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Technological prospecting: The case of cultured meat

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ABSTRACT

Cultured meat, derived from cellular agriculture, is an emerging food biotechnology. Although it is not yet available on an industrial scale, there are speculations regarding the technical and economic challenges that controversy over the viability of this product. Therefore, our study aimed to map the technological development of cultured meat. For this, we used patent registrations, start-ups, and their investors as the main indicators for analysis, observing the assumptions established in the Schumpeterian trilogy of technological innovation. We also identified the stakeholders involved in this sector, as well as their role and relevance. From these observations, we found that some technical aspects of cultured meat production can still be improved, aiming the production in economies of scale. Patent registries demonstrate that R&D efforts are precisely directed at these issues. In this sense, some start-ups that work with cultured meat are located in the Silicon Valley region. In general, our results make some comparisons possible with the trajectory of other food biotechnologies, allowing it to reflect on the dynamics and economic and technological balance behind cultured meat, which is already a millionaire sector and still has a tendency to expand in impressive proportions.

1. Introduction

A set of global challenges is currently intensifying the concern of society about food security, fueled by estimates of population growth, climate change (Kaur et al., 2018), and urbanization (Haase et al., 2013). These phenomena have led to transformations in dietary patterns and, consequently, to changes in food production systems (FAO, 2017). Parallel to this, concerns about land and water use (Mattick et al., 2015) and animal welfare emerge (Croney et al., 2018).

In this sense, the promise of cultured meat with production in scale represents a possible rupture in the modern food system (O'Keefe et al., 2016), also called "post-animal bio-economy" (Jönsson et al., 2019). This product, considered speculative and unusual, "crossing science fiction, popular media, political and scientific discourses" (O'Riordan et al., 2017), guides moral and ethical debates (Datar and Betti, 2010) and encourages a diversity of questions (Hartmann and Siegrist, 2017). Hence, cultured meat consists of edible biomass from the *in vitro* cultivation of stem cells or from stem cells taken from live animals (Post, 2014; Mattick et al., 2015).

Despite the possibility of producing food synthetically derived from alternative sources, permeating the scientific environment since 1800 due to the emergence of organic chemistry (Burton, 2019), controversial and ambiguous issues regarding these products remain (Fernandes et al., 2021). In the specific case of cultured meat, speculation is evident about the technical and economic viability of production on a commercial scale (Stephens et al., 2018). In August 2013, when Ph.D. Mark Post of Maastricht University, Netherlands, presented to the public the first hamburger produced with cultured meat, "staged as a hybrid science media event somewhere between press release, experiment and cookery show" (O'Riordan et al., 2017), we verified the maximization of the efforts from the private sector in enabling the development and commercialization of this product (Specht et al., 2018).

Consequently, we observed an increase in the number of start-ups and investors (Specht et al., 2018), which shows that scale production is becoming more doable (Mattick et al., 2015). Once the start-ups are characterized by their performance in a context of accelerated innovation (Dvalidze and Markopoulos, 2020), they can be considered as inserted halfway between invention and innovation, as they seek to enable the economic exploitation of an invention, making it an innovation with the potential to be disseminated in the market on a commercial scale. Therefore, they are the "predominant source of innovation in all categories of food technology" (Kaul, 2021). In this sense, we highlight technological prospecting as a way of mapping technological development, identifying new markets, and tracking the capabilities of a given sector (Linhares et al., 2018), configuring itself as a technological intelligence tool that provides inputs for prospective technology studies (Parreiras and Antunes, 2015).

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In this perspective, one of the official indicators recognized worldwide for mapping technological advances in a given sector or area of knowledge corresponds to patent analysis (Tussen et al., 2000; Vincent et al., 2017; Linhares et al., 2018). Thus, patent documents present information relevant to industry, business, and the formation of public policies (Tseng et al., 2007). Given the above, the research we carried out aimed to map the technological development of meat grown from the perspective of cellular agriculture, using as R&D patent indicators the registrations of patent families, start-ups, and their representative investors. In this way, we compare the results from the patent family portfolio with the evolution of the emergence and intensification of investments in start-ups that intend to establish a (technically and economically) scalable production of cultured meat.

2. Technical and economic aspects

Despite being a technically viable product, cultured meat still faces challenges in minimizing costs (Datar and Betti, 2010) and replacing some elements in its production process (Roberts et al., 2015; Acevedo et al., 2018). In essence, the main challenge of cell culture technology is to replicate biologically natural cell growth from inside a living animal in a laboratory (Stephens et al., 2018). Among the uncertainties inherent to the production, there is the possibility of transforming the endothermic cell (requires additional heat) to exothermic (creates its own heat), as well as the identification of the conditions under which this phenomenon occurs (Stephens et al., 2018). In summary, “typically, tissue engineering for cultured meat focuses on growing myogenic ‘muscle’ cells (myocytes) alone via the regenerative pathway, as these are the main constituent of meat” (Stephens et al., 2018b).

Thus, the production process of cultured meat is theoretically endowed with simplicity. It is basically composed of four phases, namely: (i) cell harvesting; (ii) expansion of stem cells number; (iii) differentiation of stem cells into skeletal muscle cells and fibers, and; (iv) assembly of the final product. In the first phase, stem cells from the live skeletal muscle of bovine (or any other animal), called satellite cells, are initially removed through a biopsy needle (Post, 2014). This cell typology is justified because the muscle is composed of a set of fibers with multiple nuclei, which proliferate when its precursor cells merge (Pandurangan and Kim, 2015), forming myotubes (Hocquette, 2016). Then, the mechanical and enzymatic step is performed to isolate the satellite cells, proceeded by the cellular expansion that corresponds to feeding through a culture medium, which is a fluid rich in nutrients and vitamins indispensable for cell growth (Post, 2014). Generally, this culture medium is supplemented with a percentage of serum from calf blood (Post, 2017), also known as fetal bovine serum (Catts and Zurr, 2014).

This production process can still be understood as myoblast growth in a culture medium inside a bioreactor (Datar and Betti, 2010). For this, there is the culture of progenitor cells without the need for animal slaughter, the construction of edible scaffolding suitable for the proliferation of these myoblasts, the composition of cell culture media, and, finally, the use of bioreactors where myogenic stimuli are performed to obtain muscle fiber (Enrione et al., 2017). Table 1 summarizes the main technological and industrial challenges for improving cultured meat production.

Therefore, it is necessary efficient substrates for cells proliferation with specific growth factors, as well as bioreactors compatible with high cell density, to provide nutrients and remove residues properly (Young et al., 2013) since cells have a higher density power *in vitro* conditions when compared to *in vivo* (Pandurangan and Kim, 2015). There are also challenges concerning the maximization of the growth efficiency of cell lines, formulations of alternative culture media, development of edible scaffolding to facilitate the production of thick cuts of meat, and the creation of scalable culture platforms that enable simultaneous growth and differentiation of multiple cell types (GFI, 2018).

Under the economic aspect, the market for meat-substitute products, characterized by a high level of innovation, was estimated at $3,185.8 million in 2013 (Hocquette, 2015). This situation can be justified by the growing tendency of food transformation, making protein the focal point of each meal and reflecting both opportunities and challenges for the food industries, especially regarding cost and quality trade-off (Layman, 2014). The first hamburger produced with meat grown by Ph.D. Mark Post’s laboratory, in August 2013, took three months to be manufactured (Bhat et al., 2015) and cost $330,000.00 (Shapiro, 2018) with funding from Sergey Brin, co-founder of Google (Mattick and Allenby, 2013).

Considering material costs for cultured meat production, approximately 90% of them refer to the cell growth medium, also known as culture medium (Jones, 2010). This situation explains the investments in research that try to discover and develop fluids composed of culture medium and alternative scalable substrates (scaffolds), such as serum from algae (Driessen and Korthals, 2012), alginate gels (Schuster et al., 2017), salmon gelatin and glycerol, for example (Enrione et al., 2017).

However, the cost-benefit analysis that considers the use of certain materials to produce cultured meat (Datar and Betti, 2010) deserves attention, given the controllable and manipulable nature of production (Verma et al., 2012). As projected (Dance, 2017), initially we have the commercialization of a premium product, which corresponds to cultured chicken meat sold in a restaurant in Singapore since December 2020 and whose price corresponds to US$ 23.00 for a trio of dishes (Scipioni, 2020).

Regarding the commercialization of cultured beef hamburgers, estimates suggest that prices can range from US$ 11 (Henchion et al., 2017) to US$ 50 (Wakefield, 2019). Though, over time, the cost of producing cultured meat was minimized, as in less than three years, the American start-up Memphis Meats produced the first meatball from cell culture (BBC, 2017) at the cost of approximately US$ 1,200 (Shapiro, 2018).

A techno-economic analysis modeling a future large-scale farmed meat production unit shows that until 2030, production costs tend to be competitive with those related to some conventional meat production systems (Swartz, 2021; Vergeer, Sinke, and Odegard, 2021). Thus, similarly to what happened with other biotechnologies, the processes are being improved and the technology developed. Likewise, scanning the first human genome cost billions of dollars, and nowadays only requires a few hundred dollars (Shapiro, 2018).

3. Technological prospecting through patents

For the operationalization of our technological prospection study, we initially carried out a mapping of patents on cultured meat because they are configured as the main technological development drivers for a given sector. For this purpose, we selected the worldwide patent database Questel Orbit, as it corresponds to one of the largest patent databases and is updated daily (Questel Orbit, 2022). In addition, it allows the analysis of different variables contained in patent documents through exclusive tools (Vincent et al., 2017). Therefore, our search strategy included the following terms, boolean operators, and truncations: (cell + cult + AND meat) OR (cultured meat) OR (*in vitro* meat) OR (cultured beef) OR (myoblast + AND meat). These words should be contained in the title, the abstract, or claims of patent documents. Through these criteria, our initial portfolio was composed of 123 patent families.

According to scientific literature, the first patent registration on cultured meat in the studied perspective was published on June 24, 1999, requested in the Netherlands by the doctor and former prisoner of war Willen van Eelen, the businessman Willem van Kooten and the dermatologist Wiete Westerhof (Jönsson, 2016). Therefore, we set the date of publication of the records as an exclusion criterion (from 06/24/1999 to 04/12/2022).

In addition, considering the diversity of technological domains to which patents belong, we determined the International Patent Classification (IPC) as the search filter belonging to the same technology areas as the first patent in order to obtain a portfolio more aligned with the re-

Table 1
Design requirements and parallels within the cell-based therapeutics industry for cultured meat critical technology elements.

Critical technology element	Design requirements for cultured meat	Relevant technologies and advances within the cell-based therapeutics industry
Cell line development	• Derived from agriculturally-relevant species • Capable of differentiation into meat-relevant cell types (muscle, fat, fibroblast, etc.) • Genetically stable and immortalized • Optimized for large-scale growth (tolerate suspension, controlled differentiation, etc.)	• Development of small-molecule cocktails that can replace the need for genetic approaches to induce pluripotency and facilitate maintenance of pluripotency • Footprint-free methods of cell line engineering using RNA or protein delivery or excisable transposons • Improved protocols for cell freezing to maintain viability and phenotypic fidelity
Cell culture media	• Animal component-free, antibiotic-free, ideally chemically defined	• Development of methods for streamlining iterative optimization of animal component-free media formulations
	• Optimized for meat-relevant cell lines and co-culture of multiple cell types • Extremely low cost and high-volume production capacity • Engineered or synthetic growth factors	• Immobilizing growth factors on beads to prevent depletion in the media via perfusion
Scaffolding materials	• Edible and/or biodegradable and food-grade materials	• Biocompatible, non-animal-derived scaffolding materials pioneered in the regenerative medicine field • Use of tunable scaffold parameters (stiffness, etc.) to spatially direct differentiation
	• Support cell adherence • Support vascularization and media perfusion • Biomechanical properties suitable for tissue maturation • Scalable production capacity	• Degradable materials that enable cell migration and vascularization after patient implantation • Integrated, closed systems with increasing automation to reduce errors and contamination risk associated with human handling
Large-scale bioreactors	• Support cell proliferation as well as tissue maturation/perfusion • Large volume, low maintenance	• In-line monitoring of media components to adjust perfusion in real-time
	• High-yield cell harvesting • Real-time, in-line cell monitoring for quality control • Integrated media filtration and recycling system • Highly automated; closed system	• Novel technologies to improve the efficiency of cell separation and harvesting

Source: Specht et al. (2018).

search proposal. In other words, we defined a second exclusion criterion corresponding to patent families that did not have an IPC classification in category A23L or C12N, which refer to the macro areas called Human Needs and Chemistry and Metallurgy, respectively (Wipo, 2022a).

Based on these parameters, our portfolio was composed of 78 patent families, in which we analyzed their assignees and their application. Subsequently, we compared these results with the evolution and emergence of start-ups worldwide, also mapped using secondary data. Finally, we presented the perspectives for the sector analyzed, considering the compilation of this information. For data analysis, we used graphic representations provided by the database and electronic spreadsheets to organize the records obtained.

Hence, we observed that the first registration of patent families refers precisely to the patent filed by Van Eelen et al. (1999), whose proposal consisted in extracting cells from the embryonic muscle or somatic cells through a biopsy. It also dealt with constructing a thin scaffold that would enable cell growth, which the researchers claimed would result in an edible product. In 2006 another invention by Van Eelen concerned a meat product from *in vitro* cultivation of non-human cells in a culture medium free of dangerous substances, capable of producing a three-dimensional animal muscle tissue (Van Eelen, 2006).

This deposit currently has the American company Just as assignee, which operates in the manufacture of vegetable-based foods. In 2018, the company globally presented chicken nuggets produced from cells taken from the feathers of chickens (Morris and Cook, 2018). In December 2020, the Government of Singapore approved and regulated the marketing of laboratory-grown chicken meat (BBC, 2020), providing the opportunity for the company Just to be the pioneering start-up in the marketing of this product. Cultured chicken meat is served at the 1880 restaurant, an establishment characterized by its innovative menu and customers concerned with social issues. The product is priced at US$ 23.00 and is available in a trio of dishes (Scipioni, 2020).

Practically two years after the first hamburger with cultured meat was produced, we verified the publication of a family of patents whose invention was authored by Genovese et al. (2015). It refers to a method of specification and scalable culture of the muscle to improve the production of cultured meat. The inventors defined meat in the abstract of this record as “any metazoan tissue or cell-derived comestible product intended for use as a comestible food or nutritional component by humans, companion animals, domesticated or captive animals” (WO201566377). This definition meets the concept of meat presented by the European Parliament (2003), which points out that the product is a skeletal muscle with adipose and connective tissue naturally included or adherent.

In addition, this registry has a group formed by the Curator of the University of Missouri and the University of Missouri itself, the start-up Memphis Meats and the American activist organization People for the Ethical Treat of Animals (PETA) as assignees. We highlight that Memphis Meats was also founded in 2015, and its co-founder is Nicholas Genovese (Memphis Meats, 2019), a scientist responsible for different research in the area of regenerative biology and life sciences (Roberts et al., 2015; Genovese et al., 2017) as well as affiliated with the Bond Life Sciences Center, University of Missouri. Regarding the partnership formed by all these agents, we found that Michael Roberts was one of Genovese’s advisors at the University of Missouri, and PETA financed his postdoctoral research, which sought to differentiate bovine stem cells into muscles. The researcher was also able to find alternative culture media to replace fetal bovine serum (Dance, 2017).

Also, the start-up Memphis Meats announced in 2016 the first cultured meat-based meatball produced in the world (BBC, 2017). In early 2018, the food company Tyson Foods became part of the start-up as one of the investors, which already counted with Bill Gates and Richard Branson (Sorvino, 2018; Tyson Foods, 2018). Nevertheless, this was not the first time that the second-largest meat processing company in the world showed interest in food from alternative production processes because, in 2016, it acquired a 5% stake in Beyond Meat for an undisclosed amount (Strom, 2016). In April 2019, Tyson Foods sold its stake in the company to develop its own line of alternative proteins (BBC, 2019). Nonetheless, Beyond Meat went public, acquiring US$ 241 million and maximizing its market cap (GFI, 2022).

Yet considering the patent assignees group members, there is PETA, which in 2008 announced a $1 million prize for the first scientist who produced and brought cultured meat to the market during the next three years (Fox, 2009). As no laboratory claimed the award until the end of the term, it was never made available. However, the organization continues to support initiatives in this perspective, and its manifestation fostered an interest in the theme and enabled the approach of different researchers worldwide (Ferrari and Lösch, 2017).

In turn, start-up Aleph Farms – created in 2017 through the efforts of food company Strauss Group, Technion-Israel Institute of Technology, and veteran CEO, food engineer, and biologist Didier Toubia – is the assignee of four cultured meat-related patents. We highlight that this has been requiring the protection of one invention per year since 2017, demonstrating the continuous investment in R&D. This company intends to launch cultured beef steaks – which take between three and four weeks to manufacture – to the market by the end of 2022, depending on regulatory approval (Aleph Farms, 2022). This start-up is also a pioneer in trying to produce cultured space meat through its space program (Clayton, 2022).

At the end of 2018, the Israeli start-up SuperMeat became the assignee of a patent whose invention was attributed to Savir et al. (2018), which consists of a production method of a hybrid food. It combines a substance of plant origin with a number of cultured animal cells, which, in turn, do not actually form a tissue. Also, the North American start-up Wild Type became the assignee of a patent whose invention was attributed to Elfenbein and Kolbeck (2018). The idea is to produce food using a variety of cells (including muscle, fat, and liver cells) grown in culture conditions without pathogens and exposure to toxins.

We also highlight that Yonsei University Industry-Academic Cooperation Foundation, the incubator for Korean research and cooperation between industry and school, is the assignee of six families of protected patents in the second half of 2020. This set of patents includes multiple essential ingredients for the production process of cultured meat, such as culture liquid composition, porous cell culture support, and platform for producing, for example. Likewise, Jiangnan University, located in China and directly administered by the country's education ministry, is the assignee of four patents concerning the process of manufacturing cultured meat, published in 2019 and 2020.

"Recently numerous researchers in academia and companies have been putting significant efforts into scientific and translational development in this field. Since various pillars of cultured meat manufacturing hold substantial translational potential, there has been a steady interest in filing patent applications globally in the past decade" (Ng et al., 2021). Therefore, it is observed that most patent documents were requested by the private sector, demonstrating that cultured meat corresponds to a technology that is of interest to the industrial area. We also verified that there is attention from universities and research institutes about this technology, which shows significant efforts in R&D (Letti et al., 2021).

By looking at the countries where the patent family portfolio has been protected, we can observe the countries where the assignees believe that the innovations can be commercialized first. In other words, countries that present the greatest commercial tendency for the patents analyzed (Wang et al., 2019). In this sense, we see the predominance of protection of innovations in North America, the European Union, and Asian countries. We emphasize that most of the protective measures in these countries took place through the Patent Cooperation Treaty (PCT), which allows assignees who wish to protect an invention in different countries (involving 152 contracting countries) to do it simultaneously (Wipo, 2022b).

Regarding the technological domain to which the analyzed patents belong, we verified that they focus on areas such as food, foodstuffs, or non-alcoholic beverages. They also cover microorganisms or enzymes, food compositions, chemical aspects or use of materials for bandages, mutation or genetic engineering, and culture media, for example. We infer that the search resulted in a portfolio containing registrations of families of adherent patents with the subject investigated, given the sequential logic of the first patent on such innovation. However, the lack of clarity in the writing of patent documents due to the use of unusual terms to express standard semantics and vice versa may have caused distortions in the framework of these classifications (Judea et al., 2014). Even considering the representativeness of the database we used, some patent registrations may not have been included in the search given the terms and criteria utilized.

Furthermore, concerning the production process, we highlight the dependence on regulatory and governmental actions, as "materials used in the product development are novel and untested within the food industry and demand urgent regulatory and safety assessment systems capable of managing any risks associated with the development of cultured meat" (Bhat et al., 2019). Thus, as cultured meat proves to be technically viable, the next step for its commercial development must be the organization of the institutional environment, emphasizing issues of regulation and standardization. Such considerations have direct implications for the attitudes of consumers, which can contribute to maximizing their acceptance of the product, whose discussion is relevant, although it is not the focus of this study.

4. Analysis of start-ups and their investors

In an environment of accelerated innovation, a technoscientific network formed by start-ups, laboratories, and research institutions has directed efforts to make cultured meat a reality relatively quickly (Mouat et al., 2019). Thus, five years after creating the first cultured hamburger in the world, we observed the emergence of 31 start-ups that try to produce synthetic proteins, of which 30% were created only in 2018 (Burton, 2019).

However, not all the production processes employed by these companies are based on cell culture. The fermentation of animal proteins that can convert a certain raw material into the desired substance is currently already used on a commercial scale (Burton, 2019), as in the biosynthesis of insulin (Becker and Wittmann, 2015) or biofuels (Shaw et al., 2016). Among the start-ups that use fermentation for protein production, we highlight Clara Foods, a company that produces egg albumin, for example (Clara Foods, 2019), and Perfect Day, which transforms plant sugar into milk proteins and already have products on the market (Perfect Day, 2019).

These companies are closer to scaling up their production of alternative sources of proteins precisely because they employ a relatively old production technique (Dance, 2017). Estimates suggest that the alternative meat market may reach $140 billion in the next decade, implying the capture of around 10% of the world's conventional meat industry, which represents approximately $1.4 trillion (Franck, 2019).

The number of cultured meat start-ups practically quadrupled between January 2018 and January 2019 (New Protein, 2019). By the end of 2018, $73 million were invested in the sector since its emergence with commercial potential in 2015 (GFI, 2019a). Also, among the resources invested in its development, we can observe the contribution of public funding. The Dutch government funded the initial stages of Ph.D. Post's research into hamburger production (Dance, 2017), Singapore invested in sovereign funds for the production of cultured meat (Begum, 2019), and the Chinese government has an agreement to acquire $300 million of the product from Israeli start-ups when the product is available (Roberts, 2017).

Despite this, it is considered an emerging multi-million field financed mainly by the private sector (Dance, 2017). We note that even the conventional meat industry is interested in this new food biotechnology (Dance, 2017). As a pioneer in this area, the food production and processing multinational Cargill invested an undisclosed amount in Memphis Meats in 2017 (Cargill, 2017) and also participated in a Serie A investment round led by VisVires New Protein to provide investments to Aleph Farms (Cargill, 2019).

The leading Swiss meat processing and convenience products manufacturer, Bell Food Group, announced in 2018 a $2.4 million investment in Mosa Meat. The company points out that this strategy guarantees early access to an alternative method of meat production (Bell Food Group, 2018). Still, concerning the partnership between conventional protein producers and cultured meat start-ups, we highlight PHW-Gruppe, one of the largest poultry producers in Europe, investing $3 million in SuperMeat (Byrd, 2018). This situation is in line with the fact that cultured meat can encourage companies to adopt more environmentally friendly strategies and tend to contribute to their value chain (Reis et al., 2020).

We found that the companies Memphis Meats, CUBIQ Foods, and Mosa Meat received investments of $22 million, $14 million, and $9 million, respectively. CUBIQ Foods received around $11 million in investments from Moira Capital Partners. We clarify that the company directs efforts toward producing healthy fats, such as palm oil, for example, and not just animal fat (León, 2018).

In addition, Memphis Meats has the participation of Tyson Ventures, the venture capital arm of Tyson Foods, which in 2018 joined its diversified group of investors, including DFJ, Cargill, Bill Gates, and Richard Branson (Sorvino, 2018; Tyson Foods, 2018). Memphis Meats changed its name to Upside Foods, and in 2020 it achieved a $161 million Series B, characterizing itself as the largest publicly disclosed capital infusion in the cultured meat industry (GFI, 2020).

On the other hand, the Mosa Meat originated in the University of Maastricht, the pioneer in the production of cultured meat for presenting the first hamburger from cell cultivation in 2013, has a group of investors formed by the co-founder of Google Sergey Brin (Jönsson, 2016), Bell Food Group (Bell Food Group, 2018) and M Ventures, which is a corporate venture capital arm of Merck, a multinational that operates globally in the segments of biopharma, life science and performance materials business (Merck Group, 2018).

In addition, there are other stakeholders that direct efforts to the production of cultured meat. New Harvest is one of them, characterized as a non-profit research institute founded in 2004 in New York (New Harvest, 2019). In 2013, Isha Datar went from CEO to executive director of the organization, and New Harvest's main strategy was to create start-ups and finance research projects. We highlight that Datar was the founding director of Perfect Day and Clara Foods, whose capital received for this was returned to New Harvest for investment in other research, emphasizing the non-profit character of the organization. Also, in the early stages of its research, this organization invested in Mosa Meats (Mouat, Prince, and Roche, 2019). Since 2016, New Harvest changed its operating strategy and began to only finance and strategically conduct public, collaborative, and open research aimed at cellular agriculture (Mouat, Prince, and Roche, 2019). It has invested more than $2 million in grants for ten research projects in four different nations and five areas of knowledge since 2008 (New Harvest, 2019).

The Good Food Institute (GFI) is also an American non-profit institution that focuses on producing plant-based or cell culture alternatives to animal products. It involves entrepreneurs, scientists, and policymakers, providing strategic support to companies, promoting innovation, educating organizations on the R&D of meat considered "clean" and its benefits, and leveraging the availability of herbal products in the consumer market (GFI, 2019b). The institute regularly publishes calls for research funds to address technical and economic challenges in the production of meat grown on a commercial scale (GFI, 2019c), which was its priority area for financing (GFI, 2018).

5. Panorama and perspectives

Based on the presented panorama and the assumptions of the Schumpeterian trilogy of technological innovation (Schumpeter, 1936), we can observe that the biotechnology of cultured meat has presented significant advances over the last years. This can be both caused and reflected in the growth of investments, especially private ones, in start-ups in the sector. Therefore, we verify the technological development trend of this product, whose investments represent the interests of globally known stakeholders. Although it is not possible to establish a causal link between the number of patents and the success of start-ups, such indicators of technological innovation lead to market gains and maximize the bargaining power in relation to investors (Gaulé, 2018).

Initially, it is worth highlighting the importance of product nomenclature for its acceptance in the market (Szejda et al., 2021). This technology emergence comes from the engineering of regenerative tissues and integrates the scientific field of cellular agriculture, but there is no consensus on its nomenclature since it is called "artificial meat" (Bonny et al., 2015), "*in vitro* meat" (Mattick et al., 2015; Bryant and Barnett, 2019), "synthetic meat" (Marcu et al., 2015; Fernandes et al., 2020), "clean meat" (Specht et al., 2018), "cultivated meat" (Szejda et al., 2021), cell-based meat (Ong et al., 2020; Reis et al., 2020; Santo et al., 2020), cellular meat (Warner, 2019) or ironically called "frankenmeat" (Burton, 2019; Mouat et al., 2019) or "frankenburger" (Petetin, 2014). However, the term "cultivated" corresponds to the preferred one by companies in the sector, followed by "cultured meat" (GFI, 2021).

In addition, recurring crises that have occurred since the 1990s that impacted meat safety (Verbeke et al., 2010), such as the preoccupation about transmitting diseases through food (Bhat and Bhat, 2011), intensified the desire of consumers for alternative sources of protein (Verbeke et al., 2015). However, despite the tendency to maximize the consumption of plant-based proteins, food preferences change slowly (Tuomisto, 2019), which can be justified by the nutritional importance of meat (Godfray et al., 2018) and its symbolisms and historical meanings (Bekker et al., 2017) as the main food in different cultures (Rozin, 2013).

Therefore, it is worth noting that this logic derives from the Schumpeterian trilogy of technological innovation, composed of invention-innovation-diffusion. In short, this theory from the economy points out that technological innovation comes from a linear process, which begins with the invention, considered the materialization of the idea. When this invention has commercial potential and is exploited economically, it becomes an innovation, which is then inserted and disseminated in the market (Schumpeter, 1936). Upon reaching the market, technological innovation causes changes in the current socio-technical system with which it is associated, fostering transformations in socioeconomic conditions (Geels, 2004).

As a justification for this circumscription, we highlight the advent of maximization amount of patent data and the diversity of analysis tools to contribute to the studies of technological trends and R&D activities in different sectors (Vincent et al., 2017). Partnerships between start-ups and consolidated companies represent interesting strategies for making innovation feasible and achieving superior results (Katila et al., 2008). On the other hand, governments and start-ups generally have a set of conflicting priorities and resources (Doblinger et al., 2019), although yet complementary to the development of science and technology.

We also point out that some start-ups targeting meat production through cell cultivation are assignees of relevant patents. Moreover, considering the countries where the analyzed patents are protected, we can hypothesize that the United States, China, and Europe are the most promising areas for the market development of these food technologies. We emphasize that the Chinese government has invested much capital to finance research for this purpose, including Israeli start-ups (Roberts, 2017).

Since 2011, China has become the world leader in filing patent registrations, which both explains and is explained by its high degree of investment in R&D (Chen and Zhang, 2019). In the context of agribusiness, the government has implemented a set of policies aimed at fostering innovation through commercial companies (Jin et al., 2017); therefore, investing in cultured meat is not an atypical initiative for the country.

In addition, coincidentally or not, eight cultured meat start-ups are located in the Silicon Valley region (Burton, 2019). The entrepreneurial alchemy of the place has historically contributed to the emergence of companies of global disruptive power (O'Mara, 2019), and those "who are making investment decisions in the global heart of innovation in particular have been shown to exert a strong influence on the evolution of business, so their outlook may be a significant factor in determining the future" (Cannice, 2019).

Moreover, when comparing the ecosystems of the US and EU cultured meat start-ups, Schimanietz and Lukács (2020) found that despite the North American entrepreneurial ecosystem being more mature than the European one and thus showing superior performance in most of its domains, both share the same core challenges – which correspond to regulatory approval, cost parity and knowledge sharing. In addition., "in Europe, the Netherlands is at the forefront of lab-grown meat technology where analysts expect producers Mosa Meat and Meatable to push for EU regulatory approval in the next few years. In the US, it is widely expected that Bill Gates-backed Memphis Meats and New Age Meats will do the same" (Henshall, 2021).

The fact that plant-based proteins are already being sold may have contributed to the maximization of investments in cell culture start-ups, as they are indications that the market is growing. Nevertheless, as the costs of producing cultured meat are still high, start-ups are directing efforts to produce cheaper meat (Fernandes et al., 2021), such as hamburgers and nuggets. Also, we shall consider that investment in production processes for gourmet or premium foods is also an interesting strategy for companies. For example, the *Foie gras*, a typically expensive and controversial dish, has been designed for laboratory cultivation by start-ups like JUST and Integriculture. It precisely happens because it has a high price, being a product with which initially the cultured meat industry would be able to compete (Morgan, 2018).

Thus, these indicators show us the panorama of technological development of cultured meat, contrasting with the identification of stakeholders who want to take this product to the supermarket. The projection is that the first possible product is ground meat, followed by other types of vascularization, such as fillet (Welin, 2013), and, finally, by the three-dimensional production of meat cuts similar to conventional ones (Datar and Betti, 2010). Coincidentally or not, the growth of the cultured meat sector "has been made possible by venture capitalists, located primarily in Silicon Valley, who for years now have been investing in start-ups founded by biomedical entrepreneurs" (Bloch, 2019).

6. Conclusions

Our study of the technological prospection of cultured meat demonstrated that its stage of development provides the technical viability of industrial production. However, it still requires some improvements to be effective as innovation and promote economies of scale. From identifying investors of start-ups and other stakeholders, we can observe that this sector is highly organized, involving agents from sectors that are potential competitors. In addition, we observed that regulatory aspects inherent to the institutional environment still constitute challenges to the market development of this biotechnology.

In this sense, we observed that it is only a matter of time for the cultured meat to be inserted into the market on an industrial scale, competing directly with the proteins already known, both of animal origin and plant-based. Nevertheless, it is worth remembering that the threat of this food biotechnology to the meat production chain will potentially be greater since it is a system that is traditionally consolidated.

Furthermore, if we think about the socioeconomic importance of meat chains, the changes will undoubtedly be too impactful. We refer to the possibility of gradual but disruptive transformations in the world's socio-technical meat production system that we know today. Therefore, the contribution of our investigation is based precisely on providing scientific information on the stage of development of this technology and the identification of those who want it to be commercialized. From this, researchers in agribusiness and, more specifically, in animal production, can develop technologies and tools aimed at optimizing conventional meat production. In the same way, stakeholders in the meat industries can use the information presented to support their decision-making process, developing strategies with a view to potential changes.

In this way, identifying the stakeholders that target interests and efforts to develop viable production of cultured meat can contribute to the anticipation of prospective scenarios of this emerging food biotechnology. In addition to making inferences regarding the probable transformations pertinent to the agricultural context and the value chains of agri-food products.

Finally, we believe that our research goes beyond the technological area, as it deals with a subject that surpasses the borders of an experimental laboratory, providing insights into changes in power sources, whose potential implications are still unprecedented. Moreover, we recognize that since claiming the priorities of an invention using patent registration requires some novelty, it is common for these documents to use unusual or overly specific terms, which may have left records of patent families out of our analysis. In addition, when we study technologies whose commercial potential is being developed, the disclosure of information by the involved ones is too restricted. Consequently, detailing some points identified in our research was unfortunately not possible. Therefore, we assume that there is other information that would address the gaps in our study if integrated with this analysis.

Ethical statement - studies in humans and animals

Not applicable.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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Supplementary materials

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