4% in agriculture and food production, whose impact on employment is even higher, about 8%, and primarily concentrated in less advantaged and marginal rural areas (Kurrer and Lawrie, 2018). Therefore, the potential upscaling of cultured meat production may affect both employment and agricultural income in such areas, enhancing their marginal character as well as the rate of abandoned land, exacerbating inequalities between and within countries (Bryant, 2020; Hocquette, 2016; Stephens et al., 2018).

Farmers’ concerns also involve the potential upscaling of in vitro production that might result in high price competitive meat (Bonny et al., 2017; Chriki and Hocquette, 2020). On the other hand, if alternative meats became price competitive or even less expensive than farmed meat, farmed meat could stand as a premium-priced product since alternative meats would substitute lower quality meats, such as burgers (Bonny et al., 2015, 2017). Potential synergies between conventional meat and alternative protein sources may arise to the extent that the two categories of products might meet different consumers targets (Godfray et al., 2019; Newton and Blaustein-Rejto, 2021; Rubio et al., 2020; Treich, 2021). Thus, the eventual success of cultured meat may translate into a transformation rather than the extinction of conventional meat production. As suggested by Newton and Blaustein-Rejto (2021), Rubio et al. (2020), and Treich (2021), low-quality meat might be supplied with clean meat, while demand for higher quality meat would be satisfied by conventional producers, with the latter being of small-scale and more sustainable nature. They also suggest potential blending between conventional and alternative meat products.

Godfray et al. (2019) speculate that the next decade will witness the upscaling of cultured meat marketing, from niche to mainstream market, but excluding low-income countries, and focusing just on middle and high-income environments (Hocquette, 2016; Stephens et al., 2018). They also hinge on a scenario where cultured meat remains a niche market for a specific consumer segment. In the authors’ opinion, the significant investment of major food companies in alternative meat production start-ups would make the latter scenario less likely to occur. Indeed, the participation of big food

i. Kaplinsky and Morris (2000) developed a generally accepted definition for Value Chain: “The value chain describes the full range of activities, which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), to delivery to final consumers, and final disposal after use” (Kaplinsky and Morris, 2000; p. 4). A value chain is global when its activities and tasks are performed and coordinated within different countries of the world.

j. https://www.theguardian.com/business/2019/apr/02/burger-king-vegan-whopper-meat-free-impossible-launch.

k. https://www.reuters.com/article/us-marfrig-product-launch/burger-king-to-roll-out-marfrig-veggie-burgers-nationwide-in-brazil-in-nov-idUSKCN1VO1JM.

l. https://techcrunch.com/2019/10/10/lab-grown-meat-could-be-on-store-shelves-by-2022-thanks-to-future-meat-technologies/?guccounter=1.

multinationals and a further improvement in the taste and texture of these alternative products would pave the way for future expansion into the mass consumption markets of high income countries. They also suggest how governments may accelerate cultured meat development and marketing: the (yet potential and speculative) health and environmental benefits related to cultured meat might induce fiscal exemptions and smooth regulations (as occurred with solar power back in the 90s and 00s) (Godfray et al., 2019; Reis et al., 2020a; Santo et al., 2020; Stephens et al., 2018).

Some other major challenges involve further scientific explorations to reduce the cost of the growth media, for now reaching up to 80% of the total production costs (Choudhury et al., 2020); replace the FBS, which downgrades the acceptance of this new food, with an animal-free medium for mass production; produce suitable scaffolds for the scaling-up of the industry (Choudhury et al., 2020; Reis et al., 2020a; Santo et al., 2020). Also, focusing on product differentiation, i.e., figuring out how to produce high-quality cuts, might be crucial for market acceptance (Chriki and Hocquette, 2020).

Although agricultural inputs will be still required for the cell-based meat production, the volumes would be much lower, resulting in a significant release of farmworkers, from farmers to veterinarians and meat processors (Bonny et al., 2015; Godfray et al., 2019; Mouat and Prince, 2018; Santo et al., 2020; Stephens et al., 2018). Thus, in vitro meat production in urban environments would depress rural economies and accelerate the loss of rural populations. On the other hand, new jobs might be created and workers with diverse skill sets might enter the food chain, as chemists, engineers, biologists, and factory and warehouse employees. This might boost urban job creation, increasing the demand for skilled jobs and developing the knowledge economy (Chriki and Hocquette, 2020; Stephens et al., 2018; Tubb and Seba, 2019). The economic impact of cultured meat upsurge would reverberate over other related sectors, such as vaccines and therapeutic substances. All in all, policy implications might be significant, from food safety, production, and marketing (labeling) to farmers' welfare (Godfray et al., 2019; Santo et al., 2020). Remarkably, the feedstock industry, if conventional meat production reduced substantially, would undoubtedly suffer unless it re-shaped production into alternative meat products inputs.

As much as Rubio et al. (2020) warn about too many lacking details, from inputs to industrial-scale production schemes, before production costs to be assessed reliably, it is reasonable to expect a supply chain driven by large multinational processors, given the prohibitive entry investment level and the need for economies of scale for being competitive. This calls for high levels of policy interventions in many if not all aspects—consumption, production technology, farmer support, and employment transition—to avoid any breach in the production process, guarantee a safe product for the consumer, and an independent and public-driven scientific research.

In the EU context, Kurrer and Lawrie (2018) advocate for policy intervention easing the transition of farmers from animal farming to growing crops for both human or biofuel purposes, besides clear-cut policies for correct and non-misleading labeling for cultured meat products so that differences are signaled to consumers and cultured meat sold as a separate product from conventional meat. Support should be provided to farmers keeping the animal farming, maintaining genetic diversity, and supplying highly differentiated meat products. Moreover, training might be provided to farmworkers willing to work in the newborne meat environment, and effective support should be offered in the transition phase towards different agriculture-related activities. Although these represent naïve and non-exhaustive examples, they aim to deliver the message of the pivotal role of policies in smoothing and easing the transition towards new consumption and production methods. Once (and whether) proved the environmental and health benefits of cultured meat, EU policymakers might be particularly interested in its wide application in the light of the upcoming EU Green Deal and the Common Agricultural Policy.

4 Consumer perception of cultured meat

Some topics - such as consumer perception—have been quite widely analyzed by the literature.[m] The first investigations were conducted in North America, a country where current livestock production problems and the benefits of cultured meat are themes that have been commonly discussed by the media over the last decade (Goodwin and Shoulders, 2013). Online reactions to news concerning cultured meat reveal that while environmental and public health motivations resonate within some segments of the population, other segments mostly reject them, especially when the unnaturalness of the product negatively prevails. Nevertheless, it is acknowledged that the tone of the news itself impacts the readers' opinions (Laestadius, 2015; Laestadius and Caldwell, 2015).

m. For a comprehensive review of consumers' perception and acceptance, refer to Bryant and Barnett (2018, 2020).

The analysis on the EU consumers blossomed from 2015 on. Typical consumers' objections to cultured meat relate to either personal or societal concerns. The former relates to safety issues (Hocquette, 2016; Laestadius and Caldwell, 2015; Siegrist et al., 2018; Siegrist and Sütterlin, 2017; Verbeke et al., 2015a), the nutritional value and the taste, texture, and appearance of cultured meat (Bekker et al., 2017a; Laestadius and Caldwell, 2015; Tucker, 2014; Verbeke et al., 2015a,b; Wilks and Phillips, 2017). The latter mainly pertains to the end of the present agricultural model, distrust in the companies producing cultured meat, and the energy required for production (Bekker et al., 2017a; Laestadius and Caldwell, 2015; Tucker, 2014; Verbeke et al., 2015a,b; Wilks and Phillips, 2017). Some findings suggest more in-depth investigations are required for a better understanding consumers' profiles (van der Weele and Driessen, 2019). The positive perception of cultured meat is mainly related to animal welfare and environmental sustainability (Bryant and Barnett, 2018; Mancini and Antonioli, 2019, 2020a) and, although with lower frequency, to food security and safety (Laestadius, 2015; Mancini and Antonioli, 2019).

Cell-based meat is often associated with GMOs, as both technologies evoke a sense of unfamiliarity (Verbeke et al., 2015a), leading to a lack of trust (Siegrist and Sütterlin, 2017), uncertainty, and concerns over potential adverse long-term consequences (Marcu et al., 2015; Siegrist and Sütterlin, 2017). Many studies compare cultured meat and the other alternative protein sources, the former proving to be more appealing than insect proteins (Circus and Robison, 2019; Dupont and Fiebelkorn, 2020; Gómez-Luciano et al., 2019) but less familiar than plant-based meat, which is already available on the market (Bryant et al., 2019; Circus and Robison, 2019).

4.1 The role of information

An essential element related to consumer acceptance is information provisioning, as shown by empirical analyses concluding that the higher the consumers' familiarity with cultured meat, the higher their acceptance rate (Bekker et al., 2017a; Mancini and Antonioli, 2020b; Verbeke et al., 2015a). Information, particularly regarding the environmental benefits, results in being an essential medium to address Belgians positive perception towards cultured meat (Verbeke et al., 2015b). In fact, the unfamiliar can be turned into the familiar by choosing informational themes, selecting the wording, and the most suitable metaphors to influence consumers' opinion (Marcu et al., 2015). Some authors report a significantly higher acceptance rate when participants are given a non-technical rather than a technical description of cultured meat (Bryant and Dillard, 2019; Siegrist et al., 2018). However, information can change the explicit attitude, i.e., the evaluation constructed through the cognitive elaboration of available information (Gawronski and Bodenhausen, 2006) towards the unfamiliar object, that is cultured meat, in the direction of the valence of the information (Bekker et al., 2017b).

According to some studies, there is no significant difference in consumers' attitudes between frames that emphasize personal rather than societal benefits (Bryant and Dillard, 2019; Rolland et al., 2020). On the other hand, significant differences are found when social or personal benefits are described versus technological and scientific ones: a frame highlighting societal or personal benefits leads to significantly more positive perceptions than those highlighting the technological/scientific aspects of cultured meat (Bryant and Dillard, 2019).

Familiarity with cultured meat, that is the amount of previous information a person may have when he or she is invited to take part in the survey, results in a possible predictor of cultured meat acceptance (Mancini and Antonioli, 2019; Weinrich et al., 2019) and it is sometimes found to be the most vital driver of acceptance (Weinrich et al., 2019).

Nevertheless, solving the "information deficit" may result insufficient to overcome the aversion to novel technologies applied to food production (Faccio and Fovino, 2019; Wilks et al., 2019).

Indeed, Baum et al. (2021) found that information had a major impact on explicit attitudes and purchasing evaluations but not on implicit attitudes (Baum et al., 2021). To overcome the inefficacy of providing information on implicit attitudes, they proposed to analyze the consumers' attitudes by showing images of the product and exploring their reactions.

It is a matter of fact that the social representation of meat in different food cultures has impacted the acceptance of the product over time (Bekker et al., 2017a; Chiles, 2013); thus it is likely that the transmission of identities and ideologies through food will influence the future meat market (Fernandes et al., 2021). Therefore, for years to come, consumer research will have a crucial avenue in exploring to what extent the consumers' beliefs are effectively influenced by information and which characteristics of cultured meat need approaches other than information provision to face psychological barriers, such as distrust and fear (Mancini and Antonioli, 2020b; Wilks et al., 2021).

4.2 The socio-demographic factors

Different attitudes are associated with cultured meat acceptance in EU countries. In 2005, the European Commission asked European citizens whether they approved producing meat from cell cultures. Although the range of answers varied across countries, in 19 out of 25 countries, at least one in two did not support this practice (Eurobarometer, 2005), whereas a more recent study by Surveygoo in 2018[n] finds higher acceptance in the USA than in the UK.

Many surveys have been conducted in very recent years, but inconsistency in research questions, sampling methods, and descriptions of cultured meat make the results not fully comparable. In Italy, for instance, one survey focused on the acceptance of intrinsic attributes versus positive externalities of cultured meat (Mancini and Antonioli, 2019). It is found that people generally agree with the positive externalities of cultured meat (i.e., the improvement of animal welfare, the protection of the environment, and food security enhancement) but show lower appreciation for its intrinsic characteristics (i.e., safety, taste, and nutrition) (Mancini and Antonioli, 2019).

A cross-country survey analyzed the acceptance of cultured meat in a sample of older community-dwelling adults (i.e., older than 65 years) in five European countries. The highest acceptance is found in the Netherlands, a slightly lower acceptance in Finland, the UK, and Spain, and a very much lower acceptance in Poland (Grasso et al., 2019). According to the authors, the findings suggest that cell-based meat will be more easily welcomed in the so-called "pragmatic" countries, whereas consumers of more traditional values countries may take longer to accept it.

Recently, research on consumer acceptance has involved Asian and South American countries in comparison with the US and EU countries. The former (i.e., China and India) are found significantly more positive about cultured meat than consumers in the US (Bryant et al., 2019), while South American consumers, namely from the Dominican Republic and Brazil, show to be more conservative than a sample of respondents based in Spain and the UK (Gómez-Luciano et al., 2019).

The relationships between sociodemographic traits and consumers acceptance of cultured meat have been further investigated. Indeed, it is found that preferences for cultured meat relate to age, gender, views of other food technologies, and attitudes towards the environment and agriculture and there is a consensus over the fact that younger, higher educated people and males are more favorable to cultured meat (Bryant and Dillard, 2019; Mancini and Antonioli, 2019; Shaw and Mac Con Iomaire, 2019; Slade, 2018; Wilks and Phillips, 2017; Zhang et al., 2020).

Younger participants show the most positive attitude towards cultured meat, implying that older people prefer to stick to established habits (McCrae et al., 1999), which can be translated into a cautious attitude towards cultured meat.

The positive attitude of higher educated people towards cultured meat is consistent with previous research reporting that people holding a higher education degree are more likely to engage in analytical thinking (Sinclair, 2011) than emotional attitudes, possibly making them more available to new food scenarios than lower educated consumers.

Studies investigating gender differences in perception find out that men show a higher acceptance of cultured meat than females. The cautious perception shown by females towards novel foods is confirmed by several studies (Moerbeek and Casimir, 2005; Qin and Brown, 2007) showing that women display more negative attitudes than males and are less willing to try cultured meat (Seehafer and Bartels, 2019). These results are consistent with some findings regarding insect-based food where females show a more significant food-neophobic attitude when compared to males (Pambo et al., 2018). Nevertheless, the "females" group represents an interesting case of changing perception after information provisioning. One survey reveals that women show lower acceptance of cultured meat than men but, after the detailed information provision, women level off the group of men (Mancini and Antonioli, 2020b).

Interestingly, cultured meat appears to be well perceived by meat-eaters, particularly those who are higher in meat attachment (Circus and Robison, 2019), more than vegetarians and vegans (Bryant and Dillard, 2019; Mancini and Antonioli, 2019; Wilks and Phillips, 2017). The latter provide ethical-related reasons as to why they do not consume meat. While they show to be familiar with cultured meat positive externalities they are not willing to try, buy, or pay a premium price for cultured meat (Mancini and Antonioli, 2020b). Indeed, it is found that those who do not consume meat for ethical reasons may support the product in terms of its improvement to both animal and environmental conditions but show no willingness to participate in its consumption (Wilks and Phillips, 2017). This is because cells used for cultured meat production derive from animals, hence qualifying cultured meat as real meat. Therefore, meat substitutes, such as plant-based burgers, are preferred to cultured meat (Slade, 2018).

The research focusing on to what extent socio-demographic factors impact cultured meat acceptance is still at a very early stage, thus offering a wide range of opportunities for future analysis. At the moment, some dichotomies seem to be very interesting for more investigation: for instance, whether cultured meat fits better meat-based versus vegetarian diets or rich versus poor countries markets. Both dichotomies open the door for implications in consumer communication, supply chains organization, and policy terms. If, as per Bill Gates' wish (Gates, 2021), cultured meat replaced conventional meat in rich countries, marketing strategies would have to find out the effective communication paths to reach wealthy and demanding consumers whose expectations may cover not only health and ethical principles but also religious concerns (Hamdan et al., 2018, 2021).

n. https://www.datasmoothie.com/@surveygoo/nearly-one-in-three-consumers-willing-to-eat-lab-g/.

4.3 Price and taste

In consumers' perception, cultured meat price is a crucial issue (Bryant and Barnett, 2020). Scholars have collected very different perceptions; some consumers expect cultured meat to be cheaper than conventional meat, while some others expect it to be more expensive (Gómez-Luciano et al., 2019).

Price is a common concern related to cultured meat (Laestadius and Caldwell, 2015; Verbeke et al., 2015a,b), and it is found to be a predictor of the purchase intent (Gómez-Luciano et al., 2019; Grasso et al., 2019). Some consumers show to be willing to pay a premium price, particularly after the provision of additional information on the positive externalities of cultured meat (Mancini and Antonioli, 2020b). The perceived healthiness, nutrition, and safety are other important predictors of the willingness to pay for cultured meat across countries (Gómez-Luciano et al., 2019).

A second key issue is taste, towards which consumers are quite skeptical, as most of the surveys conclude, besides texture and appearance (Shaw and Mac Con Iomaire, 2019; Tucker, 2014). As consumers are not willing to compromise on the taste of meat substitutes (Verbeke et al., 2015a) and need the so-called "familiar flavor" to reduce food neophobia (Stallberg-White and Pliner, 1999), sensory tests, whenever possible, are advisable.

Ultimately, it is the authors' opinion that these two features—price and taste—are strictly interrelated to socio-demographic factors to the extent that price and taste are dependent variables of the economic and social features of the final market where cultured meat will be sold. It is indeed reasonable to assume that the richer the consumer to which cultured meat is addressed, the less crucial the price, and conversely, the more crucial the taste.

5 The naming, terminology, and regulatory framework for cultured meat

To gain meaningful insight, other key topics deserve attention: the naming, the nomenclature, and the regulatory framework for cultured meat.

Several studies on consumer science pose the problem of the most suitable name for this product. Depending on the stakeholders' interests, several alternatives are proposed, as the name is likely to have a role in consumer perception and acceptance of the product (Bryant and Barnett, 2019). Therefore, "clean meat," "animal-free meat" and "slaughter-free meat" are the most preferred options by the advocates of culture meat; "synthetic meat," "chemical meat," "artificial meat" and "fake meat" are favored by conventional meat producers; while "cultured meat," "cultivated meat," and "cell-based meat" seem to be preferred by those searching for a more accurate description for the product (Marcu et al., 2015; Ong et al., 2020; Wilks and Phillips, 2017).

Nevertheless, when the product under analysis is a disruptive innovation, naming is not merely a consumer science matter: it entails the understanding of the essence of the product, to make policymakers able to lay out a comprehensive regulatory framework, which is the first requirement for the enhancement of consumers trust and confidence in the safety and benefits of cell-based meat (Ong et al., 2020).

A key issue will be establishing if cultured meat can be labeled as "meat". Both US and European agencies set definitions for "meat" and "meat products" to counter food fraud and imply that meat should come from a part of an animal, but whether or not the part of the animal includes living cells, which is the case for cell-based meat, remains unclear (Ong et al., 2020). Advocates of traditional agriculture propose to exclude all but conventional production methods from the "meat" category, while proposers of cellular agriculture support the use of compound names to distinguish cell-based meats from conventional meats.

However, at the time of writing, the regulatory framework is not set yet neither in the US nor the EU. It will probably take a long process, varying in time and the contents of legislative measures across countries.

In March 2019, the US Department of Agriculture (USDA) Food Safety and Inspection Service (FSIS) and the US Department of Health and Human Services (HHS) Food and Drug Administration (FDA) announced a formal agreement to jointly oversee the production of human food products derived from the cells of livestock and poultry. The FDA will oversee the cell culturing production stages from initial cell collection to harvesting, whereas meat production and labeling will be overseen by USDA-FSIS (Sancar, 2019).

Regarding the EU, cultured meat most likely falls under the Novel Food Regulation 2015/2283, where a food product can be classified as novel whenever it has not been consumed by the EU population to a significant degree before May 15 1997.[o] However, defining cultured meat as a novel food has raised a debate since the European Commission has reluctantly commented on the definition of cultured meat as a novel food (Seehafer and Bartels, 2019). Also, provided that the Novel Food Regulation excludes genetically modified foods from its remit, some doubts are expressed about the assumption of

o. To be classified as a novel food, the food must also fall into one of the categories of art. 3, paragraph 2 lit a) of the Regulation 2015/2283.

cultured meat as not a genetically modified product. Indeed, the potential for genetically modifying the cells is a crucial issue of contestation (Stephens et al., 2018). Recently, it was argued (Post et al., 2020) that, when iPSCs[p] are used as starting cells, the EU GMO legislation will be likely applied.[q]

It is the authors' opinion that, although still relatively little debated, the regulatory framework is a main stake in the cultured meat arena to the extent that a widely approved nomenclature together with standardized quality standards and labeling are crucial prerequisites for an informed consumer choice and wider spread trust towards this novel food.

6 Conclusion, opportunities, and future challenges

While meat consumption has been relatively steady in the developed world in the last decade, annual per-capita consumption of meat has doubled since 1980 in developing countries due to the growing population and increasing per-capita incomes. World meat production is projected to double by 2050, most of which in less developed countries.[r] Such a trend has been regarded as unsustainable for the environment. Indeed, some studies suggest that 18% of global GHG can be attributed to livestock farming, a larger percentage than that of the world transport sector. The present level of meat production and consumption not only has a significant impact on the environment but also on human health, as some severe diseases are more likely to be observed in meat eaters than non-meat eaters (Godfray et al., 2019). Therefore, environmental and health urgencies, as well as animal welfare expectations, demand alternative and more sustainable diets. To this end, the scientific community, the animal food production system, and policymakers have been envisaging new strategies to mitigate the impact of increasing demand for protein sources. One of them—the replacement of meat with alternative protein sources—is proving to be a very rapidly evolving and promising scenario. For instance, seaweed or legume-based burgers have been undergoing a rapid market expansion for some years, and the global plant-based meat market is forecast to increase from \$4.6 billion in 2018 to \$85 billion in 2030 (Santo et al., 2020). Another alternative protein source is represented by insects that might provide proteins for both human consumption and livestock feed. Entomophagy has raised the interest of private and public stakeholders in several countries because it retains some crucial advantages, such as good nutritional characteristics (Rumpold and Schlüter, 2013), a low environmental impact, and it requires small spaces for rearing insects (Van Huis, 2013). Despite all these advantages, Western societies show a low acceptance of entomophagy (La Barbera et al., 2018). A third option is represented by cultured meat, which is often presented as the best choice for those consumers who are sensitive to both the animal welfare and the environmental impact of conventional farming but are not willing to change their diets (Macdiarmid et al., 2016).

These three main alternatives (i.e., plant-based meat, insects, cultured meat) take along specific challenges as they differ in technological innovation, have different impacts on the environment, and face different degrees of socio-economic and institutional barriers.

The advantages and drawbacks of some alternative protein sources were recently analyzed (Tomiyama et al., 2020), and it is found that cultured meat requires a higher degree of technological change compared to plant-based products, already available on the consumer market, or to insects. Indeed, many technical barriers still have to be overcome to achieve mass production of cultured meat. First, an animal-free medium is required to meet vegans' expectations, who are unwilling to accept fetal sourced ingredients and to reduce the end price, which is undoubtedly one of the main challenges to gain market acceptance (Tomiyama et al., 2020). Secondly, the production of structured meat cuts requires further innovations, including efficient bioreactor systems and scaffolds (Allan et al., 2019). These major challenges have led some scholars to state that "in vitro meat is still in its infancy" (Chriki and Hocquette, 2020, p. 7). Nevertheless, such highly technological foods may have an advantage in that they can catch the investments of innovative companies willing to support technological breakthroughs, which does not seem to be true for other alternative protein solutions such as pulses, as they lack the involvement of powerful corporates (van der Weele et al., 2019).

Cultured meat will have to face other significant challenges compared to plant-based meat or insects. One of them is related to environmental sustainability when/whether the production will shift from the experimental to the industrial level. The cultured meat production will require a certain level of energy and, in the long term (i.e., 100 years), such energy requirement might become heavier than that of conventional meat production (e.g., greater demand for electricity by laboratories in all phases of the production process) (Mattick, Landis, and Allenby, 2015). This is not the case for pulses, as they need very little processing, and probably for plant-based meat and insects (van der Weele et al., 2019).

p. Induced pluripotent stem cells.

q. Directive 2001/18/EC of the European Parliament and of the Council of March 12, 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC—Commission Declaration.

r. FAO, 2018. http://www.fao.org/ag/againfo/themes/en/meat/home.html.

The regulatory frameworks for each meat substitute differ; some protein sources fall under established legislation, whereas others still miss a reference framework and need a prompt intervention by the legislator to regulate their mass production and distribution in the consumer market. So far, this specific field has received little attention from the literature regarding cultured meat, although the level of institutional intervention required to shift from the laboratories to the industry surely deserves more attention. Indeed, the cell-based technology is very rapidly evolving to meet the multiple market requirements, for instance, the production of whole cultured meat cuts implies a more sophisticated tissue engineering approach. The pacing of technological improvements calls for a fast-moving legislative framework able to regulate a large number of issues, ranging from the management of waste of cell-based production to the intellectual property rights issues and labeling of cultured meat (Stephens et al., 2018). It is worth noting that the cell-based meat production technique is a credence attribute. Thus, it is susceptible to unfair behaviors such as adulteration of cell-based meat with conventional meat (e.g., a hamburger claimed as "animal-free" while still a fetal bovine serum is adopted). To protect consumers' choice, there is a need for a clear labeling regulation, both public and private standards to be upheld by cell-based meat companies before claiming to be "animal-free" (Ong et al., 2020). Similarly, clear standards have to be outlined to prevent the market from being overwhelmed by many vague classifications, such as "clean" or "sustainable" meat.

The institutional intervention also involves the public support and economic incentives that the cultured meat industry (and the other alternative protein sources) might receive for the development of the upcoming industry in the next few years. In the European Union, the European Green Deal sets out how to make Europe the first climate-neutral continent by 2050 and addresses the challenge of sustainable food systems. In this framework, the European Commission promotes the "… source of alternative proteins such as plant, microbial, marine and insect-based proteins, and meat substitutes" (European Commission, 2020; p. 16) as critical areas of research. If, as it seems, alternative protein sources are acknowledged as a feasible food scenario able to tackle both nutritional issues and environmental and social urgencies, the public institution is likely to play a key role in addressing innovation in the private sector, as well as a proper communication to citizens, for the sake of society. On the other hand, reducing the need for animal heads for meat production will entail disruptions for farmers' incomes and welfare. In this regard, the agricultural policy should address such drawbacks supporting livestock farms conversion to avoid a mass exit from the agricultural sector and strengthening their role in providing public goods (Arfini et al., 2019). Meanwhile, it is not clear whether the cultured meat industry might receive public funding in the United States. As far as the FDA and USDA are the two agencies in charge of the oversight of cell-meat production, some questions, such as funding, remain unsolved. Indeed, the two agencies create budgets and assign federal fundings, which may not align with Congress appropriation, and conflicts arise (Santo et al., 2020).

Public involvement will also be crucial to allow small entrepreneurs and companies to participate in the cell-based meat value chain and avoid the oligopoly of a few powerful corporations. This leads to the debate surrounding who will mainly benefit from the industrial development of cultured meat. Some authors argue that small businesses might find room in the value chain, even though the possibility to access government subsidies and the required knowledge and skills remain an issue (Stephens et al., 2018). At present, however, the involvement of some investors, such as Tyson Foods and Cargill, seems to give substance to those who fear an increasing power of well-consolidated agribusinesses in developed countries and growing disparities between North and South (Hocquette, 2016). Many concerns have also been expressed by those actors who have a key role in conventional farming, as new skills will be required and new responsibilities will be assigned. A recent survey in Brasil (Reis et al., 2020b) revealed that professionals feel threatened by the rise of the cell-based meat industry, even though some opportunities are expected in the field of cellular nutrition and genetics. The so-called "protein transition" towards meat alternatives might significantly affect some producers and rural communities where intensive farming is deeply rooted, like some North American states. There, a reduction in livestock demand could result in higher unemployment at farming and meat processing levels, rural population loss, and the disintegration of rural economies dependent on agriculture (Chriki and Hocquette, 2020; Johnson and Lichter, 2019). Such a scenario is not shared by those authors arguing that the conventional meat industry would remain alongside the cultured meat industry due to the increasing demand for meat products in developing countries (Stephens et al., 2018). Moreover, some categories of farmed meat could become a premium product if alternative protein foods achieved price parity or even lower prices than intensively farmed meat (Bonny et al., 2015). As it is reasonable to predict that a share of consumers will not accept to consume lab-grown meat, high-quality meat (e.g., the European quality labeled meat as Geographical Indications, or endemic meat cuts and races) (Mancini, 2012) might experience an increase in the premium consumers are willing to pay for their consumption.

Once (and whether) the technical and institutional frameworks will be set, cultured meat will be available on the markets, and consumers will be called to try and buy cell-based meat. The intense activity of consumer-science researchers unveiled some crucial insights regarding consumer perception and potential acceptance of cultured meat. Main consumers' concerns are of two kinds: the first one relates to the perceived unnaturalness of cultured meat, which is also at the root of health and safety concerns. This plays a central role in cultured meat rejection, in particular in Europe, and it is the main component of the so-called "emotional objections" towards cultured meat (Weinrich et al., 2019). Advocates for cultured meat believe that new approaches are required to address "the underlying worldviews, fears, and conspirational mindsets that are associated with people resistance" (Wilks et al., 2019; p. 144). In this regard, the analysis of the attitude towards novel foods should start from the "understanding of the food identity profile of the members of the population of interest [...] to tap the psychological variables linked to the system of values that drive food choices" (Faccio and Fovino, 2019; p. 10). To this extent, some food industry professionals and investors, such as the CEO[s] of the plant-based meat Beyond Meat company, propose the "meat is made" metaphor to decouple the product itself from animal farming. They believe that people eat meat not because it comes from an animal but despite the fact it comes from an animal (Adams, 2017); therefore, the communication based on the idea that meat may not come from slaughtered animals would reconcile people sensitiveness towards animal welfare and their meat-based diets. Indeed, this would represent a solution to the so-called 'meat paradox' where one believes in the value of animal well-being but consumes products that caused animal suffering (Aaltola, 2019). Removing the animals from the food system is also the main concept underlying the "post-animal bio-economy," where the high-tech solutions and the levers of capitalism tackle the challenges of the present era, including hunger and climate crisis (Bugge et al., 2016).

The second category of concerns is related to taste and price. These two aspects of cultured meat, however very different in type, can be considered at once because they both will find a market response when the product will eventually be on sale.

According to Bruce Friedrich, the Executive Director of the Good Food Institute (GFI), a non-profit organization that advocates cultured meat: "The vast majority of people aren't going to change their diet based on ethical considerations [...]. The solution is to compete with animal agriculture on its own terms",[t] supporting the idea that taste and price will be the key points that will make up consumers' acceptance.

Whereas the advocating scientists and food industry entrepreneurs believe that cultured meat taste will be the same as farmed meat, even better given that cultured meat will be enriched in a way to get the perfect recipe combining organoleptic, nutritional, and health requirements, the price remains one of the most significant barriers to the acceptance of cultured meat. Although production costs have fallen since the first beef patty was introduced in 2013,[u] the cost of animal-free growth medium remains very high, 50 times higher than what it would need to be cost-competitive with farmed meat (Santo et al., 2020), and efficient mass production methods are still under development. There is a widespread consensus among the experts that cultured meat is unlikely to be price competitive with farmed meat, at least shortly (Tiberius et al., 2019), thus placing it in a niche market for wealthier consumers, preventing its mainstream adoption as for now (Böhm et al., 2018).

However, it seems reasonable to affirm that the future scenario for meat alternatives is hardly predictable because it is a complex environment where alternatives interact and compete for consumers and investments (van der Weele et al., 2019).

Two global consulting firms report on potential scenarios of the future world food system. Although reports' estimates look somehow speculative, they both emphasize the disruptive potential of meat alternatives on the present livestock farming and meat industry sectors. The first one (Tubb and Seba, 2019) depicts the replacement of the current animal-based agriculture system with a new model of production by 2035, where foods will be engineered by scientists at a molecular level and uploaded to databases accessible by food designers anywhere in the world. According to this scenario, two technological innovations - the precision fermentation (i.e., the combination of precision biology with the process of fermentation) and cell-based meat—would shrink the cost of modern foods to be at least 50% and as much as 80% lower than the animal products they replace, and quality would be superior - more nutritious, healthier, and tastier—with much greater variety. This would accrue in a decline of the U.S. beef and dairy industry and their suppliers, which together exceed $400bn today, by at least 50% by 2030, and by nearly 90% by 2035. Interestingly, consumer resistance to modern food disruption is not considered a major barrier as "resistance is never as deep-rooted or intransigent as we may think" (Tubb and Seba, 2019; p. 35). The authors conclude that, although inevitable, policymakers, investors, businesses, and civil society as a whole have the power to slow down or speed up the adoption of modern foods.

The second report (Gerhardt et al., 2020) predicts a scenario in which cultured meat represents 35% of the global meat market in 2040, with the remaining shares divided between conventional (40%) and novel vegan meat replacements (25%). Unlike classic vegan replacements (e.g., tofu, seitan, mushrooms, or jackfruit), novel vegan meat replacements will benefit from sensory profiles much closer to conventional meat due to the use of hemoglobin and binders extracted via

s. Ethan Brown. See Broad (2020).

t. Quotation from Friedrich's opening keynote at the 2019 Alternative Protein Show held in San Francisco (CA).

u. The proof of concept cooked in London by Prof. Mark Post cost about 300.000 USD. Today, Post suggests 9 USD for the same patty. Despite the impressive cost reduction, it is still expensive when compared to the conventional hamburger price (about 1 USD).

fermentation from plants. Whereas classic vegan replacements are estimated unlikely to grow beyond the current trend, the report forecasts the disruption of the conventional meat industry due to the inexorable technological progress of start-ups working on cultured meat and novel vegan meat replacements, supported by large corporations funding. The report closes up by stating that cultured meat will eventually prevail over the novel vegan meat replacements in the long run, whereas the latter is depicted as a transitional product category that will bridge the consumers to the new food model based on cell-based meat.

Again, in the authors' opinion, it is currently too early stage to make reliable projections that need to be grounded on technological and institutional frameworks that are still uncertain. There is no doubt that science is providing the tools to bridge society to new agri-food system models, and private investors have promptly acknowledged this idea. At this point of action, a crucial role will be played by the policymakers who are in the position to address the technological breakthroughs into sustainable agri-food systems that, as the European Commission (European Commission, 2020) declares in the "Farm to fork strategy," meet citizens expectations and represent an opportunity for farmers, fishers and aquaculture producers, as well as food processors and food services.

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