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Socio-economic futures for cellular agriculture: the development of a novel framework

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Novel agri-food technologies such as cellular agriculture present strong economic opportunities, with potential to reduce the environmental footprint of agriculture, improve animal welfare, and feed the world. A rich body of literature has emerged in the past five years that evaluates those claims, and illuminates the diverse food system futures framed by novel agri-food technology actors across the food system. To date, those characterizations of food system futures rely mainly on public data, such as technology advertisements and press releases, and have yet to engage deeply with a broader suite of social, economic, and material pathways for their emergence. The need for a robust social scientific framework through which to describe and evaluate concrete futures for novel food technologies such as cellular agriculture is needed. In this paper, we draw from a set of fifty-two interviews and 3 focus groups with key cellular agriculture stakeholders from industry, academia, investment, and research institutions. We found three key considerations for cellular agriculture futures: to understand the places and scales across which cellular agriculture 'happens', to balance competitive industry interests with public-private collaboration, and to navigate the extent to which cellular agriculture interfaces with traditional agriculture. From these considerations, we draw from the literature to deduce three dimensions across which to describe and evaluate concrete futures for novel agri-food technologies, broadly: centralization, access, and integration. Plotting food system futures across these three variables illuminates assumptions, preconceptions, and enabling conditions that may engender more or less desirable futures.

KEYWORDS

cellular agriculture, sustainable food systems, agri-food technologies, futures, scenarios

1. Introduction

The Anthropocene is marked with numerous significant environmental risks to humans and the biosphere, such as climate change, biodiversity loss, pollution, and others, presenting critical sustainability challenges for communities and nations across the world (Biermann et al., 2016). Among our greatest challenges is determining how to transition to sustainable agriculture and food systems (Rockström et al., 2017), and a major shift in how we produce, distribute, consume, and dispose of food and food production byproducts is required (Willett et al., 2019). While not a sole solution to these challenges, emerging agri-food technologies that enable high yields with

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low environmental footprints have the potential to serve as key components of sustainable and resilient food production systems (Newell et al., 2021; Newman et al., 2023).

Among the emerging food production approaches with a potential role in sustainable food systems is cellular agriculture (Klerkx and Rose, 2020). Cellular agriculture consists of a suite of cell culture and fermentation technologies and techniques for manufacturing protein and other food products (e.g., fats, flavours, etc.) that are conventionally obtained through traditional agriculture (Newman et al., 2021). Some of these technologies/techniques include precision fermentation, tissue engineering and cell culturing, as well as alternative proteins including plant-based protein manipulation and extrusion, among others (Bhat et al., 2017). Cellular agriculture has the potential to deliver protein products for human consumption in a reasonably-priced, environmentally-sustainable, and more ethical manner (Post, 2012; Mouat and Prince, 2018; Smith et al., 2022). However, cellular agriculture is not a panacea for all the agricultural challenges of the Anthropocene, and consideration needs to be given to the uncertainties associated with its potential benefits and promise, such as the potential emissions and contribution to the global kilocalorie supply (Lynch and Pierrehumbert, 2019; Glaros et al., 2022) and the resource consumption and land use associated with feedstock and inputs in product processes (Newman et al., 2021). Nevertheless, it has potential to contribute in a non-trivial manner to global food system sustainability efforts.

Delineating hypothetical and/or possible futures for cellular agriculture is an important exercise (e.g., Jönsson, 2020; Mendly-Zambo et al., 2021), as it provides insight into the opportunities, challenges, and potential trajectories in which the industry could develop and grow. An array of approaches are used across a variety of disciplines to describe diverse futures for cellular agriculture. Some studies quantitatively model hypothetical production futures in order to estimate cellular agriculture's potential for feeding the population of Earth and beyond (e.g., Cannon and Britt, 2019). Other studies present the potential future of cellular agriculture as a component of food systems with the goal of illuminating potential social, economic, and environmental trade offs across different scales (Mendly-Zambo et al., 2021; Glaros et al., 2022). Cellular agriculture may indeed generate material benefits (increased food production, reduced land use, new business opportunities), but could also result in unintended consequences such as increased agricultural production across other parts of the supply chain (Newman et al., 2021).

More critical future studies research explores the power dynamics that are shaping cellular agriculture's emergence (e.g., Guthman and Biltekoff, 2021; Helliwell and Burton, 2021). The 'promise' of cellular agriculture includes feeding the world, reducing land use pressures, avoiding harm to animals, providing healthier protein sources, among many others (Sexton et al., 2019; Newman, 2020; Soice and Johnston, 2021). Proponents paint its future as a means to support life on Mars, as a way to nestle backyard pigs next to bioreactor-produced pork sausages, as the next microbrew style food industry, and even as a way to feed refugee camps (Jönsson, 2020). Aspirational narratives for cellular agriculture serve to 'make its market', driving resources and capital toward specific configurations of state, community, and private actors (Mouat and Prince, 2018). Further research in critical future studies scrutinizes what kind of futures are presented, by whom, and with what potential ethical or political effects; cellular agriculture is not a neutral suite of technologies, and will create 'winners' and 'losers' across the food system (Jönsson, 2020). Helliwell and Burton (2021) note that the reporting of promissory visions of cellular agriculture can lead to 'narrative silences', where the potential unintended consequences that require consideration are unexplored.

Overall, much of the existing efforts to document and critically analyze cellular agriculture futures are devoted toward exploring the narratives, framings, and promises of cellular agriculture, their attendant responses, and problematizing them (e.g., Lonkila and Kaljonen, 2021). Analysis has so far sought to identify key debates over the perceptions of and palatability toward cellular agriculture products. For example, Sexton et al. (2019) consider debates over cellular agriculture products as 'clean vs. dirty', 'real vs. fake', and as 'tradition vs. progress'. Jönsson (2020) considers debates over cellular agriculture products as 'familiar vs. unfamiliar', 'good vs. bad' for livestock, and 'artisanal vs. sci-fi', among others. Much of these efforts utilize discourse and narrative analysis methodologies and draw from society and technology studies to critique the promises of technology. More recent studies have begun to scrutinize how these tools and technologies factor into broader debates in the social sciences around food systems. For instance, Chiles et al. (2021) consider ownership and participation as key drivers for more inclusive food systems, and describe what future for cellular agriculture could lead to these outcomes. These authors conclude that the development of accessible and shared standards, as well as more cooperative opportunities are crucial for a more democratic cellular agriculture future. What is missing from futures-oriented literature is methodical or systematic way to imagine solutions to those critiques, alternatives, or 'barely imagined possibilities' (Kish and Quilley, 2017).

This paper contributes to research and understanding on the future role of cellular agriculture in food systems, and broadly, it enhances knowledge on novel agri-food technology governance. We identify key considerations for cellular agriculture futures through analysis of stakeholder interview and focus group data. We combine a focus on the operational considerations for cellular agriculture's emergence in the medium term (e.g., what types of products will be produced, who will support the industry, how will facilities be distributed) with a broader political economic lens (considering who is left out or affected by novel agri-food technologies). We draw from a methodological approach with the goal of illuminating concerns over cellular agriculture's emergence (Jönsson, 2020). We subsequently deduce a framework through which to evaluate novel food technologies' futures within food systems, and apply it to the case of cellular agriculture.

2. Methods

The data used for this research were collected for a larger strategic initiative on the role cellular agriculture could play in Canadian food systems and economies (Ontario Genomics, 2021). Data collection involved a series of stakeholder interviews (of approximately 1 h in length) conducted in early-2021. A total of 24 interviews took place with a total of 52 interviewees. Approximately half of the interviews ($N = 13$) were one-on-one, while the remaining ($N = 11$) included between 2 to 8 interviewees in each. Interview questions focused on the state of the cellular agriculture industry and technologies, potential benefits and issues, challenges and barriers to adoption, factors that would contribute to the emerging industry's ability to be beneficial for society, and possible futures for the industry. The interview protocol and study were approved by the University of the Fraser Valley's

TABLE 1 List of Interviewees and focus group participants.

Type of organization	Number of interviewees	Number of focus group participants	
		Participants who were also interviewees	New participants
Academia	8	3	1
Cellular Agriculture-Related Startups	6	2	0
Conventional/Traditional Agriculture and Food Business	6	1	1
Biotechnology Companies	5	3	0
Investors and accelerators	8	3	1
Provincial Government Stakeholders	8	4	0
Federal Government Stakeholders	8	4	0
Not-for-Profit	1	1	10
Other Stakeholders	2	2	0
Total	52	23	13

Human Research Ethics Board (file number: 100662). Letters of consents were signed by participants, and returned to the researchers via e-mail. The next phase of data collection included organizing and transcribing a series of three focus groups comprised mostly of previous interviewees (N = 23) and an additional set of participants (N = 13). Focus groups are guided small-group discussions, serving as a means to triangulate data and validate findings from the individual interview phase (Lambert and Loiselle, 2008). The focus group participants were given a list of benefits, challenges, and actions/priorities for cellular agriculture, and were asked to discuss those which appeared most important, irrelevant, and/or were missing. This list was created based on a preliminary analysis of interview data (Ontario Genomics, 2021).

Altogether, 52 stakeholders were interviewed and 36 stakeholders (23 of whom were previously interviewed) took part in 3 focus group sessions, representing federal and provincial governments, academia, start-ups, industry, funders, NGOs, and international organizations (Table 1). Representatives of cellular agriculture startups, traditional agriculture and food, and investment firms were predominantly from the United States and Canada. Provincial and federal government actors who took part in this study were from Canada, specifically. The geographical focus of the participant sample was due to the Canadian context of the larger study (i.e., Ontario Genomics, 2021); however, from a broader research perspective, North America provides an interesting case study because it is a key region for the emergence of the cellular agriculture industry, yet its social networks and governance considerations have not been widely explored in the literature.[1] We acknowledge that our interviews were limited to English speaking stakeholders, neglecting a large part of the world involved with and/or affected by any transition to cellular agriculture. Nevertheless, given the nascency of this industry, our focus on this geographic context and relatively large qualitative dataset captures the current industry context, like similar studies (see, e.g., Moritz et al., 2022).

1 In contrast to, for example the United Kingdom (Cellular agriculture in the UK: a review)

To address our research questions, we undertook a grounded theory approach. We started first with an inductive, open coding, thematic content analysis of our interview data. An inductive approach to thematic content analysis evolves, such that "the codes and themes derive from the content of the data themselves" (Braun and Clarke, 2012, pg. 58). In analyzing the interview and focus group data, we identified key considerations for future trajectories of a cellular agriculture industry as described by the participants, allowing the data to 'speak for itself.' After the inductive coding was completed, we undertook axial coding to categorize and bin codes into broader categories or dimensions. An axial coding exercise categorizes the themes that naturally emerge from the data in order to "develop more abstract conceptual categories" (Scott and Medaugh, 2017, pg. 1).

Upon delineating these broader theoretical categories from our data, we then developed a framework through which to plot futures for novel agri-food technologies. Moving beyond critiques of narratives, framings or promises, this framework can be used to qualitatively describe diverse futures. We drew from similar exercises that plot qualitative variables to arrive at our chosen framework. For example, Carolan (2018) represents the diverse ways farmers and digital equipment manufacturers perceive 'access', along a continuum of overlapping Venn diagrams. Similarly, Rotz and Fraser (2015) model food system resilience across a 3-Dimensional cube. The authors argue that movement across the cube in specific directions creates 'more resilient' futures. We drew from both these studies to develop our framework, where our emergent themes can be used to qualitatively plot food system futures.

3. Results

3.1. Considerations and dimensions of cellular agriculture futures

3.1.1. Decentralized: the importance of place, culture, and location

We found that place is a crucial dimension to consider when describing some of the social, economic, and environmental tradeoffs for cellular agriculture. We define place as a function of the local social, economic, and environmental contexts (Cheng et al., 2003) in which cellular agriculture operates and serves as part of the food system. From a consumer perspective, cellular agriculture products will appeal differently to individuals of diverse backgrounds, beliefs, and economic status. The potential market for cellular agriculture proteins in Canada and the United States is incredibly diverse. There will likely be strong reactions from consumers, both positive and negative, to the introduction of specific forms and types of cellular agriculture proteins that vary between places. Beyond consumers, reactions may also vary between communities and places that have strong ties to conventional agriculture and/or fishing industries. Agri-food production and business practices have a long-standing history in Canada and the United States. Thus, there will likely be strong reactions from farmers and producers, both positive and negative, to these novel proteins. While in contrast, conventional farming practices and traditions are longstanding. For example, in Canada there are strong heritage and identity associations in Alberta with beef and cattle-derived proteins. As one participant described:

> …some farmers have been around their farms for hundreds of years. They're looking to pass them on to future generations…if they had to completely pivot and do things differently and look at getting into cellular agriculture rather than conventional agriculture, that might be a hard, hard turn around, a hard idea to adapt to.

Similarly, Atlantic communities in Canada have long histories of harvest and processing cod and lobster. To some participants, understanding what a cow-derived or a whitefish-derived cellular agriculture product will entail for diverse consumers as well as communities is critical knowledge as products begin to commercialize.

Place also defines and shapes the environmental footprint of cellular agriculture, specifically the places and regions in which facilities are located and inputs are sourced. Cellular agriculture has potential to be extremely energy intensive, and its environmental performance depends on the energy sources, land, and feed inputs that go into individual operations (Mattick et al., 2015). Choice of facility location and feedstock will significantly influence the environmental footprint of cellular agriculture facilities. As many interviewees and focus group participants noted, cellular agriculture is potentially energy-intensive production process if care is not taken to decarbonize electricity sources or reduce overall energy usage through targeted site selection. Harvesting waste (e.g., heat, byproducts) outputs from local and regional industries could mitigate against some of the potential environmental impacts of cellular agriculture production. Such a scenario would likely entail shifts in land-use practices, and a rethinking where 'agriculture' takes place. As one participant noted: "I think there's opportunities [to cellular agriculture] for building agriculture in urban areas."

3.1.2. Centralized: bigger and better to meet future protein demand

Participants emphasized how cellular agriculture can embed within global protein value chains. Some comments indicated that place-specific dimensions are subordinate to the need to centrally scale-up production to match increasing global demand for livestock proteins. Attention here is given toward enabling increased scales of production through technological enhancements and collaboration with existing big food and agriculture players. This is with the goal of incorporating cellular agriculture into existing food and agriculture industrial chains.

A key consideration here is for the role that big food and agriculture play in accelerating the transition toward cellular agriculture. Some interviewees and focus group participants stressed that large protein producers, processors, distributors, and food retailers will have an important role to play as cellular agriculture products commercialize:

> And too [the food system is] highly integrated and already exists and has countless interactions and relationships and contracts and business agreements and so, you know, the ADMs of the world and the Cargill's of the world, *et cetera*, are still going to run the food system in the future, no matter how that food is produced.

Participants indicated that the clout existing actors have within the food system is and will be lasting; support from these players is crucial for novel cellular agriculture players as they access large markets. Furthermore, buy-in from existing industry players will provide consumers with increased trust that these novel products are safe and represent a suitable alternative. Overtime, this may manifest in mergers and acquisitions as traditional agriculture players embrace cellular agriculture:

> So [big protein companies] themselves are actually looking at bio manufacturing as the future to increase their own margins…And so and I think, you know, I think this is something we are in early days. **They might just want to be an investor. But as these companies mature, I'm sure there's going to be acquisitions by these big companies** (**emphasis added**).

Interviewees and focus group participants also highlighted the importance of scaling cellular agriculture to respond to food insecurity and the increased demand for animal-derived proteins at a global scale. Rather than focusing on concerns about the local markets (and the cultures that may be affected by cellular agriculture transitions), participants discussed how cellular agriculture products could reach or exceed parity with traditional livestock, globally. Participants highlighted the importance of scaling to make cellular agriculture products viable.

3.1.3. Open: cellular agriculture and the public good

Many of the interviewees and focus group participants expressed that minimizing risks and barriers of entry to the industry is crucial to developing a robust cellular agriculture industry. Currently, there is little to no public funding for the industry that exists (outside of Singapore, Netherlands[2]), although other governments from countries such as the United States, and Israel, are supporting the industry in other ways. Most seed funding is secured through private sector and angel investment.

2 The Dutch government in April 2022 announced 60 million Euros of funding to establish a cellular agriculture ecosystem in the Netherlands (https://gfieurope.org/blog/netherlands-to-make-biggest-ever-public-investment-in-cellular-agriculture/#:~:text=The%20Dutch%20government%20has%20announced%20%E2%82%AC60%20million%20)(%2465.4,and%20producing%20animal%2Dfree%20dairy.)

> "There's a lot of funding, which is…great, basically being driven by venture capital funding at this point of time."

A number of participants argued for shifting from a venture capital-driven supporting ecosystem toward a government and public sector-supporting ecosystem that incentivizes long-term research with commercial potential. The bulk of current investment (private capital) in cellular agriculture relies on rapid and large-scale returns and is insecure over time, as described by one participant: "…venture typically has like a 7-to-10-year exit horizon. And [cellular agriculture] is not an industry that's going to be fully up and running and turning out…within seven years."

Funding to support start up designs and broad-based research with commercial potential would serve to strengthen the emergence of a robust cellular agriculture industry. It was noted that this type of funding should support industry research from conception to commercialization:

> …we tend to invest a lot on the R&D side and then we end up with a stall point. But we know that a lot of times when governments (are) involved in the pre commercialization…up to the pilot commercialization side, that projects tend to be more successful.

Other participant comments related to the value of public sector support in the form of research infrastructure. Besides direct funding to proposed research designs and start-ups, public funding could also support the development of accessible infrastructure for research, innovation, and start up. University and public-run accelerators could support spaces for easy, accessible, and collaborative use of critical infrastructure for cellular agriculture (e.g., bioreactors, lab space, genomic sequencing technologies). Such publicly-funded supports could serve the dual purpose of enabling innovation, while also promoting or mandating open access research. Currently, most research and development in the cellular agriculture industry is patented and guarded by private companies and startups. Given the early stages of this industry, it is unsurprising that pioneering companies are relatively secretive over their techniques and technologies for cellular agriculture production. Yet, to some interviewees and focus group participants this poses a challenge for the industry as it matures, furthering the potential for oligopoly or monopolistic market conditions:

> Again, because of the nature of the space being kind of heavily IP guarded right now, like a lot of the start ups are working on their own, which is, I think, OK for the time being. But as they start to scale and go big time, there's going to be a need to kind of come together.

Only a handful of participants explicitly discussed the potential for cellular agriculture production to be used as tools for community food security or international food and agricultural development. Cellular production tools could be distributed at low cost to remote communities with little access to global value chains. For example, one participant described the potential for cellular agriculture production to occur in remote regions of Canada, specifically:

> Covid-19 highlighted that for many parts of the world, empty grocery shelves, that people we are seeing for the first time, that's…another benefit that cell agriculture could offer to Canada as well. In particular, places like northern Canada, like the territories, food usually needs to be flown in there because it's hard to grow food. If accepted by all populations, it could be part of a food security resolution to help ensure some more food security in other parts of Canada like that.

Another participant argued further that cellular agriculture products ought to scale to a price point at which they can be purchased across multiple classes of individuals. Catering solely to niche markets will not affect broader change to addressing food insecurity:

> …If … a person living paycheck to paycheck, can afford to go buy at a McDonald's, like, [are cellular agriculture products] going to be sold at a McDonald's is sort of the question. I think if we get there, that's when this model will work. If you are just catering to people who are rich then I do not see the benefit.

3.1.4. Closed: cellular agriculture and the private good

In contrast to the proponents of public sector support models, other interviewees and focus group participants emphasized the importance of competition as a means to drive the price of production downward, supporting a transition toward cellular agriculture. In this vein, IP can be used to attract top talent and incentivize commercial research and the scaling up of production. A subset of participants perceived universities and government as a hindrance to competition and the development of a robust cellular agriculture industry. These participants suggested that government should have a minimal role in cellular agriculture transitions, consisting mainly of removing red tape to research, production, and commercialization. These participants also indicated that university involvement is often 'at odds' with commercial interest, and should instead prioritize research with commercial potential. Here, third-sector and private sector incubators and accelerators are promoted as potentially more productive models to follow to create a robust (i.e., competitive) cellular agriculture sector.

> University is not where companies can grow very fast and they need to move very fast. They need to make independent decisions. **The IP has to be there.** It has to be clear. And universities just kind of block these things for companies, make it very challenging. And if there are, there is funding that is available to sort of help startups that are formed outside universities. That is, I think is completely absent (**emphasis added**).

A common prediction presented by many participants was that cellular agriculture will initially develop as niche products. Rather than enter the market as a scaled, affordable, potentially widely-consumed good, these products will emerge as expensive experiential foods, with limited distribution and available from particular restaurants. Furthermore, it was suggested that these products will cater toward specific populations, who crave unique 'food experience' and/or are concerned with industrial livestock practices. By extension, such a niche market would be accessible only to those willing to participate and with sufficient income, but would ultimately be expanded, and would extend the public conversation regarding cellular agriculture:

> …you'll see likely more high end restaurants having small samples similar to what Impossible Foods was when it first came to market at high end restaurants in the US, small samples, high priced, but starts the buzz and starts the conversation that this can become a part of our food system.

3.1.5. Complementary: including farmers for the environment and value-addition

A common refrain in our interviews and during focus groups was that it is too early to know or predict what market cellular agriculture will penetrate. Will it replace conventional protein production, as some early news headlines claimed? Or, will it join the chorus of alternative protein products (e.g., plant-based), appealing to a different consumer altogether? Several participants expressed higher confidence in the latter possibility:

> And then I know what we have seen on the alternative protein side is that they are not really…those products are not taking away from the market share of meat. It's growing a new category.

Currently, much of the discussion regarding cellular agriculture frames it in opposition to conventional livestock. Contrastingly, some participants noted that reframing cellular agriculture as complementary to, rather than in competition against conventional meat, will enable a shorter and more productive pathway forward for the industry:

> …If the charge is being laid [that] we are going to replace meat products with [cellular agriculture], it'll be a steeper climb versus going into it with eyes wide open to say, hey, this is a new source of nutrition. It has better bioavailability. It has these health benefits. It has all these benefits.

One common method described by multiple participants to integrate cellular with traditional industry is through the utilization of agricultural byproducts and the integration of cellular agriculture as a low-value addition rather than replacement for livestock products. Using various byproducts as direct feed inputs for fermentation or cell-culture techniques could also reduce agricultural waste emissions and mitigate against potential land-use tradeoffs to growing feed for cellular agriculture (similar to bioethanol production). Agricultural and forestry byproducts can play a large role in the development of feedstock for fermentation and cell culture processes. As one participant describes, Canadian agriculture can provide abundant inputs into a thriving cellular agriculture industry:

> And the benefit to the Canadian ag sector is to focus more on kind of downstream processing to higher value products. It's just a no brainer. I mean, whether it's bio-based manufacturing, using various agricultural products as inputs to those processes or cell ag, we are perfectly positioned to be a leader in this space because we own a lot of the inputs.

Some interviewees and focus group participants predicted that cellular agriculture products will likely only function as a value-added ingredient into global value chains. These cellular-produced ingredients could be added into processed products, used as a livestock feed, or incorporated into hybrid products (including plant, and meat-based hybrids).

A subset of participants who were more skeptical of the disruptive potential of cellular agriculture also identified the benefits of animal agriculture for the environment and emphasized the importance of labeling regulations. These individuals highlighted the crucial role of livestock grazing in maintaining biodiversity in grasslands and contributing to natural nutrient input markets (e.g., manure). Regarding labeling, these participants discussed it as important to ensure transparency when introducing cellular agriculture products to market by clearly distinguishing them from traditional agricultural goods. This was viewed as both a means for minimizing conflict with existing livestock industries and a necessary and helpful clarification for consumers. One interviewee shared that in their preliminary market research, clear descriptions of cellular agriculture products were found to associate with more positive attitudes toward these products:

> I think people thought if you give to [too much information], basically…it's going to turn people off because it's, you know, science-focused or whatever. But the way we phrased it anyway seemed to work pretty well.

3.1.6. Replacement: Safeguarding the environment and reducing animal suffering

In contrast to the views around complementarity, other interviewees described the relationship between cellular agriculture and traditional agriculture as more disruptive in nature. This view was not discussed across any of the three focus groups. These individuals described cellular agriculture as a method to 'do without' and 'phase out' animal-based agriculture. The justification for such disruption is largely framed in ethical and environmental terms:

> So animal agriculture is second largest contributor to climate change, largest contributor, deforestation. It's the source of massive ethical issues. It's just terrible on every level. And the problem is that our meat consumption *per capita* continues to increase in North America year over year. And if the population increases in meat consumption *per capita* increases, that means we need more meat. And if we continue doing things the way that we have, we are just going to burn the whole globe down. So we do not really have a choice but to look at alternatives as far as I'm concerned.

While some participants highlighted what cellular agriculture can do for traditional agriculture, others instead highlighted what traditional agriculture can do for cellular agriculture. This was a common theme described during focus groups. Participants noted how livestock farmers could shift their core business models to support an emerging cellular agriculture industry, or might indeed be transitioned to a new employment landscape. For example, from an employment perspective, some interviewees and focus group participants recognized the labour disruption potentially caused by a transition to cellular agriculture, and how the novel industry could absorb some of those losses:

> … maybe there are hopefully some facilities that can absorb if there are any potential losses in the traditional role, **there's hopefully enough manufacturing in this [cellular agriculture] space that can absorb those losses that we might see in the farm**. So I'm hoping that there could be large scale facilities that can actually employ people. That's what I would like to see.

Similarly, novel roles for livestock farmers could be developed. These livelihoods could be retained both for the conservation of livestock genetic materials as well as for securing and maintaining more 'prized' cell lines. In such scenarios, animal husbandry could be practiced in a much more harmonious way.

3.2. A framework to assess novel Agri-food technologies: application to cellular agriculture

In this section, we build on futures studies by presenting a series of dimensions (identified as per the analysis discussed above) that define different cellular agriculture futures. We synthesize a set of three dimensions across which to consider cellular agriculture futures from our interview and focus group data. We suggest that the three key dimensions that define and shape potential cellular agriculture futures are: centralization, accessibility, and integration. These dimensions inform a framework that we have structured as a cube (Figure 1).

The framework's cubic structure provides a three dimensional continuum across which futures can be formed, pursued, debated, and re-formed (Rotz and Fraser, 2015). The cubic form implies a continuum where futures are not likely to be defined completely by one or another variable (e.g., completely 'accessible' or completely 'inaccessible'). In so doing, futures are not dichotomized as binaries, rather they are considered along more nuanced spectra. In what follows we describe each of these variables and their representation within the literature and our dataset, determined through our axial coding process.

3.2.1. Centralization

Centralization relates to the scale of cellular agriculture operations, and how these will be distributed spatially, economically, and with respect to power and ownership. The centralization dimension includes the extent to which big agri-business (if at all) participates (as well as their role) in transitions to novel agri-food production systems. A key question (Table 2) regarding centralization is: how will transitions toward a novel agri-food technology be organized geographically?

The themes from the interview and focus group analysis that informed the development of the centralization dimension include place and scale. A highly centralized future for cellular agriculture is one in which a few key traditional protein players acquire and merge cellular agriculture operations as part of their core services, distributing these 'novel' proteins across global value chains. In this future, place-based considerations are less influential, in terms of product design or facility placement. Here, less attention would be placed toward *where* specific facilities will be located or *for whom* products are designed. Cellular-produced proteins would be designed not for specialized, local markets, but for broader global value chains and a global protein marketplace. Relying on buy-in from large agricultural players across the value chain would be crucial to facilitate this centralized future.

In contrast, a highly decentralized future for cellular agriculture would be one in which a plethora of operations are integrated within circular and more locally– and regionally-scaled value chains. Somewhere in-between is a future in which a combination of novel industry actors and traditional agriculture players work to develop and distribute products across multiple scales. In a highly decentralized future, there would likely be diverse cellular-produced proteins exchanged within and for local/urban food systems. Working with and recognizing cultural preferences and norms around specific proteins would be a key research consideration for cellular agriculture stakeholders. Individual facilities would also likely be embedded within local industrial value chains, engaging in more circular patterns of resource and byproduct exchange. This would likely require that facilities be located directly within or close to urban and peri-urban areas.

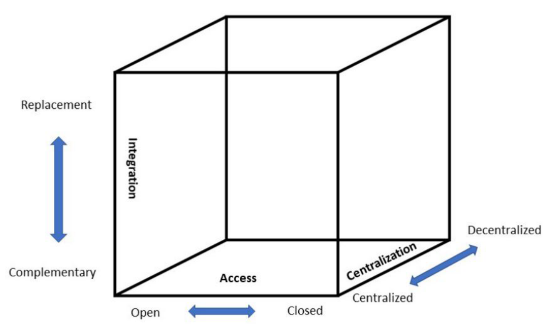

FIGURE 1
Framework to assess cellular agriculture futures.

3.2.2. Access

Access considers the degree to which the knowledge, capital, and infrastructure supporting novel agri-food technologies are 'open' or 'closed'. It also incorporates the broader economic governance of food technologies and food commodities, as public or private goods. Access is a measure of the degree to which knowledge, capital, and products are organized as public or as private goods. The governance of intellectual property (IP) is a critical dimension to consider, as it affects accessibility to the scientific knowledge underlying novel foods and food technologies. Access is also a function of measures in place for enabling research and data sharing and minimizing risks to actors entering a field, as well as by whom these measures are implemented (private vs. public vs. non-governmental/third-sector). Finally, access considers the governance of food products themselves (i.e., not just the technologies that produce them), relating to considerations around whether these products constitute a niche commodity or can substantially increase food supply and affordability across scales. A key question (Table 2) regarding accessibility is: to what extent are novel food technologies treated as a public or a private good?

The themes we observed through data analysis that informed the development of the access dimension include fostering a collaborative versus a competitive landscape for cellular agriculture transition. Overall, an extremely 'open' cellular agriculture future would be one in which there are strong public and civil society-led incentives for open access research into the basic science and infrastructure supporting cellular agriculture. In an extremely open future, we could envision the treatment of cellular agriculture proteins and infrastructure as 'common public goods' and distributed as such or, in a slightly less radical vein, where the price of products moves beyond parity with traditional agriculture. An extremely 'closed' cellular agriculture would be one in which there are strong private incentives for increased IP production, and where proteins are marketed and distributed as niche, high-value products. Somewhere in-between is a

TABLE 2 Dimensions of the cellular agriculture futures framework, with related questions for considering futures and relevant participant quotes.

Dimension	Representative quotation and application to cellular agriculture	Questions for consideration
Centralization	It's super unclear how [cellular agriculture] is going to play out because it's early days, like it's unclear how verticalized these companies are going to be.**There's a non-zero chance that the future is three companies that produce all the meat**, all the cell ag meat in the world, and they are based out of the US. I do not know. But then they have production facilities across the globe and then they need facilities in order to expand their production footprint. So. Or you can have hundreds of companies, or [it] could be that you have also hundreds of companies that aren't, you know, are dealing with different stages, whether it's media optimization or providing bioreactor infrastructure (**emphasis added**).	Will novel agri-food technologies contribute to global food value chains, or will they contribute to local food production at a regional/city scale? Will micro-enterprise be incentivized and a distributed manufacturing base be established, or will this industry operate under 'business-as-usual' scale-up scenarios? Will existing 'big ag' players acquire these startups and incorporate novel foods and agri-food technologies as part of their core business services?
Access	Most people aren't going to be able to afford [cellular agriculture product] currently it's a novelty. So how can we actually get enough protein to meet the world's needs? Is this the way to do it?	Is Intellectual Property (IP) considered as an accelerator or a hindrance to the development of a novel agri-food technology industry? What research and infrastructure supports ought to take precedent, and by whom are these supports created (non-profits, private organizations, public institutions)? Will products created through these novel methods and technologies scale to contribute to global food security, and how will they do so?
Integration	We're seeing consumers diversify their diets substantially. If you look in people's fridges today, there is a much greater variety than there has ever been.**And is [cellular agriculture] going to be a novel product that you eat when you go to a restaurant or on a special occasion you are trying to show off? Or is this something that will universally replace whatever product it is an analog to?** I think all those questions remain important in terms of crossing the hurdle to get started, but then also to see…the size of the market potential that they have (**emphasis added**).	Will novel agri-food technologies be integrated within or alongside existing value chains, or replace those chains in novel ways? What role will there be for farmers in a transition to widespread use of these novel agri-food technologies? How, or in what ways, are these novel agri-food technologies framed as 'disruptive'?

We note that the questions for consideration were derived from our examination of the themes identified through inductive coding (section 3.1).

future in which public-private partners work together to scale cellular agriculture to reach parity with traditional agriculture.

3.2.3. Integration

The integration dimension captures the extent to which the products created through novel agri-food technologies replace or complement existing agricultural industries and supply chains. Integration directly confronts the promises and claims of 'disruptiveness' or 'transformability' espoused by proponents and critics of novel food technologies, respectively. Integration relates to the potential opportunities for economic co-participation between novel and incumbent industries. It also involves considerations around the potential market for novel technologies, such as if products will target conventional products (i.e., direct market competition) and, if so, what specific species of crop or livestock will be affected. Moreover, integration highlights the extent to which novel products will appeal across diverse markets, including plant-based eaters and consumers of small-scale or alternative food systems, versus traditional agriculture's bulk marketbase. Will these products be sold at supermarkets, farmers' markets, or both? An important question (Table 2) the integration dimension presents is: to what extent (if at all) will novel food technologies interface with traditional agriculture?

The themes we identified through interview and focus group analysis for cellular agriculture futures that informed the integration dimension consist of industry disruption and farmer inclusion. In a highly complementary future, cellular agriculture and traditional agriculture would use synergies across their value chains to enable each others' sectors. For example, cellular agriculture producers could produce ingredients to plug into traditional food products, pet foods, or livestock feed, rather than designing novel foods altogether. In this scenario, cellular agriculture would exist to provide value-added opportunities for farmers and ranchers (as well as fishers). Moreover, cellular agriculture would contribute to satisfying increasing global demand for protein rather than taking away shares of the protein market from traditional agriculture, potentially even through producing niche proteins not currently consumed on a wide basis (e.g., wild game, bison, or boar meat).

In contrast, in a high replacement future, cellular agriculture would compete with traditional agriculture directly, disrupting the sector and enabling a broader transition to new sources of protein. Here, farmers could transition to the new industry through novel training programs, or adapt through specialized livestock genetics programs that breed cell lines for cellular agriculture and/or for the preservation of livestock genetic diversity. In this scenario, cellular agriculture would continue to produce traditional agriculture livestock proteins, including beef, pork, chicken, and widely consumed fish species such as tuna or salmon (see Table 2).

TABLE 3 Eight scenarios for cellular agriculture.

Eight scenarios	Hypothetical scenario description
1. Toward Replacement, Open, Centralized	Cellular agriculture attempts to replace livestock production. Public-private collaboration makes infrastructure and technology supporting cellular agriculture more accessible, and a few key cellular agriculture players produce the bulk of cellular proteins at an affordable cost to most consumers.
2. Toward Replacement, Open, Decentralized	Cellular agriculture attempts to replace livestock production. Public support for open access research and infrastructure provisioning provides communities with means to produce their own proteins of choice.
3. Toward Integration, Open, Centralized	Cellular agriculture industry is grown alongside traditional livestock production. Public-private collaboration makes infrastructure and technology supporting cellular agriculture more accessible, and a few key traditional agriculture players produce the bulk of cellular proteins at an affordable cost to most consumers.
4. Toward Integration, Open, Decentralized	Cellular agriculture industry is grown alongside traditional livestock production. Public support for open access research and infrastructure provisioning provides communities with means to produce their own proteins of choice.
5. Toward Replacement, Closed, Centralized	Cellular agriculture attempts to replace livestock production. Private and venture capital-led investment scale-up cellular agriculture to the point where prices match or are slightly more than current animal-derived proteins.
6. Toward Replacement, Closed, Decentralized	Cellular agriculture attempts to replace livestock production. The cellular agriculture market stays fragmented, with multiple competitors and incentives for private-led IP generation.
7. Toward Integration, Closed, Centralized	Cellular agriculture industry is grown alongside traditional livestock production. A few large protein players buy-out smaller cellular agriculture start-ups.
8. Toward Integration, Closed, Decentralized	Cellular agriculture industry is grown alongside traditional livestock production. The cellular agriculture market stays fragmented, with multiple competitors and incentives for private-led IP generation.

These are hypothetical futures based on our framework, and were not described by participants in this study.

3.2.4. Hypothetical scenarios – application of framework

Drawing from Figure 1, we describe eight scenarios represented as each point of the 3-dimensional cube (Table 3). Importantly, these scenarios were not described by any interviewees within our research. These are hypothetical futures, manifest across the three dimensions we observed and analyzed in our data.

Each of these scenarios described above may be more or less desirable to diverse stakeholders, and each engenders further tradeoffs. For example, a more 'radical' approach to cellular agriculture's development is likely Scenario 2. In this future there is little room for traditional protein production, and novel assemblages of actors (i.e., government, civil society) would play a stronger role in the pursuit of cellular agriculture's development. While a more inclusive approach to development, this scenario may fail to scale to affect or satisfy increasing global demand for protein. In contrast, a 'business-as-usual' scenario for cellular agriculture is likely Scenario 7. In this scenario, there would be little change in terms of what proteins are available in the marketplace, and what large protein businesses are involved in the global-scale production, processing, distributing, and retailing of proteins. While potentially scaling up more quickly and efficiently than other scenarios, this would do little to address the challenges of corporate concentration in the food system and would likely only result in incremental improvements to the environmental costs of livestock production.

We note that these scenarios are *potential* pathways (e.g., Moore et al., 2018), not singular pathways leading to some predetermined destination. As such, these scenarios are all likely to be enacted, pursued, and indeed, happen concurrently. Already, we can see tensions in the literature between 'open' versus 'closed' futures (e.g., Chiles et al., 2021), 'replacement' versus 'complementary' futures (e.g., Newton and Blaustein-Rejito, 2021), and 'centralized' versus 'decentralized' futures (e.g., Jönsson, 2020; Dueñas-Ocampo et al., 2023). Absent the top-down imposition of a strategy to develop cellular agriculture, its development in the coming decades will thus likely fall somewhere between any and all of these diverse scenarios. Further, while we treat each dimension separately in the original framework (Figure 1), we note that in practice there may be interdependency between each and as such some scenarios may be more likely to occur than others. As one example, open scenarios are more likely to be decentralized, given the distributed nature of open innovation systems (Carson, 2010). However, this does not preclude the possibility of having scenarios that are simultaneously open and centralized, or that are closed and decentralized.

4. Discussion

The framework developed through this research for identifying novel food technology futures was developed based on cellular agriculture research, but it relates to other frameworks for evaluating and describing food systems' transitions. The three dimensions identified through our analysis are both specific to cellular agriculture, as well as relevant to broader, more critical debates over food system futures. In particular, centralization, access, and integration have featured implicitly and explicitly in such debates for decades. Yet, cellular agriculture provides novel fodder for this debate, as its technical, material, and social implications are unique and non-trivial.

Centralization is a term widely featured in critical agri-food studies. This term is often synonymized with 'consolidation', and can be wielded with the intent of clarifying power imbalances between actors across the food system, and highlighting corporate concentration in the food system (Clapp, 2014). In this vein, centralization and consolidation are associated with concerns over the social and economic welfare for those most vulnerable participants in the food system. Another discussion of centralization clarifies the form of real, material networks of food commodity flows (e.g., Rotz and Fraser), as well as the nature of interactions between food system actors across multiple scales (e.g., Tendall et al., 2015). Where networks are comprised of fewer actors with stronger 'ties' between each, the system is more vulnerable to shock and disturbance (Homer-Dixon et al., 2015). Some view centralized networks as efficient due to their economies of scale, while others view decentralized (i.e., distributed) networks as more deliberative and collaborative, engendering more diverse and democratic outcomes (de Roest et al., 2018). Centralization is a prominent theme in much of the cellular agriculture literature, considering the extent to which the industry could become captured by big agriculture companies or is governed as a smaller-scale distributed industry (Mouat and Prince, 2018; Jönsson, 2020).

A key theme that emerged through this research relates to the potential for consolidation to play out in the cellular agriculture space. There is potential for traditional protein players (producers, processors, distributors, retailers) to play a significant role in the industry's development, either as shareholders or potentially through the acquisition of mature startups. To many participants, this involvement was described as a 'good' thing, as it enables advanced scales of production and a more rapid transition toward cellular agriculture futures. Yet, to other participants, a more decentralized future with novel players was more desirable, where cellular agriculture could contribute to more self-sufficient, localized food systems, in both urban and remote areas. Given the uncertainty over the potential configuration of the future cellular agriculture industry, it is crucial to understand what extent of centralization is acceptable or indeed desirable by the diverse stakeholders that will invariably be affected by a transition to cellular agriculture.

A crucial finding from this study was the importance of place to discussions of centralization for cellular agriculture. Enacting a stronger emphasis on place directly confronts more centralized futures, as it requires a more distributed focus toward the myriad of local contexts, cultures, and economies in which cellular agriculture can be embedded. A place-based lens for cellular agriculture futures would contribute to future discussions of the industry's potential political, social, and environmental impacts. Leveraging an interest in addressing the environmental impacts of cellular agriculture through targeted site selection could be one strategy for considering and assessing the potential suitability for cellular agriculture at a particular locality. Additional considerations around suitability could incorporate social factors, including what communities might be affected by a cellular agriculture facility, what consumers may buy-in or be unable to buy-in to local cellular agriculture products, and what products might appeal (or not appeal) to particular communities. Social science literature supporting cellular agriculture often focuses on consumer-facing questions around palatability, perceptions, and potential markets (e.g., Bryant et al., 2019). Future research could undertake community-based research approaches that take into consideration place-based needs, ideas, and cultural contexts, allowing communities to self-determine their interactions with emerging cellular agriculture technologies and facilities.

Access is another term that is widely considered across critical food system discussions. Accessibility often refers to the ability of individuals to procure food, considering its price, availability, and various enabling (or hindering) social and political factors. Access is also a critical concept applied to agri-food technologies, and if and how producers can effectively utilize new tools (Carolan, 2018). Crucially, how technologies are designed for use, repair, and dissemination influences the degree to which they provide benefits to users/producers.

More accessible futures for cellular agriculture would also likely echo the sociotechnical pathways outlined by Chiles et al. (2021), including the development of open data and technology standards and open knowledge platforms. Similar to debates regarding digital agriculture technologies and other novel food tools, our research identified a general interest in increasing public participation in cellular agriculture transitions. This could either be through creating broadly accessible infrastructure for aspiring researchers and entrepreneurs, or through incentivizing open access research with commercial potential.

Yet, there is a clear tension between private and public sharing of IP, infrastructure, and basic science supporting cellular agriculture. On the one hand, if agri-food technologies are made 'open', it is not immediately clear if cellular agriculture would be considered more accessible. In such scenarios, absent public policies to support training, education, and adoption for these novel tools, it is uncertain (and perhaps unlikely) that new actors could readily make use of the open source cellular agriculture technologies. As Rotz et al. (2019) contend, regarding corporate use of open source software: "In this way, open source technologies simply do not offer a serious challenge to the status quo in the absence of the kinds of structural shifts necessary to regulate corporate integration" (pg. 212). On the other hand, making agri-food technologies too 'closed' prevents participation in this industry. For example, if the future of cellular agriculture is to be designed and completely run by large-scale agri-food business, it may prevent broad-based, public participation and control of these food production methods, as well as the benefits that participation/control could provide for local, decentralized food systems.

To date, future scenarios for cellular agriculture have not extensively considered how food commodities produced through these technologies could be governed. In this research, proteins produced through cellular agriculture were found to potentially exist across a wide spectrum of accessibility. Interviewees and focus group participants noted that cellular agriculture products could consist of cheaper ingredients to be embedded within global food value chains, niche commodities, and even as a tool to alleviate food insecurity in remote regions. The research also identified that access would be lower for cellular agriculture products if they are governed and commercialized as niche, high-value commodities. Such findings echo critiques of plant-based alternatives and insects: alternative proteins marketed as sustainable food security solutions, but sold to consumers at a premium price (Müller et al., 2016). In contrast, other participants described the potential for cellular agriculture technologies and products to be deployed in remote and/or food insecure areas. In such ways, the consideration for more radical proposals for cellular proteins as food commons was hinted at in our dataset, though not in the context of food sovereignty (e.g., Vivero-Pol, 2017). In these more radical veins, ownership of food and food technologies and self-determination in face of novel technologies are key dimensions to consider for more accessible futures.

There are many uncertainties over the potential social, economic, and environmental impacts of cellular agriculture, given that product demand has yet to be tried in widespread markets. Despite promises to radically alter the livestock industry and contribute to environmental goals for the agricultural sector, it is too early yet to know how consumers will respond, and what other sectors will benefit and/or compete with cellular agriculture products as they commercialize. Thus, there is a disconnect between the expectations of cellular agriculture and its potential real-world effects and outcomes (Mouat and Prince, 2018); it is yet uncertain to what extent cellular agriculture will or can replace traditional agriculture. Relatedly, the way in which cellular agriculture is framed will resonate very differently to various audiences (Bryant and Dillard, 2019). For example, individuals from communities that maintain more intimate relationships with animals through harvest and consumption (e.g., hunters, Indigenous communities, farmers, fishers, etc.) will likely have differing perspectives and reactions to the way in which cellular agriculture is marketed and discussed in the public.

Integration considers the degree to which cellular agriculture will interface with traditional agriculture. This is often discussed in the literature with reference to the points of contestation between the two industries, whereby protein is differentially labeled, discussed, and framed by both sets of actors (Sexton et al., 2019). However, crucial to our findings are framings of cellular agriculture that are complementary to rather than antagonistic with traditional agriculture. We found that many participants were keen to advance a more complementary framing that emphasizes the commensurability between both traditional and cellular agriculture value chains, and opportunities for livestock farmers. This allows us to ask: what may cellular agriculture do *for* traditional agriculture? This position was advocated by several stakeholders who took part in this study. Alternative proteins are often pitched as replacements for animal agriculture, leading to academic and public skepticism, as well as difficulty separating hype from actual industry potential (Guthman and Biltekoff, 2021). Our findings suggest that behind-the-scenes the conversation of industry experts is more nuanced than gleaned from otherwise public facing data. Similar to Moritz et al. (2022), we found that the potential for cellular agriculture to integrate with conventional agriculture is imagined as a business and transitionary opportunity. Future research is required to assess both the material and discursive potential for more wholly integrated futures for the protein industry.

There is a clear tension here with respect to the potential for livestock farmer participation in cellular agriculture transitions. In one capacity, advocates for a 'just transition' support the inclusion of farmers. Though the specifics of such inclusion are as of yet fuzzy, they could include livestock genetic diversity conservation or shifts toward manure production (rather than dairy or meat production). If inclusion takes the form of training and support to exit the industry, such policies risk the ire of industry and lobby groups. Similar debates have taken place for sectors such as coal and long haul trucking in response to the United States' government recommendation for coal miners and truckers to 'learn how to code', and are now being applied to agriculture (Blattner, 2021). Such government programs assume access to opportunity (i.e., training, skills) will deliver concrete economic outcomes for those affected by technological disruption: an assumption with very mixed outcomes (Greene, 2021). The genre of integration that takes place (complementary or full replacement) will depend on a myriad of factors, including the needs of those economically and culturally affected by cellular agriculture technologies. We argue that policies developed for cellular agriculture will differ substantially depending on the degree of 'integration' that is politically accepted by cellular agriculture, traditional agriculture, and public stakeholders.

Finally, a key finding of ours was that the specific form of protein produced through cellular agriculture 'matters'. As one of our participants suggests:

> And we got to think to that right now, most of the stuff you read with [cellular agriculture], if you look at it, it's always targeted toward meat…So I think we talk about agriculture, but we also got to think about, you know, all the other protein sources that that we are consuming now. And how do we augment that? How do we because as the world population grows, I think there will be more demand for protein. Some people will want the traditional protein and some people will be very happy using a substitute protein.

In more complementary scenarios, proteins without a widespread history of consumption could be developed to mitigate against potential conflict with traditional livestock products. This strategy might also include the further development of plant-based protein industries, e.g., improve taste, texture, nutritional profile. In more replacement-based scenarios, cellular agriculture research could continue to target commonly consumed meat products, such as beef, chicken, pork, and fish species such as tuna and salmon. In either case, the research that is undertaken now to develop cell lines, microbes of interest for fermentation, and supporting growth media and scaffolding will shape the trajectory for future research and commercial endeavors. The state of current livestock stem cell research, for example, is nascent (Post, 2012; Post et al., 2020), while more experimental efforts have developed products as unique as mastodon-derived collagen (New Harvest, 2016).

5. Conclusion

Novel agri-food technologies such as cellular agriculture have great potential to contribute to more sustainable food systems of the future. Yet, it is crucial that scholars, policy-makers, and food system practitioners consider and examine technologies' diverse possible futures in order to better understand how these tools may or may not fulfill their promises. The stakeholder consultation data used for this manuscript was based on interviews and focus groups with a broad representation of stakeholders to better understand their perspectives for the future of this set of cellular agriculture technologies. We found that the places in which cellular agriculture facilities and products are embedded and the scales at which facilities operate are key dimensions to consider as cellular agriculture is extended across diverse markets. How infrastructures, knowledge, and protein products themselves are treated, as public or private goods, will also likely contribute to the accessibility of cellular agriculture transitions. The framing of cellular agriculture as complementary to or in competition with traditional livestock will also shape its potential livelihood impacts. We then categorized these themes across three dimensions through which to qualitatively describe novel agri-food technology futures: centralization, access, and integration.

Our study moves beyond current studies that explore agri-food technology futures by developing a framework through which to identify and assess future scenarios for implementation. The framework developed in this research can be utilized to elucidate the key assumptions and potential tradeoffs to possible futures for agri-food technologies such as cellular agriculture. It can further be used to describe and identify desirable futures. This is of particular relevance to the public, where the application of this framework may serve to anticipate and design futures that are more inclusive and socially sustainable. To assess the validity of this model, future research is required that engages a variety of stakeholders to define possible and desired futures for cellular agriculture as well as novel food technologies more broadly.

Data availability statement

The datasets presented in this article are not readily available because no identifiable or unidentifiable datasets are able to be included with this manuscript, per our consent protocol. Requests to access the datasets should be directed to AG, alesandros.glaros@ufv.ca.

Ethics statement

The studies involving human participants were reviewed and approved by Human Research Ethics Board (HREB), University of the Fraser Valley. The patients/participants provided their written informed consent to participate in this study.

Author contributions

RN, EF, and LN contributed to conception and design of the study, and collected data for analysis. AG led data analysis and wrote the first manuscript draft. AG and RN wrote sections of the manuscript. All authors participated in data analysis and contributed to manuscript revision and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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