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The social implications of cellular agriculture and the future of food

Edited by
Evan Bowness, Evan Fraser, Robert Newell, Lenore Lauri Newman
and Rodrigo Luiz Morais-da-Silva

Coordinated by
Alesandros Glaros, Sarah-Louise Ruder,
Mariana Hase Ueta and Jessica Mukiri

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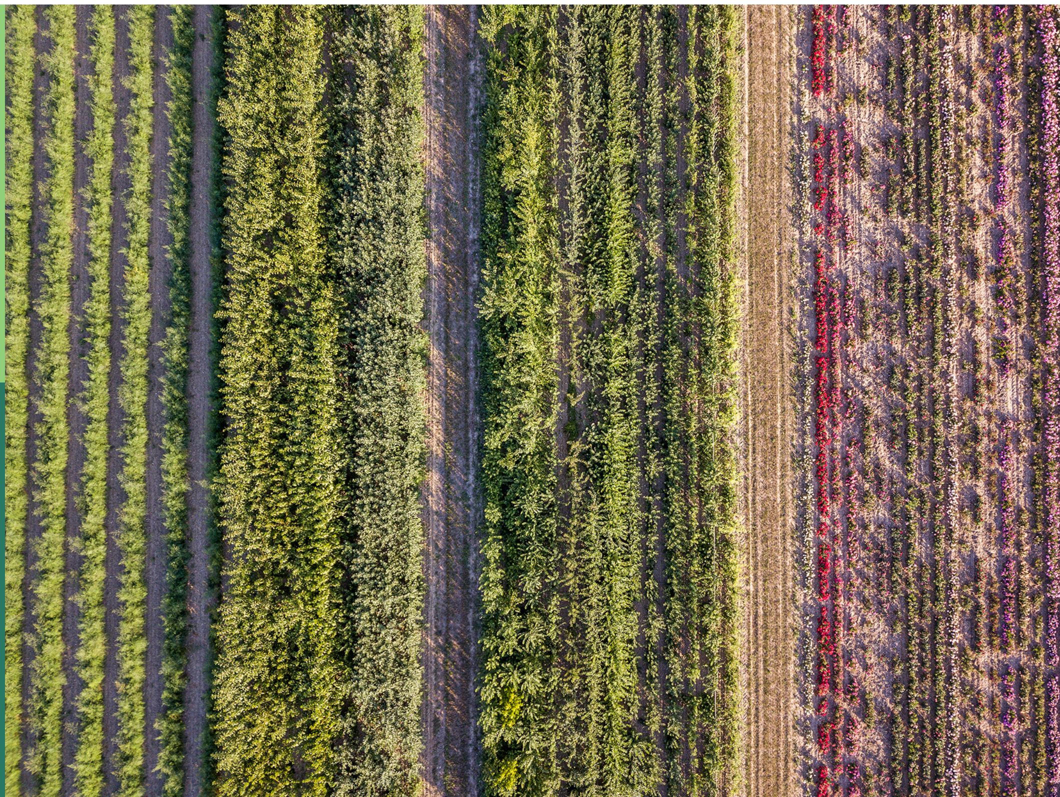

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The social implications of cellular agriculture and the future of food

Topic editors
Evan Bowness — Western University, Canada
Evan Fraser — University of Guelph, Canada
Robert Newell — Royal Roads University, Canada
Lenore Lauri Newman — University of the Fraser Valley, Canada
Rodrigo Luiz Morais-da-Silva — Federal University of Paraná, Brazil

Topic coordinators
Alesandros Glaros — University of Guelph, Canada
Sarah-Louise Ruder — University of British Columbia, Canada
Mariana Hase Ueta — Technical University Dresden, Germany
Jessica Mukiri — University of British Columbia, Canada

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EDITED AND REVIEWED BY
Patrick Meyfroidt,
Université Catholique de Louvain, Belgium

*CORRESPONDENCE
Evan Bowness
✉ ebowness@uwo.ca

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Editorial: The social implications of cellular agriculture and the future of food

Evan Bowness[1]*, Jessica Mukiri[2], Sarah-Louise Ruder[3], Mariana Hase-Ueta[4], Rodrigo Luiz Morais-da-Silva[5], Robert Newell[6] and Alesandros Glaros[6]

[1]Department of Geography and Environment, Western University, London, ON, Canada, [2]Institute for Resources, Environment and Sustainability (IRES), University of British Columbia, Vancouver, BC, Canada, [3]School of Sociological and Anthropological Studies, University of Ottawa, Ottawa, ON, Canada, [4]Philosophy Group, Wageningen University & Research, Wageningen, Netherlands, [5]School of Business and Management, Federal University of Paraná, Curitiba, Paraná, Brazil, [6]School of Environment and Sustainability, Royal Roads University, Victoria, BC, Canada

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Editorial on the Research Topic
The social implications of cellular agriculture and the future of food

Cellular agriculture has been widely promoted as a technological solution to myriad problems with conventional food systems. Cellular agriculture products are grown from culturing cells, including cultivated meat, dairy proteins from animal cells, and ingredients like cocoa and coffee from plant cells (Barzee et al., 2022). Proponents argue that it offers a way to produce animal-based proteins and other agricultural goods with lower greenhouse gas emissions, reduced land use, and fewer ethical concerns. However, while framed as a promising innovation, cellular agriculture remains embedded in longstanding assumptions—that food systems must continually expand to meet rising demand, economic growth should drive agricultural innovation, and technology can overcome ecological and social limitations. These assumptions conflict with evidence that global food systems face severe critical threats including climate change (Malhi et al., 2021), resource constraints (Rockström et al., 2023), and, increasingly, geopolitical instability (El Bilali and Ben Hassen, 2024).

In April 2022, members of the editorial team launched this Research Topic at a workshop entitled *The Social Implications of Cellular Agriculture and the Future of Food*, held on the traditional and unceded lands of the Katzie Nation in western Canada. The event convened researchers, NGOs, Indigenous elders, and cellular agriculture technology developers to examine the potential benefits and risks of this emerging technology to discuss the tension between its transformative potential and its entrenchment within existing harmful paradigms behind dominant approaches to food production. The theme is an underlying thread connecting the eight articles in this Research Topic.

Transformation or entrenchment?

Glaros et al. provide a framework for identifying the potential trajectories along the dimensions of centralization, access, and integration. Their framework maps different possible futures for the cellular agriculture industry. For example, they find that stakeholders hold varying perspectives on the extent to which venture capital investment and consolidation is a "good" thing and/or necessary direction for cellular agriculture. This suggests that future industry pathways will require negotiation, likely fraught with tension across competing worldviews.

Hibino et al. and Powell et al. explore consumer attitudes toward cellular agriculture products in Japan and Canada, respectively. Hibino et al. identified a mix of enthusiasm and skepticism toward cultured meat, with concerns about "unnaturalness," food safety, and transparency tempering optimism about its ethical and environmental benefits. Powell et al. analyzed attitudes toward yeast-derived dairy, finding that while some consumers appreciate its potential advantages, concerns about food processing and corporate control remain concerns. These studies suggest that consumer acceptance depends on several factors, including concerns about transparency, regulation, safety, and cultural values about food.

Beyond consumer attitudes, the economic implications of cellular agriculture for existing food producers deserve attention. Manning et al. examined UK farmers' perspectives on cultured meat, identifying widespread concerns about corporate control, land-use displacement, and rural marginalization. Farmers largely perceive cellular agriculture as a corporate-driven approach to food production, and fear that small and mid-scale producers will be excluded from its economic benefits. To address these risks, the cellular agriculture industry must be developed in a way that prioritizes equity. Rao et al. argue for a "just transition" approach, emphasizing the need for community engagement, interdisciplinary collaboration, and transparent governance mechanisms. Without such measures, they caution that cellular agriculture risks reinforcing existing patterns of exclusion.

Other contributors provide structural critiques of cellular agriculture's position within the broader food system. Jiménez Rodríguez draws on vegan queer ecofeminist theory to critique the capitalist and patriarchal structures that shape the industry, arguing that these structures limit its transformative potential. They also highlight the industry's reliance on animal-derived inputs, such as fetal bovine serum. Similarly, Hedberg critiques the narratives used to justify cellular agriculture's development, particularly the "bad animal narrative," which blames livestock for environmental degradation while overlooking systemic failures in industrial agriculture. Through a review of life cycle assessments (LCAs), Hedberg shows how techno-fix approaches often obscure the complexities of sustainable food systems and risk reinforcing existing power asymmetries. Finally, Poirier offers a historical perspective, arguing that cellular agriculture is less of a departure from industrial animal agriculture than its proponents claim. He highlights the industry's close ties with conventional meat corporations, questioning whether its primary objective is to serve the public good or to extend existing agribusiness models into biotechnology.

A just transition or just another transition?

Taken together, these studies highlight the competing forces that can shape the future of cellular agriculture. While some argue that this technology holds the potential to mitigate ethical and environmental harms associated with industrial animal-based food production, others caution that its trajectory may simply reproduce (and perhaps even exacerbate) many of the current environmental and social justice issues associated with the food system. Although many questions remain unanswered and new ones continue to emerge from the papers in this Research Topic, two key directions for future research stand out.

First, as suggested by Rao et al., future research on cellular agriculture should adopt a "just transition" perspective (Moritz et al., 2024), ensuring that its development does not reproduce existing inequities but instead fosters more inclusive and democratic food systems. This means centering the needs of potentially affected communities, ensuring accountability in research and development, and preventing the continued consolidation of power among dominant actors.

Second, in line with arguments made by Jiménez Rodríguez, Hedberg, and Poirier, there is a need to interrogate the deep cultural assumptions and perceived entitlements underpinning the growing interest in cellular agriculture. This raises questions about the viability of indefinite economic expansion on a finite planet, the long-term sustainability of globalized industrial food production, and the limits of technological solutions to systemic food and ecosystem crises. Rather than looking to how new food technologies will sustain "business as usual, but greener" (Baskin, 2019, cited in Stein, 2024), scholars and policymakers must confront the reality that food production operates within real biophysical and geopolitical constraints. These constraints demand urgent analysis on the gap between hopes for ecological modernization and the actual pathways to bring human societies in line with the boundaries for Earth system's integrity (Rockström et al., 2023).

The trajectory of cellular agriculture remains uncertain. Its development raises a fundamental question: Will this technology disrupt the social and ecological harms embedded in industrial food systems, or will it replicate them?

Author contributions

EB: Writing – original draft, Conceptualization, Funding acquisition, Writing – review & editing. JM: Writing – review & editing. S-LR: Writing – review & editing. MH-U: Writing – review & editing. RM-d-S: Writing – review & editing. RN: Writing – review & editing. AG: Writing – review & editing.

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REVIEW
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On the Intertwining of Cellular Agriculture and Animal Agriculture: History, Materiality, Ideology, and Collaboration

*Nathan Poirier**

Department of Sociology, Michigan State University, East Lansing, MI, United States

This review essay documents continuities between (industrial) animal agriculture and cellular agriculture and raises key questions about whether or not the technology might be able to deliver on its promise of food system transformation. It traces how industrial history, connections to the livestock industry, and disavowal are extended through the innovation of cellular agriculture. In particular, it is shown that cellular agriculture has had connections to (industrial) animal agriculture since its very beginning and at nearly every step since then. I argue that cellular agriculture can be positioned as the epitome of (industrial) animal agriculture in terms of history, material practices, and ideology. Such a critique of cellular agriculture has become somewhat commonplace but while a number of papers have raised similar concerns individually, there exists no sustained focus on such similarities to make this point holistically. Such connections are important in framing the future of cellular agriculture and the fate of farmed animals and the environment. Carefully considering the continuities between cellular agriculture and animal agriculture is crucial when considering whether promoting cellular agricultural is a prudent approach to addressing problems associated with animal agriculture. The cumulative number and extent of connections covered in this essay leads to questions of who will benefit with the advent of cellular agriculture.

Keywords: cellular agriculture, transitions, meat, industrialism, animal agriculture

Edited by:
Evan Bowness,
University of British Columbia, Canada

Reviewed by:
Stephanie Rutherford,
Trent University, Canada
Garrett Broad,
Fordham University, United States

****Correspondence:***
Nathan Poirier
poirie11@msu.edu

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INTRODUCTION

> While the immediate ethical advantage of reducing the consumption of animals by promoting consumption of *in vitro* meat should, I think, be obvious, we will need to pay attention to the complexities generated by a practice that obscures the origins of killing.... Contemporary industrial processes employed in the production of commercial imitation meats were developed early in the twentieth century to improve the productivity and profitability of livestock. We should consider how this industrial history is extended by the innovation of *in vitro* meat in terms of what I'm tempted to call its seductive power. We should consider as well its relationship to disavowal.
>
> -Terhaar (2012, p. 75)

This essay answers Terhaar's call to show how industrial history, connections to livestock, and disavowal are extended by the innovation of *in vitro* meat (IVM).

To date, I am not aware of a published peer-reviewed paper that answers Terhaar's call to explicitly trace out how IVM falls neatly in line with animal agriculture. The connections between IVM and industrial animal agriculture have been noted by several authors (Jönsson, 2016; Guthman and Biltekoff, 2020; Helliwell and Burton, 2021; Howard et al., 2021; Lonkila and Kaljonen, 2021; Poirier, 2021). This current article expands upon those inquiries by offering a more systematic analysis of those connections. In particular, this essay will argue that IVM has had connections to (industrial) animal agriculture since its very beginning, and at nearly every step since then. This work is part of a broader conversation about whether IVM does or does not have transformative potential, and its unique contribution to this conversation is tracing the historical links between IVM and (industrial) animal agriculture. IVM is a technological approach to creating meat without (or nearly without) the use of nonhuman animals. The dominant production process involves taking a biopsy of a living animal (Melzener et al., 2021) and isolating either stem cells or muscle cells. These cells, along with nutrients to promote cell growth, are placed in a bioreactor which keeps conditions ideal for cell formation and overall cleanliness of the process. Cells adhere to a scaffold mechanism as a growth platform and helps myoblasts to fuse together to form myotubes (Edelman et al., 2005, p. 660). Finally, myotubes are exercised to create myofibers which are used in meat emulsion and form the basis of IVM products which can be formed into various types of meat to be cooked and eaten as such (Pandurangan and Kim, 2015; Bhat et al., 2020).

Thus, despite the differences between cellular and animal agriculture, this paper argues that IVM could be positioned as the epitome of (industrial) animal agriculture in terms of ideology, materiality, and history when viewed by its many similarities to animal agriculture. To be clear, this is not to say that IVM necessarily or absolutely *is* the epitome of animal agriculture, but that it is not unreasonable to view it as such. To this end, it is not particular differences this paper is concerned about. Rather, it focuses on the many similarities. This is because, admittedly, the differences of cellular agriculture from animal agriculture potentially leave room for IVM to significantly reduce harm to humans and nonhumans if developed in a critical manner that is oriented around social justice and consciousness raising (Poirier, 2018a). As I see it, the similarities are where potential problems lie and thus they are the focus of my interrogation. I approach this review essay from a vegan perspective that disapproves of all animal use by all who have a choice (except in extreme and absolutely necessary circumstances). Thus, veganism, as defined and operationalized in this essay (see overview below), is critical of both IVM and animal agriculture and is concerned about who benefits and who is harmed by social practices. My concern is that IVM will not, ultimately and despite its many seemingly promising potential benefits, serve the interests of nonhumans, and the number and strength of connections to animal agriculture will influence this likelihood.

Unlike most review essays that cover the general lay of the land regarding IVM (e.g., Stephens et al., 2019; Chriki and Hocquette, 2020), this review essay has a narrower aim of providing an overview and discussion of the literature on IVM that makes connections to animal agriculture, and to argue that these connections pose significant challenges for IVM to significantly diminish, let alone replace, (industrial) animal agriculture. Articles in this review essay were largely chosen based on the list of articles from my comprehensive examination that focused on the topic of IVM and included some history of animal agriculture. Articles were compiled along the lines of the following criteria: (1) earlier articles I consider particularly foundational to the study of IVM, (2) relatively recent publications on IVM that present the most recent thought on the subject, (3) articles in between "early" and "recent" periods that are of particular importance to the field of IVM as a whole, and (4) Google Scholar searches (under various names of IVM) for articles that somehow mentioned or indicated connections to animal agriculture in their titles or abstracts. My initial list was revised slightly after input from all four of my committee members. In reading these articles, I kept track of which peer-reviewed articles and books mention connections between IVM and (industrial) animal agriculture, and these sources were read with special attention paid to these connections. For the purposes of this review essay, "connections to animal agriculture" is conceived of broadly and include any mention of the practice of animal agriculture, the use of animals in IVM production (either direct or indirect), the (recent or historical) role of farmers, financial or strategic collaborations with the meat industry, or statements that alluded to some sort of potential alignment with animal agriculture [such as Shapiro (2018) referring to cellular agriculture as a "second domestication"]. Not wanting to be bound to a list created for a comprehensive exam, several additional works were chosen beyond this list *via* prior knowledge of their content, as well as through keeping up with recent publications on the topic of IVM. Sources that do not make the aforementioned connections are generally not discussed. Connections between cellular agriculture and animal agriculture were loosely grouped into categories of ideology, history, materiality, and collaboration with sections dedicated to expanding on these themes.

Some preliminary notes should be set forward before proceeding. First, I refer to animal cells grown in a lab by tissue engineering and cell culturing techniques as *in vitro meat*, IVM for short. This is because (1) *in vitro* highlights this distinction with *in vivo* which refers to work that is done with or within a living organism and (2) IVM is the original term, even though the industry widely eschews it now for multiple reasons (see Friedrich, 2019). The second note is that I view the roles of both nonindustrial animal agriculture and industrial plant agriculture as intrinsically posing problems from a vegan perspective (see below). Thus, IVM is problematized against all *industrial* agriculture, whether animal- or plant-based, and all *animal* agriculture, industrial or otherwise. Hence the phrase (*industrial) animal agriculture* will be used throughout this paper to highlight this orientation. When viewed through a vegan and total liberation lens as this essay does (see below), all connections between IVM and (industrial) animal agriculture are problematic and especially so when taken together. Others have critiqued IVM from a vegan perspective, as exemplified by the website https://www.cleanmeat-hoax.com/. While this website provides much useful information, it is not itself peer-reviewed and contains information from a number of sources which were not peer-reviewed, as well as a number of quotes taken out of context. This review article extends such arguments by presenting newer information gleaned from peer-reviewed sources.

Total liberation is a concept theorized and empirically grounded by Pellow (2014) to refer to a politics that aims for maximal emancipation for humans, nonhuman animals, and the environment. Liberation in each of these domains is seen as essential to the others and conversely, any perceived liberation is incomplete if others are oppressed. Total liberation is rooted in an anarchist conception of autonomy such that individuals are viewed and treated as possessing and able to act under their own wills but not to an extent to which they impinge upon others' ability to do so. A similar concept to total liberation, known as "consistent anti-oppression" has been developed by Brueck and McNeill (2020). In Feliz's conception, consistent anti-oppression refers to the acknowledgment of interconnections between social justice groups (human and nonhuman) to consistently and effectively achieve liberation for all. In both Pellow's and Feliz's terms, total liberation/consistent anti-oppression implies a holistic, ethical veganism. Although views on veganism vary from a diet, to lifestyle, to social movement (Dutkiewicz and Dickstein, 2021; Lipnevič, 2021), many animal rights activists, especially in the more radical domains, view veganism as much more than a diet but as a political platform to resist all forms of exploitation. In particular, many Black and indigenous vegans "affirm that veganism is one key aspect of social justice needed to destabilize the same oppressive systems that keep us bound to it as marginalized people through the use of nonhuman animal exploitation" (Brueck and McNeill, 2020, p. 12). That is, while veganism can be expressed as an abstention of consuming animal products, it also entails abstaining from consuming products that exploit human animals (Pedersen and Stanescu, 2014). Thus veganism, as used in this paper, implies more than a diet, but a political movement and broader cultural critique of injustice (Giraud, 2021).

The paper proceeds with a short review of the IVM literature that presents its basic contours, then a short review of the literature on social transitions. For the purposes of this paper, social transitions refers to a body of literature on how structural changes happen in societies. This could be in terms of whole societies themselves, or substitute commodities such as new energy sources or food products, and the effects such substitutions have on social systems and the body politic. Next is a review and expanded discussion of a subset of IVM literature that focuses on connections between IVM and (industrial) animal agriculture. Then the essay sketches some major threads in the history of animal product development since the advent of modernity. Lastly there is discussion as to why such connections should be viewed as problematic especially, but not only, from a vegan viewpoint.

REVIEW OF THE LITERATURE ON IVM

The first academic articles appeared in 2002 and present contrasting narratives on IVM. Benjaminson et al. (2002) was a NASA funded study researching ways to feed astronauts in space. The authors, all biologists, speak of meat and space exploration in glorious terms and a sense of belief in technological progress is noticed, along with an inevitability of meat consumption by humans. The article by artists Catts and Zurr (2002) was performative and philosophical, particularly aimed at challenging the nature-culture dualism. Catts and Zurr, unlike Benjaminson et al., are much more cautious and critical and ask if IVM technology should be used just because it can. Benjaminson et al. also killed the fish used for their experiments whereas Catts and Zurr obtained cells from a frog who was present—alive—at their tasting of IVM. That Benjaminson et al. are cited much more frequently than Catts and Zurr (who have several publications on the topic) may suggest a degree of fetishization of technology and meat rather than a propensity for caution and skepticism (Jönsson, 2017).

Since this pair of papers, the literature on IVM has evolved in a number of directions. Early publications largely consisted of overviews of the general IVM production process (Edelman et al., 2005; Hopkins and Dacey, 2008; Datar and Betti, 2010; Bhat and Fayaz, 2011; Post, 2012), environmental impacts (Tuomisto and Teixeira de Mattos, 2011; Tuomisto et al., 2014), or ethics (Pluhar, 2010; Welin and Van der Weele, 2012). These articles tended to present IVM in overall positive terms. For example, Hopkins and Dacey (2008) consider 13 possible objections to IVM and dismiss all of them. Similarly, Welin and Van der Weele (2012) ask if IVM will separate humans from nature and conclude that it will not.

It is also interesting to note that recent review papers of IVM deviate little if at all from earlier summary papers. Bhat et al. (2020) reads like that of Datar and Betti (2010). Stephens et al. (2019) mention that current industry challenges are essentially the same as those at the first IVM conference in 2008. Giles (2019) characterizes papers coming out at that time as repetitive. All of this leads Chriki and Hocquette (2020) to conclude in their own review article that IVM research and production has made no major advancements despite numerous publications.

The first openly critical peer-reviewed article on IVM appears to be that of Miller (2012). Like other critical papers that followed (Metcalf, 2013; Wood, 2014; Jönsson, 2016; Lee, 2018), Miller argues that the basis of the problems IVM purports to solve are left unchallenged if not strengthened. He also makes several theoretical connections to animal agriculture such as entrenching "carniculture" in terms of centering meat within human meals and minds, an instrumentalist approach to nonhumans, "real" meat becoming associated with (the upper) class while IVM is "relegated" to the lower classes, and questions the capitalist nature of technoscience to solve, frankly, anything. Similarly, more recent environmental evaluations of IVM have been less optimistic than the studies led by Tuomisto cited above (see Mattick et al., 2015; Lynch and Pierrehumbert, 2019).

Beginning around 2015, there began to be a suite of papers investigating consumer perceptions and possible acceptance of IVM (see Bryant and Barnett, 2018, 2020 for reviews). The most recent trend in the literature appears to be voices critical of the promises (and silences) of IVM proponents, the use of capitalism to drive IVM production and businesses, and partnerships with animal agriculture (Sexton, 2018; Sexton et al., 2019; Guthman and Biltekoff, 2020; Helliwell and Burton, 2021; Howard et al., 2021; Lonkila and Kaljonen, 2021; Poirier, 2021). It is this concern of similarities and continuities of IVM with (industrial) animal agriculture that is the focuses of this paper.

Jönsson (2016) gives some direct attention to the main theme of this paper. The present paper builds on Jönsson's argument and differs significantly by making different points, providing further details, and includes more recent developments. In his paper, he noted that historical developments in meat production create a continuous story with IVM as the latest point in this trajectory and even points out how IVM can be positioned as the logical endpoint of (industrial) animal agriculture, while citing Driessen and Korthals (2012) who say this explicitly. Jönsson, though, rests his argument on the supposed human "need" for meat and focuses more on IVM's ontology, and the ambiguity therein, to show how IVM both continues and breaks from previous discourses of meat. Jönsson also balances the similarities and differences of IVM to traditional meat to examine continuities and contrasts. In this review essay, I depart from Jönsson by focusing on the continuities. In 2016, Jönsson also published before cellular agriculture industries began partnering with (industrial) animal agriculture for financial investment and development assistance. Jönsson focuses on how promisory discourse of IVM draw on the history of traditional meat whereas this review essay will examine how likely such promises are to be fulfilled based on this same continuity. In these ways, this review essay extends and elaborates on Jönsson's earlier paper.

SOCIAL TRANSITIONS

Before moving into the review essay proper, I first introduce the theoretical viewpoint in which IVM will be evaluated, that of social transitions. In sociology, there is a classic model known as "stadial progression" that hypothesizes that societies transition from certain modes of productivity to more advanced ones. A typical progression might be: gatherer-hunter to agrarian to industrial to post-industrial. At each step, productivity increases and humans are said to become more "civilized." This model also envisions this order to be linear and essentially inevitable. However, Graeber and Wengrow (2021) recent book upends these assumptions by showing that such a model is socio-politically contrived and historically inaccurate. Historically, there are not energy transitions but successive additions of "new sources of primary energy" (Bonneuil and Fressoz, 2017, p.101). At best, the stadial progression model reveals that newer stages industrialize previous stages but do not replace them (Marouby, 2020).

Environmental sociologist Richard York, over a series of papers, has written on "transitions" and substitutions of energy sources and meat consumption. He makes a distinction between energy additions (new sources of primary energy) and substitutions (genuine decline of energy use) (York and Bell, 2019). From his research, he concludes that energy "transition" is a misnomer in that these claims tend to focus on proportional use of a particular energy source, not overall energy use, echoing Marouby's account of stadial progression. Reasons for this lack of proper transitions lie in the complexity of economic and social systems. Various social dynamics create and sustain hegemonic trajectories. Various paradoxes also help to explain why increased efficiency or the existence and even use of substitutes often do not proportionally displace previous resources and may even increase their use (Greiner et al., 2022). Instead, there is a global and historical trend for new resources to act as additions to overall consumption.

Closer to the relevance of this paper, York (2021) presents case studies as examples of the failure of alternate resources to displace previous ones. One is that lower environmental impact meat sources (chicken, invertebrates) only marginally displaced higher environmentally impactful meat sources (cows, pigs); another is that aquaculture has failed to decrease wild caught fish. Both scenarios have acted more as additions to overall consumption rather than replacements. The concept of transitions has also been used by IVM proponents to encourage development and eventual consumption of IVM. As covered elsewhere (Poirier, 2021), IVM proponents have proffered the advent of automobiles and petroleum as replacements for horse carriages and whaling, respectively. Both are claimed as major victories for nonhuman animals. Yet both uncritically neglect the myriad widespread negative effects resulting from automobile and petroleum extraction, production, and use, specifically to nonhuman animals and the environment (but also to human animals, see Poirier and Tomasello, 2017). Also, not incidentally, "Preventing the extinction of whales required the suppression of whaling, not per se the development of substitutes for whale products" (York, 2017, p. 2).

CELLULAR AGRICULTURE AS THE HISTORICAL OUTGROWTH OF (INDUSTRIAL) ANIMAL AGRICULTURE

To understand how IVM can represent the epitome of (industrial) animal agriculture it is helpful to look at the history of animal agriculture. For much of human history, raising, butchering and consuming animals was a private affair. This began to change with the advent of modernity in the nineteenth century. Buscemi (2018) notes two historical themes in the history of meat production centuries in the making: the separateness and opposing characterization of nature and culture, and the separation of animals from meat. As the latter happened, meat became more cultural, increasingly viewed as a human construct apart from nature. Such trends have occurred at multiple sites: on the table, in the kitchen, at the market and in the slaughterhouse (Buscemi, 2018, p. 29). Each subsequent stage in the evolution of meat—hamburgers, fast food, cutification of animals, tinned/boxed meat—helped separate animals from meat (Buscemi, 2018, p. 81). Such developments also reduce animals more toward objects, or, one might say, toward IVM.

The same trends are seen in the development of the modern slaughterhouse (Lee, 2008) and milk production (Nimmo, 2010). Sociologist Nimmo (2010) study tells the history of modern dairying in the UK. He focuses specifically on how diseases associated with dairy production were controlled in an effort to "purify the social," retain the uniqueness of human agency, and (re)establish human supremacy over nonhumans, particularly bacteria. Analogously, chapters in Lee's edited book present the history of development of modern slaughterhouses over nearly the same time period as Nimmo, roughly 1800-1900. The histories presented by Nimmo and the contributors to Lee's volume coincide in many respects. Slaughterhouses and dairy production became centralized, scientifically managed, public facilities supplying urban areas with "clean" meat and milk. The dominant discourse was directly tied to public health with public officials often overseeing funding, construction, and regulation. Rhetoric of cleanliness and disease control drove the removal of slaughterhouses from urban centers to the periphery (Vialles, 1994; Lee, 2008). This reasoning was also used to justify using technology to more humanely and hygienically slaughter animals and produce meat and milk. All of this was done largely, although not entirely, to enforce human mastery over nonhumans, reinforcing and reifying the human-nonhuman and Nature-Culture binaries (Nimmo, 2010). Removing slaughter from view created a distance between people and meat (Lee, 2008). Moreover, locating slaughter facilities closer to areas of production was considered more efficient, "the reason being that transporting" inanimate animal products "tends to pose fewer practical problems than transporting live cattle" (Vialles, 1994, p. 10). Echoing Buscemi (2018), Rochechouart was the last slaughterhouse to retain visual notions of the animals; going forward, "the slaughterhouse had to become a factory system, casting cows and sheep not as animals but as meat waiting to be harvested" (Lee, 2008, p. 61, 62).

All this is to say that, when viewed historically—the reduction of animals to meat, increased technological control over animal bodies, the removal of slaughter from sensory experience—these trends and characteristics point to IVM as an outgrowth of (industrial) animal agriculture. Given the centuries long and ever greater separation of humans from animal slaughter and meat production, even an apparent unnaturalness of IVM may be a benefit to (industrial) animal agriculture as this overcomes physical constraints of traditional meat: "In fact, what *in vitro* meat would do is to create a new physical reality that actually does match up with the self-deceptive and self-serving situation many consumers already imagine when they buy meat at a grocery store" Hopkins and Dacey (2008, p. 594). Jönsson (2017, p. 851), adds that "Cultured meat attempts to subsume animal bodies to animal-agricultural priorities." Galusky (2014) connects IVM and control to the history of meat production by noting how simplified animals and animal products are only possible through increasingly complex human systems premised on more control. It would seem as if IVM has been what the meat industry has been developing toward historically, albeit without necessarily knowing it.

It is worth noting that the point could be raised that IVM would theoretically drastically reduce (if not eliminate) animal slaughter and animal suffering. *Theoretically*, yes. This is why the ethical grounding for IVM seem so strong and may even be viewed as in line with vegan values (I am currently developing a paper on this). But the main point of this paper is to highlight why that outcome is not likely to materialize (see also Poirier, 2021). Secondly, this paper would argue that the continuities of cellular agriculture outweigh the value of theoretical discontinuities. Even if such an outcome were to be achieved, there are still pragmatic and ethical grounds for skepticism in terms of reducing human impact on earth and other nonhuman animals (see Poirier and Russell, 2019 for such a critique) especially if an IVM transition is not accompanied by a revolution in human consciousness toward nonhumans, which IVM does not currently seem to promote.

IVM causes animals to lose their "otherness" and this is an extension of technologically driven meat production. Given this trajectory, Buscemi states that "It [IVM] may be the final stage of the separation between meat and the animal" (2018, p. 143). Likewise, Neo and Emel (2017, p. 1) present three "turning points" of animal agriculture. The first is domestication, then industrialization, and finally IVM. They state: "The detachment of animals from humans and 'nature', as well as their progressively intensified commodification, arguably comes to its most extreme conclusion with the introduction of synthetic meat." Similarly, Shapiro (2018, p. 10) uses the term "second domestication" to describe the turn toward IVM, creating linguistic continuity between traditional agriculture and IVM (also sometimes referred to as "cellular agriculture").

DIRECT CONNECTIONS BETWEEN IVM AND (INDUSTRIAL) ANIMAL AGRICULTURE

There have been connections between IVM and animal agriculture at almost every step of IVM's history. A major link is the use of calves' blood, also known as fetal bovine serum (FBS). FBS is obtained by draining blood from fetal calves of dairy cattle at slaughterhouses. The blood is allowed to clot and is then centrifuged to remove the clot and any remaining red blood cells. The clear yellow substance left over is fetal bovine serum (Jochems et al., 2002). FBS was used and sourced from slaughterhouses in the first test case of IVM (Benjaminson et al., 2002), the first time IVM was consumed (Catts and Zurr, 2002), in the 2013 London tasting event of the first cultured burger (Simonsen, 2015), and in the first IVM products sold commercially in December 2020 (Stephens, 2021). Regarding the 2013 IVM public tasting event, Posts's research leading to the tasted burger was built on research that included Dutch meat producers Meester Stegeman (Jönsson, 2016). O'Riordan et al. (2017, p. 151) further note that egg and butter were used in the burgers for this event. Thus, FBS has played a fundamental role in building and IVM industry while simultaneously helping (industrial) animal agriculture.

Vasile Stanescu pushes the connection to FBS further in the 2019 debate on IVM at the Conscious Eating Conference (United Poultry Concerns, 2019). FBS requires killing a pregnant cow and draining the blood from her fetus. Thus, animal agriculture and slaughterhouses are necessary components of IVM that uses FBS. Stanescu says that to produce enough FBS to culture IVM presently, 200 million fetuses are needed per year (and growing). Since the advent of IVM research, factory farms have increased their price for FBS by 300% and FBS is "currently the single most profitable item that a factory farm sells" (Stanescu, quoted in United Poultry Concerns, 2019). In this way, IVM has been beneficial for animal agriculture. Thus, Simonsen (2015) argues that scaling up of IVM would necessitate a large animal agriculture industry from which to obtain FBS. In a similar vein but from a different angle, Mouat and Prince (2018, p. 319) state that "Animal-free food as we know it does not exist without large-scale animal agriculture."

It is imperative to acknowledge that the cellular agriculture industry has repeatedly stated that IVM will not be viable without a plant-based alternative to FBS, and that nearly everyone involved in the research and industry landscape of IVM is working on various forms of plant-based alternatives. In fact, Mosa Meats has announced they have found a plant-based alternative to FBS (Messmer et al., 2022). However, a close reading of this article reveals that the serum-free media helped in cell proliferation but failed to substantially produce myotubes. In muscle development a cluster of muscle cells is not sufficient, cells must come together and form myotubes which are the structure of muscle. The study is also limited in that it applies to a single species. Messmer et al. (2022) note both limitations, as well as others. While the authors conclude that a plant-based culture medium "is an important step toward the realization of cultured meat" (Messmer et al., 2022, p. 81), it does not yet indicate that the industry as a whole can cleave itself away from its tether to (industrial) animal agriculture *via* FBS. An important point here is that—at least from the author's perspective on total liberation—it cannot be considered vegan to create an IVM industry having built its foundation on FBS, even if it is eventually abandoned (see also Simonsen, 2015; Poirier and Russell, 2019 for fuller arguments on this point). This constitutes the knowing financial support of an industry whose sole purpose is to slaughter nonhuman animals for/as food. A key notion of total liberation is to not aid in the oppression of some while attempting to liberate others. There is a fundamental ethic of non-harm as no one is in a place where they can objectively say that some lives are expendable and others are worthy of protection.

Numerous papers note the various animal agriculture investments in various IVM companies and technology, as well as collaborations between these two sectors (Mouat and Prince, 2018; Burton, 2019; Stephens et al., 2019; Painter et al., 2020; Purdy, 2020; Howard et al., 2021; Poirier, 2021). Stephens et al. (2019, p. 7) remark that this trend has been emerging since 2017 and that "These developments represent strategic investments by the major incumbent players to keep track of the emerging sector; to ensure they are the disruptors, not the disrupted." There has also been a concomitant softening of rhetoric to "transform" the food system rather than disrupt it. Similarly, to help guard against being disrupted and to bring IVM into their business models, animal processors have begun a change in rhetoric, referring to themselves as "protein" companies (Purdy, 2020, p. 166; Howard et al., 2021). This is corroborated by Broad (2020) who says that a goal of alternative animal product companies is to get in with "dominant structures of the food system" (927), and quotes Tyson's chief investment officer as saying their investment in alternative animal products is to protect their own long-term sustainability. Poirier (2021) found identical results at the 2018 and 2019 Good Food Conferences and provides many explicit quotes from industry insiders to this effect.

Taken together, this presents clear evidence that (industrial) animal agriculture, as a whole, does not plan on significantly reducing the number of animals they slaughter, so it would seem unwise (and certainly anti-vegan) to pursue some sort of animal liberation through industries staunchly premised on slaughtering animals. The rhetoric used by industry stakeholders suggest IVM would function as an addition to existing animal meat, not a transition away from it. Guthman and Biltekoff (2020), like Jönsson (2016), discuss the theme of alternative animal products being promoted as similar to yet different from traditional animal products, easily representing the logical endpoint of current meat production: IVM is both similar enough to retain the positive associations of traditional meat, while different enough to address animal welfare concerns and remediate environmental problems. So while there may be similarities and differences, the similarities appear to carry on many of the problematic aspects of meat consumption and do not encourage a shift in consciousness needed for systemic change. Helliwell and Burton (2021, p. 186) note a near complete silence on mechanism(s) of IVM proponents and startups to target (industrial) animal agriculture in order to disrupt or replace that industry. In short, IVM proponents do not outline how to transition beyond farming. A transition should be just for all parties, which necessitates a vision. A lack of a vision makes one wonder how such an "cellular revolution" will come about. Helliwell and Burton (2021, p. 183) observe that removing animals from the land based on ethical animal welfare and/or liberation concerns sits somewhat problematically alongside visions of "a purely technocentric, reductive and utilitarian perspective on animal bodies." The authors note there are many uses for animal products, so abolition of animal agriculture also needs to be accompanied by an expansive vision that includes many social institutions. From a vegan and total liberation standpoint, the goal would be to abolish the meat industry, not help sustain it or its ideology. The lack of a vision around these issues is indeed troublesome.

Also of note is the collaboration of Memphis Meats (at the time, but now Upside Foods) and the North American Meat Institute (NAMI) in petitioning the U.S. government to set up federal regulations on IVM as meat (Stephens et al., 2019, p. 11; see also Howard et al., 2021, and Purdy, 2020, p. 176,177 on the Memphis Meats/NAMI collaboration). Gertenbach et al. (2021) note that IVM has somewhat split the vegan community and created alliances between some animal protectionists and animal agriculture, such as the Memphis Meats/NAMI collaboration (see also United Poultry Concerns, 2019; Poirier, 2021). Given the foregoing, it is not surprising when Mouat and Prince (2018) highlight the bind alternative animal products are in: they both reject animal agriculture yet depend on it for their existence, potential consumers, and financial support. It is difficult to see how the IVM industry would aim to replace (industrial) animal agriculture if it depends on it for its own existence. Bhumitra and Friedrich (2016) says animal agriculture developed through decades of putting profit before ethics but that IVM can help produce both. This sounds like the pinnacle of (industrial) animal agriculture thinking. Shapiro (2018, p. 24) makes the same point in saying that maybe animal agriculture and activists can both win through IVM. Many of these connections are not incidental but strategic, as admitted by Friedrich, Shapiro and others (see also Garces in United Poultry Concerns, 2019). To wit, at 2018 Good Food Conference, GFI, whose president and CEO is Bruce Friedrich, began adopting the term "cell-based" meat in order to not offend the meat industry (Ong et al., 2020, p. 226).

Another point of connection between animal agriculture and IVM is that of cell biopsies. Stephens (2013) notes that the cell procurement process from living animals is not a part of the IVM production process that is likely to disappear. Ong et al. (2020) claim IVM should not be labeled animal free unless (1) cells used come from a single biopsy (immortal line) and (2) no other animal ingredients are used. Both of these conditions are still unmet. An immortal cell line has not yet been developed, nor has a growth serum alternative for FBS that is efficient and cheap enough to culture meat at appropriate scales to significantly "disrupt" animal agriculture. So far, IVM remains tethered to animal agriculture in at least two fundamental ways, even in light of potential plant-based culture media (Messmer et al., 2022). If biopsies are needed, this requires ready access to animals who will have to be suitable to extract cells from (cleanliness, healthy, etc). This will necessitate farming animals as cell "donors" and likely quite a few, as Melzener et al. (2021) suggest, to maintain genetically viable herds and to ensure cell supply for ever-growing meat consumption.

Stephens et al. (2019) raise the issue that IVM may end up just being an addition to traditional meat, which would void any environmental or animal welfare benefits. They admit that current IVM proponents are motivated by altruism but realize they may be swayed by other motives or new players (e.g., the meat industry) who may not be altruistic, and that proposed benefits are not inherent to the technology itself. Another point concerns regulation. In 2019, the United States decided that the FDA and USDA would share regulatory responsibilities for IVM. A potential issue is that the USDA has an obligation to promote animal agriculture which would give this sector influence in IVM regulation (Purdy, 2020, p. 170). Sexton et al. (2019) note that the US Cattlemen's Association first said "meat" should exclude IVM but then explicitly said it should be called meat, albeit with conditions (61). Thus, the influence and control of the emerging IVM sector by the meat industry is cause for concern as the incumbent sector is likely to use the emerging sector for its own benefit (for an overview of this phenomenon, see LaVeck, 2006). IVM, under influence from (industrial) animal agriculture, could go the way of the electric vehicle which was bought up and stifled by the incumbent automobile industry a century ago. A subset of the literature on IVM concerns ways in which animal agriculture can remain viable if IVM were to capture a significant amount of the (industrial) animal agriculture market (Bonny et al., 2015; Burton, 2019; Melzener et al., 2021; Newton and Blaustein-Rejto, 2021).

There are many scenarios in which IVM and traditional meat are envisioned to coexist. Rather than eliminating (industrial) animal agriculture, Bonny et al. (2015) suggest ways for animal producers to deal with animal welfare to remain viable, including redesigning husbandry systems, using conventional breeding technologies, genetic selection, cloning, genetic modification, and agroecology. Large enterprises are most able to incorporate alternative animal products and respond to consumers quicker which may lead to a further concentration of animal agriculture (Howard et al., 2021), a trend in animal agriculture that has been happening for some time (Howard, 2021). Burton (2019, p. 42) thinks that one key problem for livestock producers to retain viability is in retaining their "natural" appeal. He advises incumbent industries to prepare now, and not to be complacent and then surprised by a quicker transition. In interviews with 37 people involved in or concerned about alternative animal products, Newton and Blaustein-Rejto (2021) find more opportunities than threats for animal agriculture to remain viable given IVM. Opportunities consist of growing ingredients for plant-based meat, growing inputs for components of IVM production, raising cell donor animals, operating bioreactors on-farm, farmers could diversify or transition, rejuvenated value on high welfare farms, create blended products or products from cultured components, obtain jobs in alt-meat production facilities, improve pollution in rural environments from meat facilities, or receive payments for ecosystem services from freed up land. Allowing for a variety of scenarios to materialize, Melzener et al. (2021, p. 10) conclude that "In any of these scenarios, a combination of cultured meat production with ongoing conventional meat production can be considered." Thus, there are many ways in which IVM could help sustain meat production. This is a troubling state of affairs for those wishing and working to dismantle the meat industry, especially in light of the fact that vegan food exists in relative abundance and, despite massive subsidies given to the meat industry, are already relatively cheap.

IDEOLOGY AND MATERIALITY: THE INDUSTRIAL LOGIC OF CELLULAR AGRICULTURE

IVM ideologically functions as an extension of industrial and animal science approaches to food production and environmental relations through continuities that exist between these technologies and meat production. From a perspective that takes this context and continuities seriously—such as a vegan and total liberationist lens—turning to IVM to address the various harms of (industrial) animal agriculture can be perceived as problematic in that proponents rarely encourage humans to view nature as anything more than a mere means of achieving human ends, or contest the notion that meat consumption will always be eminently and inevitably desirable. Whether implicitly or explicitly, IVM proponents generally endorse this instrumental conception of the natural world (Miller, 2012; Helliwell and Burton, 2021; Poirier, 2021). IVM attempts to solve many of the problems associated with the production and consumption of meat by furthering the logic that motivates and justifies the instrumentalization of animals. The technologies that made (industrial) animal agriculture possible are often considered the source of our crisis in current agriculture. In this context, technology is viewed as both the problem and the solution (Anthos, 2018).

The logic of industrial agriculture is to maximize desired output (e.g., protein, calories, taste, amount of meat) while minimizing costs through greater efficiency. When this is applied to living animals, it results in the current inhumane system where animals have been bred to maximize edible meat (Neo and Emel, 201, p. 52–55). This instrumental logic encourages producers to shape and manipulate animal bodies to achieve their desired outputs. There are biological and constraints that limit how much animal bodies can be instrumentalized and controlled in this manner, however. For example, high rates of lameness and mastitis occur in dairy cows when producers breed cows to produce more milk at the expense of their welfare. Similarly, chickens bred for high egg production have weakened skeletal systems as calcium is leeched from their bones during the production process (Twine, 2013, p. 145). In other words, (industrial) animal agriculture is becoming forced to consider animal welfare and/or alternative production methods in order to continue basic operations. Therefore, there are incentives for (industrial) animal agriculture to eliminate "inefficiencies" of using live animals in production and incorporate or transition to IVM.

The aim of industrialization is to "modify the problems out of the body" (Galusky, 2014, p. 936). IVM represents the epitome of this by attempting to eliminate animals from the meat making process. Instead of dealing with the various biological constraints and vicissitudes of animals piecemeal, IVM attempts to circumvent them all at once by eliminating the animal body. In (industrial) animal agriculture, many typical biological functions appear as problems to be overcome through scientific and technological ingenuity. Here, even the natural process of growing muscle is considered inefficient. Meat can be made more efficient by eliminating the practical and ethical messiness associated with housing, raising, transporting and processing living beings (Vialles, 1994; Anthos, 2018).

In (industrial) animal agriculture, whenever a perceived production or efficiency problem arises, the goal is to engineer the problem out of the animals themselves, rather than reflecting critically on the appropriateness of the expectations placed on the bodies of animals. Some examples include:

- Debeaking, de-toeing, dehorning, ear-cropping, tail-docking, castrating, and mutilating the teeth of animals to prevent them from hurting or killing each other in captivity (Davis, 2011).
- Making animals more docile by reducing sentience in cows, reducing nesting instincts in chickens, and producing pigs without legs (Fox, 1992).
- Creating a "featherless chicken" to produce animals more tolerant of hotter climates (Bennet, 2002).
- Breeding blind chickens who are less sensitive to overcrowding (Dickenson, 2007).
- An attempt to genetically engineer animals to not experience pain (Shriver, 2009).
- Breeding dairy cows to be emotionally indifferent to separation from their newborn calves (Gaard, 2017, p. 64).

Metcalf (2013) (p. 83) summarizes this logic:

> If you want to make meat without feces in it, engineer a cow that has no digestive system. If you want to have meat without diseased brain matter, engineer a cow that has no brain. If abusive labor conditions in slaughterhouses result in poor food safety, then grow meat in a bioreactor factory.

Similarly, in investigating the growing trend of eating insects, Sexton (2018) finds that body parts not considered desirable are removed, a consumer-led phenomenon. What is important here is the parallel to animal agriculture: removing parts of animals deemed "undesirable," for whatever reason (inefficiency, consumer disgust), leaving just the "meat." In light of this, IVM represents the logical end point of (industrial) animal agriculture both ideologically and materially.

The above examples illustrate how animal bodies are engineered and mutilated so they are less sensitive to conditions of confinement and abuse; animal mental, emotional, and sensory capacities are recognized to the extent that they can be manipulated. In light of these efforts to control the bodies of animals, it seems that the ultimate goal of industrial farming culminates with the advent of IVM, which is characterized by the decoupling of animal bodies and their physiological constraints (and ethical concerns associated with sentience and sapience) from the desired industrial output—flesh. Thus, it is un derstandable why Marder (2016), in a chapter titled "Meat without Flesh" calls IVM "pure meat" and "meat to the nth degree." Given the foregoing discussion, Poirier (2018b) "meat continuum," in which IVM was positioned exactly in the middle of veganism and (industrial) animal agriculture could be conceptualized in an alternate way, with IVM positioned at the far (left) end of this continuum, representing (industrial) animal agriculture taken to its logical extreme. It is important to note here that this is not an idea that those in the (industrial) animal agriculture industry would likely support. The rhetoric from that community is closer to what was discussed earlier, in that they see IVM as potentially part of a broader stream of protein sources, rather than as the ultimate goal. However, I believe it is not erroneous to frame IVM in this way. There may be multiple ways to view and position IVM, and each may be valid [see comments on the meat continuum in Poirier (2018b), and above]. In terms of ideology, materiality, and history, the trends can be argued to point toward IVM even if the meat industry does not desire or want to acknowledge this, and even if they resist in practice.

This continuation of industrial logic sweeps aside the need to engage with important questions regarding non/human relations and how the goal of increasing efficiency for the sake of profit shapes these relations. In current discussions regarding the promise of IVM:

> The ethical questions surrounding eating meat are not so much engaged as eliminated. People are not asked to confront the ethics of eating meat-whether in the basic question of killing animals, or in the technologically mediated question of the human, animal, and ecological stresses exacerbated by industrialized systems and capitalist logics (Galusky, 2014, p. 937).

Similarly, Metcalf (2013, p. 83) questions whether "our moral obligations to reduce suffering (and other harms) necessarily leads to a world in which "*organisms that can suffer are engineered out of it*" (emphasis original). In a sense, the history and practice of (industrial) animal agriculture is to remove every part of the animal—material and mental. At its base, all that really matters, or all that is really valued, is the meat. Simply put, there does not seem to be room for coexistence involving interspecies mutual autonomy. This sentiment may behind Simonsen (2015, p. 20,21) bleak dictum that: "[c]ruelty-free meat may simply be another element of the fantasy that humanity will ever be able to dwell with and among other species equitably." To a significant extent, plant-based meat products and veganism have been co-opted by mainstream approaches involving capitalism and animal exploitation industries (Giraud, 2021; Howard et al., 2021). I see no reason why IVM would be different.

While many links to traditional agriculture have been pointed out in the literature, most papers tend to focus only on certain components. This essay aimed to go further by creating a comprehensive picture pointing out just how deeply IVM is connected to conventional systems and that it always has been. The purpose of drawing together all of these connections and making them explicit is to argue that, despite being promoted as transformative, revolutionary, and in square opposition to animal agriculture, IVM is not all that different from the existing meat industry in many important ways. Nor does it seem to envision separating these ties in the future. In terms of practice, it has never really been separate from it. In terms of history, it seems to fall right in line. Many authors critical of IVM do not state their ethical orientation, so it is difficult to tell if critiques come from an animal liberation perspective or one of defending animal agriculture. These are opposite viewpoints but both can critique IVM. Authors would do well to state their intentions and positionality when critiquing IVM.

DISCUSSION AND CONCLUSION

So, is cellular agriculture different from animal agriculture? Of course, in certain ways they are necessarily different. Indeed, some of the actors are different; IVM is more centralized around certain urban hubs such as Silicon Valley in California; IVM is only newly for sale (and therefore its share of the market is vastly smaller than that of animal agriculture); and some proponents of IVM do explicitly call for eliminating animal agriculture (Poirier, 2021). Particularly, IVM advocates emphasize how the mode of IVM *production* differs from traditional meat production—that the animal is (essentially) absent (Volden and Wethal, 2021). To be sure, this is a site of significant departure. Yet there is still nuance here. It matters on who is doing the producing, and different production methods as well as scale affect the efficacy of cellular agriculture production. If animal agriculture is doing the producing or has significant influence over it, the products will reflect their priorities. However, it is not particular differences this paper is concerned about. Rather, it focused on the many and problematic similarities. IVM proponents, taken together as an industry, seem to be less concerned with diminishing animal agriculture than with building their own market sector. In light of prevailing sociological evidence of previous transitions (York, 2012, 2021), new sources of energy or food products often do little to reduce established energy or food sources. While these quantitative studies are (necessarily) more tangential to the situation of IVM (given its negligible commercial availability), qualitative empirical work focused on alternative animal products supports their general conclusions (Howard et al., 2021; Poirier, 2021).

Regardless of differences, this essay traced out connections between IVM and (industrial) animal agriculture. From a vegan perspective, animal agriculture is obviously problematic on many fronts. Therefore, it is the similarities that will likely be more concerning about the nascent IVM industry than its differences. Thus, based on an exploratory review and analysis of existing literature than spans twenty years of publications on IVM, this paper positioned IVM as the logical endpoint of (industrial) animal agriculture historically, materially, and ideologically. It was argued that this connection is important in framing the future of IVM and the fate of farmed animals and the environment. IVM has grown out of the same history and evolution of (industrial) animal agriculture and now also involves many (but not all) of those same players and tactics (e.g., capitalism). The thought process and materiality of reducing nonhuman animals to their meat are carried through to their logical extremes in IVM. These connections are too many and too close to believe that IVM will make any positive changes to the current environmental (which are really social) crises. It leaves one wondering how meaningful differences actually are (or will be). They also point to IVM likely acting as an addition to industrial animal agriculture. This sentiment was expressed clearly many times throughout the 2018 and 2019 Good Food conferences (see Poirier, 2021 for additional examples). For instance, during the 2018 panel titled "Building an Emerging Industry: Insights from Clean Meat Startups," Niya Gupta of Fork & Goode (a cellular agriculture company) plainly states: "I wouldn't see our industry supplanting or replacing much of traditional agriculture." Therefore, IVM could act as a financial or geographical prop for the meat industry to grow by diversifying their "protein" offerings and projecting a message of sustainability in a co-optation of IVM rhetoric.

As IVM is a quickly evolving landscape, the similarities and differences discussed in this paper are open to change. In particular, animal-free growth serum could be developed as this is indeed a serious line of research (Ferrer, 2021), bringing IVM closer towards veganism. Also, innovations could lead to the possibility of an "immortal" cell line, cells that can multiply indefinitely from a single biopsy. Both developments, and their potential use in the industry, would constitute further differences between cellular and animal agriculture. Climate change will also likely be a highly variable influence on both cellular and animal agriculture. Climactic and land-based changes due to global warming may force the animal agriculture industry to downscale. This may help create a "natural" market for IVM products to replace farmed animal products. By the same token, those in the IVM industry who resolutely call for the diminishment or disappearance of animal agriculture could change their rhetoric in the future, especially if faced with lucrative financial opportunities from meat processors (Stephens et al., 2018, p. 164).

Carefully considering the continuities between IVM and traditional meat is crucial when considering whether promoting IVM is a prudent approach to addressing problems associated with (industrial) animal agriculture. As industrial modes of thinking are already (and always have been) influencing IVM development, industrial priorities will shape it as well, making Terhaar's urging that opened this essay exceedingly important and deserving of focused and ongoing attention. The cumulative number and extent of the connections covered in this essay makes one wonder just who will benefit with the advent of IVM.

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NP wrote the draft of this manuscript, performed analysis, and approved the submitted version.

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Evan Bowness,
Trent School of the Environment, Canada

REVIEWED BY
Elan Abrell,
Wesleyan University, United States

*CORRESPONDENCE
Adriana Jiménez Rodríguez
✉ Adriana.jimenez@ucr.ac.cr

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Cultured meat, clean meat,... queer meat? A vegan queer ecofeminist perspective on the implications of cellular agriculture

Adriana Jiménez Rodríguez*

School of Modern Languages Literature Department, University of Costa Rica, San José, Costa Rica

This perspective article briefly explores the social implications of cellular agriculture from a Vegan Queer Ecofeminist point of view by referring to a synthesis of currently agreed-upon (possible) positive and negative effects of post-animal agriculture and highlighting how these effects actually ignore key ethical problems inherent in animal agriculture itself. By invisibilizing these, discussions of cellular-ag remain in danger of obscuring the ways in which an intact and unexamined paradigm based on capitalist, patriarchal speciesism will continue to foment exploitative and unjust practices in a dying planet. The article emphasizes the urgent need to address the complexities of cellular-ag from a multidisciplinary perspective that actively engages with the demands of true global justice for all, nonhuman and human.

KEYWORDS

cellular agriculture, clean meat, vegan queer ecofeminism, multidisciplinary approaches, global food justice

Introduction

In the past I have argued that the disconnection between fields like ecofeminism, vegan studies, queer ecologies, disability studies and animal studies, to name just a few, has weakened their individual discussions of planetary devastation in the Anthropocene as well as the articulation of possible ways in which we can survive in the ruins, like Haraway puts it (Jiménez, 2018). I think that we need to add cellular agriculture to the table, urgently, pun intended. Just how we add it, though, is extraordinarily complicated. Here I want to briefly explore the idea that cultured or clean meat is actually queer meat, but not quite in the contemporary understanding of the term *queer*. This meat is queer in its original denotation, the true strange and peculiar coupling of nature (cells) and science (technological manipulation of cells for human purposes) but alas not *queer* in the transgressive theoretical and ideological thinking practice. Some have called this cultured meat "Frankenstein meat". Whereas the original monster-character was indeed queer, vegan, even, this "monster" meat is *strange* without the political and ideological *queer* force behind it. The key argument in favor of cultured meat is that eliminating animal agriculture will immeasurably benefit nonhumans and the environment; this is a laudable claim, but it holds present and yet-to-be-imagined complications in terms of execution. However, even if feasible, eliminating the cause of undeniable suffering and devastation without understanding the intersecting oppressive forces that created it in the first place does not address the true source of human destruction of the planet and the systemic barbarity that enables it.

The story so far: Pros

No ethical vegan can oppose cellular-ag and its queer post-animal products: cultured leather, cultured dairy, cultured eggs, cultured gelatin, and cultured meat are also cruelty-free in its broader definition. Stephens et al. (2018) mention the main authors with negative views, mostly in terms of solving ethical problems with biotechnology, fetishization of meat, and decontextualization and molecularization of sustainability (Cole and Morgan, 2013; Metcalf, 2013; Marcuse et al., 2015; Lee, 2019). Conscientious theoretical nit-picking aside, the naked fact is that monumentally less nonhumans will suffer: this is irrevocably good news for the billions of nonhumans currently experiencing unnecessary and unspeakable torture and murder at the hands of humans, especially birds and sea creatures (*via* industrial fishing). The radical transformations promised by cellular-ag advocates in terms of environmental devastation are less irrevocable yet still scientifically plausible. At this point in the literature, researchers throw numbers in every direction, and these numbers vary (sometimes significantly) depending on who is footing the bill, as usual; a TEA (techno-economic analysis) commissioned by the Good Food Institute, vs. a counter-analysis ordered by Open Philanthropy, for example, bear radically different results (Fassler, 2021). Cellular-ag start-up enthusiasts, whose energy and optimistic focus is quite frankly admirable, claim that cultured meat will reverse global warming and save the world, in extravagant Global North statements such as Shapiro's "It's not difficult to envision local meat breweries popping up in nations that might have erected factory farms instead" (Shapiro, 2018, p. 258). Many scholars, myself included (an inhabitant of those "nations", in effect), actually do find it quite difficult. More cautious experts such as Mattick, point out that real effects will depend on the raw materials used for production in this new era of cell domestication and its industrialization: "while it might be plausible to reduce the global warming potential of cultured meat by selecting targeted, low-carbon energy sources, such alternative fuels may impact diverse stakeholders in different ways (Mattick, 2018, p. 33). Therefore, whereas the only factual response to exactly how much will global warming decrease with the (still aspirational) substitution of traditional animal-ag is the potential for "uncertain environmental impact" (Dutkiewicz and Abrell, 2021, p. 4) there is no possible way that (a) the planet survives present rate farm factories (b) an incursion of cultured meat production at an industrial level could possibly make the current state of affairs worse. A somewhat sober conclusion on this end of the issue is that some of the variables in consideration are not actually real at this point and speculation is complicated in the extreme, but it seems at this point that cultured meat will lower pollution, carbon emissions, and considerably help human-caused environmental damage control—cultured leather, for example, already has proven this, as Shapiro explains in *Clean Meat* (Shapiro, 2018).

The story so far: Cons

In terms of the industrialization of clean meat that is required for it to adequately substitute animal-ag, two main types of objections arise: technical and ethical. An exhaustive list of the technical issues exceeds the purpose of this short article, but the main ones include the need for cell scaffolding for whole cuts of meat (as opposed to less complex ground-meat products which do not require as much blood oxygenation), the standardization of a vegan culture medium—the traditional one is bovine serum extracted from calf fetuses, a grotesque process even in the current meat industry (Shapiro, 2018), and bioreactor scalability (Fassler, 2021). Shapiro and other authors state that alternate serums are already in use in most cellular-ag companies, and that others are even going serum-free. This is probably true but difficult to confirm because in the capital-driven race for store-ready cultured meat, secrecy is paramount—this, I believe, is a major red flag. However noble the motivations—and my research so far indicates nothing but passionate zeal to end cruelty against nonhumans from the (overwhelmingly male) humans behind every single cellular-ag effort—patriarchal capitalism can only allow altruism the narrowest of margins, mediated by profit. The rest of the issues pertain precisely to how quickly companies can start selling their products at scale, and this requires not only the science itself but the money to pay for it, as I will discuss later.

The ethical objections to industrialized cellular-ag abound, and, quite frankly, they are difficult to extricate from the technical ones for specific discussion. I believe, like many critics that have observed the epistemological holes in hailing cellular-ag as a techno-blessing that will solve all problems, that these ethical/technical entanglements also reside in the nucleus of patriarchal capitalism (and the planetary disaster that it has led us to). For starters, and in the process that Helliwell and Burton refer to as an ambiguous *remaking* of the agricultural world (Helliwell and Burton, 2021), a key aspect that worries experts across the board is worker displacement. The argument that farmers have always had to adapt and that they can "work elsewhere" sounds remarkably *a la* Marie Antoinnette. Who will oversee a fair transition from animal-ag to cellular-ag both in terms of the human workforce and of the land? How can this process be modulated fairly? Indeed, "the synthetic revolution could also lead to the intensification of production and expansion of markets in ways that could look far less liberatory than imagined" (Abrell, 2021, 45). Newman et al. (2021) apply a telecoupling method to study socioeconomic and environmental implications over distances and relevantly point out, as an example, how cellular-ag dairy substitution in Canada would affect sugar plantations in an environmentally and politically vulnerable Brazil if cane sugar were chosen as an industrial raw material for production. The complications are vast, and to think that these research efforts on transnational geopolitical consequences of post-animal industrialization are as-yet speculative further emphasizes the need for caution in simplistic, overly optimistic projections. We can also never forget that, as to now, cellular-ag, even after overcoming the vegan serum hurdle, will continue to require donor nonhumans (avian and mammal) to provide cells for line production, as only fish cell lines are immortal. This raises numerous ethical complications, which Dutkiewicz and Abrell (2021) discuss at length. They conclude that ethical cell donation will per force require a guarantee of sanctuary-life status for all nonhumans involved, as well as strict nonhuman welfare regulations even in the private ag sectors—which so far are the overwhelming majority, one more troubling fact.

Discussion: The vegan queer ecofeminist heart of the matter

Precisely as a vegan queer ecofeminist who works in the fields of literature, cultural studies and critical theory, I believe that this perspective on the social implications of biotechnological issues such as cellular-ag is of vital importance. When Dutkiewicz and Abrell argue that "while cellular agriculture might diminish direct violence against animals, it would do little to change the underlying structural and epistemic violence that undergirds the use of animals, leaving anthropocentrism and speciesism unchallenged" (Dutkiewicz and Abrell, 2021, p. 4), I believe that they are right. These authors actually mention ecofeminist scholarship, which is unusual in the literature. Present discussions on cultured meat and its implications at large display much ignorance (or purposeful silence) of the decades-old claims of ecofeminist thinkers and their extensive writing on the patriarchal nature of the "structural and epistemic violence" that undergirds the barbaric animal-ag industry. Furthermore, in "many ways, the approach predicated on cultivating meat as a consumable is directly antithetical to the approach of cultivating care toward each other, other species, and the Earth at large" (Lee, 2019, p. 59). This reminds me very strongly of Gruen's concept of entangled empathy, which I believe is much needed in any integral, multi-disciplinary approach to cellular-ag. Entangled empathy refers to a process that involves "a blend of emotion and cognition in which we recognize we are in relationships with others and are called upon to be responsive and responsible in these relationships by attending to another's needs, interests, desires, vulnerabilities, hopes, and sensitivities" (Gruen, 2015). This process requires looking at specific, detailed contexts of oppression that situate human/nonhuman relationships in locations where species, gender, race, class, ability status and many more intersect. Patriarchal capitalist oppressions interfere with proper, *just* attention to all the participants in post-animal agriculture, the nonhumans, the human workers, the humans with access to clean meat and those without, the transformed geographies of the landscape, the resources for production, the water and energy, everything. The basis of all these types of violence is patriarchy, and its current political, ideological and economic system: capitalism. From a vegan queer ecofeminist perspective, the heart of the matter is that cellular-ag is trying to revolutionize the world in terms of human-caused planetary devastation without revolutionizing anything; in other words, cellular-ag enthusiasts are claiming the impossibility of achieving planetary justice while in slavery to capital. This truly is the impossible dream. I am not alone in this assertion. Cellular-ag, argues Abrell, "has the potential to achieve... liberatory aspirations", but "its status as a project of the same capitalist system of production that gave us industrial animal agriculture raises questions about how capitalism might fundamentally limit that potential (Abrell, 2021, p. 4). I found this to be a latent concern in most of the literature.

The goal is to keep food justice in sight. This concept is key to understand the level of complexity required in adequately preparing and proposing a cellular-ag substitution of animal agriculture. Food justice involves resisting the current capitalist global food regime and will "require a radical rethinking of this rationalist, centrist conceptual structure as well as a political reorganization of power" (Portman, 2018, p. 460–461) and avoiding scenarios where "the Global South can easily become regarded as either recipient or raw-material supplier" (Jönsson, 2020, p. 931). Thus, hardened pessimistic skeptics like Fassler (2021), whose main argument is basically is that the science needed for a cellular-ag market revolution simply does not exist and that cultured meat "may never reach price parity on its own terms. It will likely need public or philanthropic support to be competitive" are in fact, not wrong. If the pressing issue is *cost*, to be able to access consumers in order to return investments, then, indeed "encouraging public–private partnerships, collaborating on public and private investment, developing infrastructure and supporting training will all be necessary" (Fraser et al., 2021). The private sector is simply not going to manage by itself; there has to be financial and political partnership with governments. Let us consider Eat Just, ready "to open a large-scale cultivated meat plant in Doha, Qatar, in partnership with two state-backed organizations—Doha Venture Capital, a VC firm, and the Qatar Free Zones Authority" (Fassler, 2021); the technology is coming, no doubt about it, and joint private and public efforts seem the only way to go. This, unfortunately, becomes a gargantuan feat in countries like the United States, where what little centralization exists is rigged to benefit the animal agriculture corporate sector, which has amassed immense power, and, which, coincidentally, has a lot to do with the present-day low prices of dead nonhuman meat that make it so pressing for cultured meat to race to compete. In fact, "farm subsidies cost the American taxpayer about $20 billion every year, more than double the EPA's budget, mostly to support wealthy corporate farms" (Shapiro, 2018, p. 162). Another important thing that governments could help influence is in taking the attention away from consumers (by financially and ideologically supporting cellular-ag products, as they have done in the past for privileged food industries). Pages and pages of research refer to how difficult it will be to convince consumers to choose cultured meat consistently—and here the hysterical anti GMO groups definitely play a part, never mind that rennet and heme are already present in store products and that the vast majority of GMO plantations actually support feed crops for animal agriculture (Shapiro, 2018, p. 203, 234). I would love nothing more than to believe that consumers just "don't think about the inefficiency, the filth, cruelty, the climate change. But once they know there's an alternative that's healthier, that doesn't include the pathogens, and that doesn't harm animals, people will absolutely switch over" (Shapiro, 2018, p. 164), but unfortunately I am not quite that optimistic. In any event, whether good sense manages to prevail or not seems irrelevant given the reality of the planet. Soon there will be no choice. This seems a judicious moment for states worldwide to take an energetic stand for survival, capitalist consumer free-will aside.

An ecofeminist, entangled-empathy, global food justice perspective is the most balanced. Where can we possibly start, when the task at hand seems close to impossible? I would like to end with a very specific example: Datar's comment in Shapiro's book (one of the few women that he mentions significantly) whose statement on the "competition" between plant-based meat products and cultured meat is emblematic of what an explicitly vegan queer ecofeminist perspective can contribute to this discussion: *we need both*, desperately, and any other alternatives that come up along the way, "a hybridization of cultured and plant-based foods similar to what Impossible Foods is doing with its yeast-produced heme" (Shapiro, 2018, p. 172). Stephens et al. concur, when they argue for "a multi-faceted response which includes a range of approaches, including promoting meat reduction and plant-based proteins, improved waste management strategies, and policy reforms that redress the systemic inequalities within contemporary protein and livestock food systems" (Stephens et al., 2018, p. 164). Only this, hand-in-hand with a real global paradigm shift, can guarantee any degree of planetary preservation.

Conclusion: Proceed with interconnected/interdisciplinary caution

The ethical and practical human atrocities that have created the current devastated state of planet Earth have officially proven to what lengths the division between fields of study need to disappear. Time is of the essence, now more than ever. Cellular-ag is the stuff of science fiction (in the *now*), and as such, we need to team up and look at all its related phenomena from a multidisciplinary perspective. Humans and nonhumans alike have too much at stake to allow for blind spots. Science can only become stronger and more ethical when aided by cultural studies experts from all its critical schools of thought. Other areas as well, for example degrowing economy theories that lead to greener economic policies, are indubitably of the utmost importance to any integral cellular-ag endeavor. How can we make this Frankenstein survive? I ague that we make this *queer* meat work (wholly engaged with true *global justice*) by understanding that a monolithic, un-interrogated capitalist-patriarchal adjacent, biological science-exclusive approach will inevitably fail. We better start engineering the political into this queer post-animal meat along with proteins and fats because we can all agree that the inexcusably horrific murderous ways in which humans are procuring their meat right now finally have an expiration date.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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How can the unnaturalness of cellular agricultural products be familiarized?: Modeling public attitudes toward cultured meats in Japan

Aiko Hibino[1]*, Futoshi Nakamura[2], Mai Furuhashi[2,3] and Shoji Takeuchi[3,4]

[1]Faculty of Humanities and Social Sciences, Hirosaki University, Hirosaki, Japan, [2]Global Innovation Center, Nissin Foods Holdings Co., Ltd., Tokyo, Japan, [3]Institute of Industrial Science, The University of Tokyo, Tokyo, Japan, [4]Graduate School of Information Science and Technology, The University of Tokyo, Tokyo, Japan

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EDITED BY
Lenore Lauri Newman,
University of the Fraser Valley, Canada

REVIEWED BY
Lisa Powell,
Sweet Briar College, United States
Ian Jenson,
University of Tasmania, Australia

*CORRESPONDENCE
Aiko Hibino
✉ ahibino@hirosaki-u.ac.jp

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Introduction: This study aims to clarify how the unnaturalness of cellular agricultural products can be familiarized to society, using the case of the Japanese public's receptivity to cultured meats. Perceived unnaturalness is a key factor in the rejection of emerging technologies. While past studies have examined the explanatory factors involved in the public acceptance of cultured meats, the relationships among multiple factors have not been fully examined. Cultured meats and cellular agricultural products have been positively evaluated because they can contribute to future food sustainability, so the trade-off between perceived unnaturalness and sustainability is a significant issue for the public.

Method: This study uses a questionnaire survey with 2,000 Japanese respondents, which was conducted in 2019. Using a categorical data analysis approach, the strongest explanatory factors for receptivity were comprehensively searched among attitudes toward cultured meats, eating habits, demographics, and so on.

Results and discussion: The results indicated that perceived unnaturalness showed a strong explanatory power for the rejection of cultured meats, but awareness of world famine problems increased acceptance of cultured meat, if the degree of the respondents' concern for unnaturalness was moderate. The perceived animacy of non-human life forms is also associated with acceptance of cultured meat, which may reflect Japanese cultural values. These results suggest multiple pathways to overcoming the disgust of new food technologies in the social implementation process.

KEYWORDS

perceived unnaturalness, categorical data analysis, animacy, Japan, cultural implications, emerging technologies, cultured meat

1. Introduction

Cellular agriculture is expected to provide an innovative food production system and alleviate the ethical and environmental issues associated with the current ones. New food products derived through technology, such as genetically modified foods, evoke controversy in their emerging phases. The societal and cultural implications of biotechnologies through various frameworks and controversies have been explored in Western cultures (Durant et al., 1998; Bauer and Gaskell, 2002; Wagner et al., 2002; Gaskell and Bauer, 2006; Einsiedel, 2009). The process of accepting cellular agricultural products seems somewhat similar to that of accepting previous food biotechnologies. Indeed, public discussion of emerging cultured meats tends toward the established metaphor and analogy frameworks concerning genetically modified foods (Marcu et al., 2015; Mohorčich and Reese, 2019). However, whether cellular agricultural technology has sociological and ethical concerns owing to its particular technological features should be carefully considered. For example, the general process for cultured meat does not include animal slaughter; a small piece of muscle is taken from a cow, pig, or chicken, and isolated muscle cells are grown into larger quantities *in vitro*. Subsequently, proliferating cells differentiate into muscle fibers in appropriate culture media and eventually grow into muscle tissue. The manufacturing of cultured meat avoids ethical problems by avoiding animal slaughter and genetic modifications.

Contextualizing the technological uniqueness of cellular agricultural technology in our sociotechnical society still requires further examination (Stephens and Lewis, 2017; Stephens et al., 2018; Treich, 2021). While cellular agricultural technology is expected to help solve the environmental need to reduce CO_2 emissions from livestock (Sexton et al., 2019; Tomiyama et al., 2020), scientific and technical solutions to sustainability problems may face acceptance issues in the public if they require excessive adaptation of existing culturally shaped habits and preferences. A sustainable society will be enacted if cultural (local) habits and preferences are adequately considered in the new sociotechnical system. In addition, it is important to consider the public's understanding of cultured meats, as there may be opportunities to build multiple frameworks for societal and ethical issues that are triggered by novel technologies (Driessen and Korthals, 2012; Bauer and Bogner, 2020). We focus on the case of cultured meat among the various application of cellular agriculture and discuss its social implementation, as it has been at the center of public and policy debate (Jönsson, 2016; O'Riordan et al., 2017).

2. Background

2.1. Public acceptance of cultured meats

Over the past few years, many social science studies have been conducted regarding the public acceptance of cultured meats. Bryant and Barnett (2018) provide a comprehensive systematic review of 14 peer-reviewed studies on consumer acceptance of cultured meats, summarized by design type, country, sample, and cultured meat type, with the main findings analyzed in detail. Bryant and Barnett's review found that previous studies have focused on the perceived image of unnaturalness (of cultured meats), safety, taste, and prices. An updated review (Bryant and Barnett, 2020) summarized 26 studies on the public perception of cultured meats, indicating that most of the public would like to try cultured meat in many countries. A systematic review by Pakseresht et al. (2022) showed that public awareness, perceived naturalness, and food-related risk perception are the important factors influencing consumer acceptance of cultured meats. As described in these reviews, previous studies have clarified several factors of consumer acceptance of cultured meats, and some have proposed predictive models (Wilks et al., 2019; Siegrist and Hartmann, 2020b). Perceived naturalness has often been examined among various important factors, as described in the following paragraph.

Notably, perceived unnaturalness is the most common objection to cultured meat among the factors studied (Siegrist and Sütterlin, 2017; Bryant and Barnett, 2018; Wilks et al., 2021), and unnaturalness is generally indicated as a critical factor to public understanding of life science technologies (Aizaki et al., 2011; Marcu et al., 2015). Concerns about whether something is "unnatural" underpins the rejection of other food technologies, such as artificial additives, chemicals (Roman et al., 2017), and novel food technologies (Siegrist and Hartmann, 2020a). Wilks et al. (2021) explored the meaning of unnaturalness in the public opinion of cultured meats and concluded that the perception of unnaturalness came from factors such as disgust and fear, rather than rational reasoning. In addition to unnaturalness, safety, healthiness, anticipated taste, and anticipated price were other personal concerns regarding cultured meats.

Some studies have examined consumer acceptance of cultured meat and its associated factors within a national context, such as Italy (Mancini and Antonioli, 2019), Germany (Dupont and Fiebelkorn, 2020), and Belgium (Bryant and Sanctorum, 2021); intercultural differences have also been explored (Bekker et al., 2017; Gasteratos and Sherman, 2018; Bryant et al., 2019; Gómez-Luciano et al., 2019; Siegrist and Hartmann, 2020b). Notably, demographic and attitudinal factors associated with the acceptance of cultured meats vary according to each country's local context. For example, international comparisons in countries including the USA, China, and India, found that public acceptance of cultured meat was affected by the perceived image of healthiness and safety in China, whereas the perception of ethical issues was critical in India (Bryant et al., 2019). Few survey studies have examined attitudes toward cultured meats in Asian countries, except for studies in China (Bryant et al., 2019; Zhang et al., 2020). A limitation of previous research is that many studies have not fully considered relationships among multiple factors in the explanatory variables; thus, the relative impact of perceived naturalness is unclear. In addition, questionnaire surveys have not fully clarified the images of cultured meats in a cultural context and how they affect people's acceptance.

What is interesting here is how a specific new food technology that emerges with a schema of seemingly positive values interact in the cultural context. This study partly relies on the social representation theory (Moscovici, 1984)—a major meta-theory focusing on the societal process in social psychology—as an analytical framework. Social representation theory provides a framework for understanding the societal process of new technologies in which the unfamiliar are familiarized. *Anchoring* and *objectification* are critical processes in the social representation theory. In anchoring, unknown objects are processed according to the existing semantic systems and customs, and in objectification, they become a reality through institutionalization in the process of materialization. While the framing of a "contribution to the sustainable society" has dominated discussions around cultured meats, it is questionable whether such framing would be adapted, as it was in the anchoring process. The factors associated with public acceptance of cultured meats differ across countries, as mentioned above, and can be reinterpreted using social representation theory in terms of how framing, rooted in the cultural context, emerges in the public understanding of cultured meats in a specific country.

Studies using approaches other than questionnaire surveys also provide useful perspectives on the familiarization process of cultured meat. Sexton et al. (2019) examined the typology of the narrative pros and cons of alternative proteins, and clarified the tensions among them. Bogueva and Marinova (2020) examined the attitudes of the younger generation, and Ruzgys and Pickering (2020) examined how messaging strategies affect the younger generation's acceptance of cultured meat. Recently, the impact of framing (Bryant and Dillard, 2019) and labeling (Bryant and Barnett, 2019) cultured meats has been considered from a practical viewpoint using empirical surveys. In addition to these questionnaire surveys, the power of metaphors concerning cultured meats (Broad, 2020), narratives in media coverage (Painter et al., 2020), and key meanings and their transitions (Stephens et al., 2019) have been examined.

2.2. Japanese context

Although cultured meat has not yet been approved in Japan, research and development of these technologies has been active since 2020. Recently, there has been intensive research and development on cultured meat at the University of Tokyo, mostly in tissue engineering. A prominent feature of this group is the research on the production of "real meat" products. While there has been much research worldwide for developing technologies to culture meat in a minced state, the University of Tokyo group and its collaborators have focused on meat in the structured state. The major characteristic of structured meat is that it is thick, with a chewy texture similar to that of steak. The Tokyo group focuses on aligning muscle fibers and building a thick three-dimensional structure that is closer to the meat from slaughtered animals.

There has been much research on Japanese public perceptions of genetically modified foods, clone technologies, and synthetic biology (Hibino, 2010; Aizaki et al., 2011; Hibino et al., 2019), but there have been no surveys on attitudes toward cultured meats. The acceptance of genetically modified foods in Japan have been as low as that of European countries since the early 2000s (Hibino, 2010). It is also concerning that the Japanese public's awareness regarding the concept of "ethical" (as a specific translation of a prefix in the Japanese marketing context) (8.8%) and "ethical consumption" (12.2%) were found to be relatively low in 2019 (Japanese Consumer Affairs Agency, 2020). This is in line with the low awareness of the concept of fair trade, as only 23.2% of respondents had heard of it in Japan (Japanese Consumer Affairs Agency, 2020). This percentage is extremely low compared to Europe, where over 80% of people were reported to be familiar with fair trade (Globescan, 2015). We can see that there is little awareness of new food technology in Japanese society, and that Japanese people are expected to be relatively cautious about accepting cultured meat.

While public attitudes toward the pros and cons of biotechnology are similar in Japan and Europe, there is a possibility that a culturally specific framework for life may be associated with public receptibility of life science products, including cultured meats. Japanese philosophical studies suggest that *life* as a concept including the fate (*karma*) of exchanging lives and the "emotions" that arise in the Japanese context; this contradicts the concept of life emphasizing individuality, primarily present in the Western culture (Sagara, 1994; Kimura, 2002; Takeuchi, 2011). Empirical analysis of media discourses in Japan showed that Japanese people have a unique frame of reference, in that they have an emotional attachment to cloned animals (Hibino and Nagata, 2006). In summary, in the Japanese context, it has been suggested that the understanding of *life* is on a continuum between living and non-living things. This way of understanding, in association with the Japanese receptivity of cultured meats, should be further investigated.

This study aims to clarify how the unnaturalness of cellular agricultural products can be familiarized to society, using the case of the Japanese public's receptivity to cultured meats. First, we aim to explore the factors determining public receptivity to cultured meat by focusing on the role of the perceived unnaturalness of cultured meat, while also considering relationships among multiple factors. Second, this study aims to clarify how the perception of animacy of non-human living things, which is salient in the Japanese view of nature, affects the public's receptivity to cultured meat. Past qualitative and quantitative studies on the public's acceptance of emerging technologies have indicated the critical role of cognition in unnaturalness. Our analysis will contribute to studies on the acceptance of cultured meats by exploring relationships between factors and their semantic meaning in a local context, which might address the issue of how contradictive perspectives can be coordinated when the feeling of disgust and globally supported evaluations of cultured meat are actualized in the public sphere. The study also addresses the pathway for managing unnaturalness based on a cultural context.

3. Materials and methods

3.1. Survey overview

A survey was conducted online among 2,000 Japanese respondents aged 20–59 years (male respondents = 1,000; female respondents = 1,000), randomly selected by a Japanese survey research company (Cross Marketing) from panels in May 2019. Cross Marketing is one of the established research companies that have experience in academic social surveys, and it has five million panels recruited on various internet media. The participants of our survey were randomly selected from these panels. After being provided with the outline of questions and information about the purposes of this study, they were asked to agree to respond to the survey. There was an incentive for participants, as those who completed the survey were awarded electronic points that could be used for purchases. The participants were equally distributed by sex and age (eight groups). The survey represented Japanese people in this age range. To maintain the quality of the answers in the web survey, the questionnaire included a trap question and eliminated respondents who did not answer the questions seriously. The research company periodically carries out duplicate checks to eliminate illegally registered panels, which also helped to maintain the quality of the answers.

Before they survey was conducted, the Research Ethics Committee of the Faculty of Humanities and Social Sciences, Hirosaki University, reviewed all the study materials and approved the study (No. 2019-01).

Considering that this study aimed to explore the factors that were most strongly associated with receptivity to cultured meats, a questionnaire was designed to cover the main items that may have been previously investigated. The major components of the questionnaire were the perception of cultured meats, willingness to eat, attitudes toward cultured meats, perceived animacy of non-human life forms, perceived naturalness of new technologies, eating habits, demographic information of sex, age, educational background, and so on (see Supplementary Table I).

First, participants were asked about their perception of "cultured meats," and they could also provide free-form responses about their perceptions of "meat" and "life." Participants answered before they were provided with a description of the cultured meat. In Japan, information on cultured meats was receiving hardly any media coverage when we conducted the survey in 2019, and a simple description of the production method for cultured meat was provided in the survey. The description was technically correct but also simple and minimal so that participants' judgments of cultured meats would not be influenced: *Cultured meat is made by isolating cells from the muscle of an animal (cattle, etc.) and culturing several cells to produce an edible piece of meat. This technology does not clone an animal; instead, it cultures tissue using cells obtained from an animal's tissue.* Our questionnaire adopted the term *baiyo-niku* in Japanese as the literal translation of cultured meat, as it was widely used in 2019. While the survey included comprehensive questions, we discussed the following three areas:

1. Willingness to try cultured meat: This study asked respondents, "Would you be willing to try cultured meat?" (five categories: "definitely no = 1"; "probably no = 2"; "unsure = 3"; "probably yes = 4"; and "definitely yes = 5"). The question of willingness to engage is common in other surveys (Wilks and Phillips, 2017).

2. Agreement with statements about attitudes toward cultured meats: "CM is unnatural," "CM is disrespectful to nature," "CM is ethical," "CM will improve animal welfare conditions," "CM will be able to solve world famine problems," "In the future, CM will be a viable alternative to farmed meat," "CM will have negative impacts on traditional farmers" (five categories: "strongly agree = 1"; "agree = 2"; "unsure = 3," "disagree = 4"; "strongly disagree = 5"). This question is common in other surveys (Wilks and Phillips, 2017).

3. Cognitive image of life: This study asked respondents, "Which items do you think are alive?" and provided multiple choices ("cells," "bacteria," "animals," "viruses," "DNA," and "atoms"). The total number of chosen items was used as an index for the broadness of the cognitive image of life (from 0 to 6).

Data were analyzed using both the R version 4.0.0 and SPSS version 27. The relationships between items were examined and supported by categorical data analysis using the Akaike Information Criterion (AIC) (Katsura and Sakamoto, 1980; Sakamoto, 1992).

3.2. Basic statistics

The basic statistic of the dependency for the distribution of a specified variable (response variable) on other variables (explanatory variables) was derived and evaluated using the AIC (Sakamoto and Akaike, 1978; Sakamoto, 1992; The Institute of Statistical Mathematics, 2020). The AIC, which is one of the commonly used criteria for statistical model selection, utilizes the maximum likelihood principle. The methodological advantages of categorical data analysis are as follows: First, this program can explore reliable variables by automatically analyzing all their combinations of through an exhaustive search for a condition (Seichi et al., 2012; Takahashi et al., 2019). This enables the modeling of public attitudes toward cultured meats without a specific assumption. Second, this program clarifies the proper division pattern of ordinal scales in explanatory variables. Third, this is useful for detecting factors that have a nonlinear relationship with target valuables.

We used the following statistics to measure the strength of the dependence of a specific set of response variables on the explanatory variable, as defined by Sakamoto (1992). The Institute of Statistical Mathematics (2020, p. 7) explained this statistic as follows:

> E denotes the response variable and F denotes candidate explanatory variable, and their cell frequencies by $n_E(i)(i \in E)$ and $n_F(j)(j \in F)$. The cross frequency is denoted by $n_{E,F}(i,j)(i \in E, j \in F)$. To measure the strength of dependence of a specific set of response variables E on the explanatory variable F, we use the following statistic:

$$AIC(E;F) = -2 \sum_{i\in E, j\in F} n_{E,F}(i,j) \ln \frac{n_{E,F}(i,j)}{n_F(j)} + 2C_E(C_F - 1), (1)$$

> Where C_E and C_F denote the total number of categories of the corresponding sets of variables, respectively.
>
> The selection of the best subset of explanatory variables is realized by the search for F which gives the minimum $AIC(E; F)$. In case of $F = \phi$, the formula (1) reduces to

$$AIC(E;\phi) = -2 \sum_{i\in E} n_E(i) \ln \frac{n_E(i)}{n} + 2(C_E - 1)$$

> Here it is assumed that $C_\phi = 1$ and $n_\phi(1) = n$.
>
> Sakamoto's original CATDAP (the categorical data analysis program package) outputs $AIC(E; F) - AIC(E;\phi)$ as the AIC value instead of $AIC(E; F)$.

This study also used $AIC(E; F) - AIC(E;\phi)$ as the AIC value. Note that the AIC index from $AIC(E; F)$ is more appropriate when comparing the goodness of fit of the model with other models. The R package of CATDAP-02 provides the base AIC value of

TABLE 1 Socio-demographics and willingness to eat cultured meat ($N = 2{,}000$).

Questions/response options	% of sample
Gender	
Male	50.0
Female	50.0
Age	
20–29	24.8
30–39	24.8
40–49	24.8
50–59	25.6
Education	
Junior high school	3.1
Completed high school	28.2
College/undergraduate/postgraduate degree	68.5
Other	0.4
Have you heard of cultured meat?	
Yes	27.1
No	73.0
Would you be willing to try cultured meat?	
Definitely yes	6.4
Probably yes	21.3
Unsure	28.5
Probably no	24.3
Definitely no	19.5

$AIC(E;\phi)$, which can be used to calculate the AIC index from $AIC(E;F)$.

This categorical data analysis was applied to evaluate the dependencies of engagement with cultured meats as a response variable to 40 explanatory variables: attitudes toward cultured meat, perceived animacy of non-human life forms, perceived naturalness of new technologies, eating habits, and demographic information (see the Supplementary Table I). The categorical data analysis program package (CATDAP) for R was developed by the Institute of Statistical Mathematics in Japan (The Institute of Statistical Mathematics, 2020). Data analysis was carried out using CATDAP-02, which searches for the best single explanatory variable and detects the best subset of explanatory variables, as well as the optimal categorization of continuous values.

4. Results

A total of 2,000 responses were obtained. Our sample was equally split between male (50%) and female (50%) respondents. The sociodemographic variables of sex, age, education, and awareness of cultured meats are presented in Table 1. Less than

TABLE 2 Top variables associated with cultured meat engagement (ordered by AIC*).

Top 20 explanatory variables	Number of categories of exp. var.	AIC**
CM is unnatural	5	−523.8
CM is disrespectful to nature	5	−437.1
CM will be a viable alternative to farmed meat	5	−299.9
CM is ethical	5	−231.1
CM will be able to solve world famine problems	5	−219.7
CM will improve animal welfare conditions	5	−165.9
CM production will have negative impacts on traditional farmers	4	−107.8
Interest in fair trade and environmentally friendly foods	5	−104.5
Preference for meat	4	−85.5
Have heard about cultured meats	2	−81.7
Sympathetic to vegetarianism	4	−67.7
Perceive naturalness of vegetables in plant factories (vertical farming)	2	−61.0
Perceive naturalness of genetically modified foods	2	−53.3
Perceive wide spectrum of animacy	3	−43.2
Perceive animacy of bacteria	2	−40.8
Sex	2	−37.8
Frequency of meat eating	4	−36.7
Perceive naturalness of organs from iPS cells	2	−31.1
Perceive naturalness of robots	2	−18.6
Top 5 subsets of explanatory variables	**Number of categories of exp. var.**	**AIC**
CM is unnatural CM will be able to solve world famine problems Have heard about cultured meats	24	−729.5
CM is unnatural CM will be able to solve world famine problems	12	−727.2
CM is unnatural CM will be able to solve world famine problems Age	24	−698.0

(Continued)

TABLE 2 (Continued)

Top 5 subsets of explanatory variables	Number of categories of exp. var.	AIC**
CM is unnatural CM will be able to solve world famine problems Perceive wide spectrum of animacy	24	−695.3
CM is unnatural CM will be able to solve world famine problems Perceive animacy of bacteria	24	−693.4

*AIC, Akaike information criterion.
**Base AIC = 6110.17.

one-third of the respondents had heard of cultured meats, which suggests that awareness was still low in 2019.

4.1. Willingness to try cultured meats

The results showed that 27.7% of respondents answered that they would like to try cultured meats (6.4% = "definitely yes"; 21.3% = "probably yes"). In addition, 28.6% of respondents answered that they were unsure, and 43.8% said they would not like to try it (composed of 24.3% = "probably no"; 19.5% = "definitely no"). This rate shows that Japanese receptivity to cultured meat was relatively low compared to that of other countries. Japanese respondents seemed less likely to try cultured meats; however, they were more positive when asked about its significance. Of the respondents, 54.6% agreed with the statement that "cultured meat will be able to solve world famine problems" ("strongly agree" and "agree"), which is about the same rate as that reported in the US survey (Wilks and Phillips, 2017).

4.2. Model for receptivity to cultured meats

Categorical data analysis was applied to search for variables that strongly affected the response distribution of the objective variable of willingness to engage with cultured meats. Table 2 shows the top 20 variables, where the lower the AIC value, the stronger the explanatory variable in relation to the objective variable. Snare analysis with cross-sectionality was used to search for the variables that indicated the main factors that strongly affected the receptivity to cultured meat, eating habits, perceptions of new technologies, and life forms. The most relevant variable for receptivity to cultured meat was the perception of its unnaturalness (AIC = −523.8, Cramer's V = 0.28). Among the respondents who thought that cultured meat was unnatural (strongly agree), about 76% did not want to try it (Figure 1). Conversely, among respondents who thought that cultured meat was natural, 40% said that they would like to try it and 56% said that they would not like to try it. These results suggest that the recognition of the unnaturalness of cultured meat could be associated with its rejection, whereas the recognition of its naturalness could be associated with both rejection and acceptance. We observed asymmetry in the finding that low eating engagement appeared in negative attitudes, such as ethical and animal welfare conditions. The only exceptions were the items on world famine, where the agreement that cultured meats could directly solve world famine problems was associated with interest in eating it.

An analysis of optimal combinations of two or more explanatory variables by CATDAP-02 showed a combination of perceived naturalness and concern for world famine problems as strongly associated with receptivity to cultured meats (AIC = −727.2) (Table 2). The combination set with the strongest explanatory power was "CM is unnatural," "CM will be able to solve world famine problems," and awareness of cultured meat (AIC = −729.5), which were stronger than the explanatory power of "CM is unnatural" on its own (AIC = −523.8) (see Table 2). The cross table shows that except for those who strongly rejected cultured meat, respondents' willingness to try cultured meat increased with the degree to which they agree that food technology was useful for sustainably food system (Table 3). To confirm the robustness of the modeling suggested by CATDAP-02, ordinal logistic regression was conducted on receptivity to cultured meat as the objective variable, and agreements with "CM is unnatural" and "CM would be able to solve world famine problems" as explanatory variables. Two factors of perceived unnaturalness and concern for the world famine problems explain receptivity to cultured meat (receptivity ∼ perceived unnaturalness + concern for the world famine problems; AIC = 5506.6, residual deviance = 5482.6, N = 2,000), which were better than the model with a single factor of perceived unnaturalness (receptivity ∼ perceived unnaturalness; AIC = 5714.3, residual deviance = 5760.4, N = 2,000).

Furthermore, opinions related to cultured meat (AIC = −299.9 to −107.8), consumption beliefs (−104.5), the variables of eating habits (AIC = −85.5), and information exposure (AIC = −81.7) show a relatively strong association with the willingness to engage with cultured meats. Regarding opinions related to cultured meats, the more highly people rated the significance of cultured meats, the more likely they were to try it. As a variable related to food preferences, those who liked meat and those with a high affinity for vegetarianism were more interested in sampling cultured meats.

Notably, variables concerning how respondents perceived life forms had a relatively strong association with their willingness to try cultured meat. The larger the number of objects that respondents considered animate, the more likely they were to be willing to try cultured meat. 31.9% of respondents who considered more than four objects as animate were willing to try cultured meat, whereas only 7.5% of respondents who considered no objects as animate expressed this willingness (AIC = −43.2) (Figure 2). The subsets of explanatory variables including spectrum of animacy (AIC = −695.3) and perceived animacy of bacteria (AIC = −693.4) were highly ranked in AIC (Table 2). In short, it can be considered that the receptivity to cultured meat is partly rooted in people's belief in animacy. Willingness to engage with cultured meat was also associated with the perceived naturalness of other currently emerging technologies, such as genetically modified foods, iPS cells, and robotics. Respondents who regarded

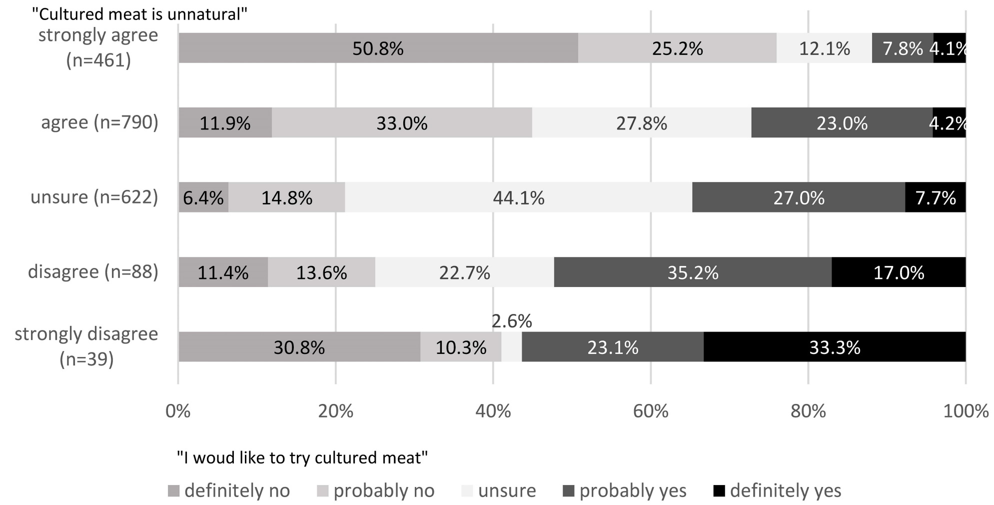

FIGURE 1
Association between agreement with "cultured meat is unnatural" and willingness to try it (AIC = −523.8).

these technologies as natural tended toward a willingness to eat cultured meats. Conversely, the attribute items were less related to an interest in eating cultured meats. The attribute variables (educational background, income, etc.) had a relatively weak effect on sampling interest.

4.3. Perceived image of life, meat, and cultured meat

We used text analysis of the participants' responses (open-ended answers) to interpret their understanding of cultured meats and life forms, as this methodology is useful for analyzing responses to unfamiliar new food technologies (Stoneman et al., 2013; Eisner et al., 2019). A text analysis of the narratives in the open-ended responses support the interpretation that perceptions of cultured meats are involved in accepting its technology in Japan. The free-answer items analyzed in this study were as follows: "What do you think about your life?"; "What do you think about meat?; and "What do you think about cultured meat?" We first extracted the top 40 most frequently occurring words from the respondents' descriptions for each questionnaire item. There was a significant difference in the frequency of word usage between those who were interested in trying cultured meats and those who were not ($p < 0.05$) (see Supplementary Table II).

Japanese respondents' descriptions can be classified into those focusing on individual objects and relational networks in an ecological system according to their receptivity. Those who were affirmative to cultured meats tended to refer to the "food chain" and "cattle (cow)" instead of "beef." The examples of narratives are as follows; *"(Meat is) something those human beings can eat only at the cost of such precious sacrifices as cattle, pig, and chicken." "(Life is) all that is in the circle of the food chain and that cannot escape from it." "In the world of the food chain, it seems inevitable that a strong one will prey on the weak, but I want to respect and utilize the dignity of individual lives as much as possible."* Such descriptions seem to reflect cultural values among the Japanese, rather than simply referring to the natural scientific concept of the food chain system. Conversely, the words that characteristically appeared in the free answers from those who rejected cultured meats were "artificial," "body," and "fear" as images of cultured meat, and "steak" and "beef" as images of meat. This may be because of an emerging framework for cultured meat that has a relational view of life, partly reflecting Japanese cultural values (Sagara, 1994; Kimura, 2002; Takeuchi, 2011). This provides a perspective on accepting cultured meats, even if it is considered an unnatural object.

5. Discussion

This section discusses perceptions of the naturalness of cultured meat, animacy, and how the unnaturalness of cell agricultural products can be familiarized in society.

5.1. Familiarizing unnaturalness with sustainability

Important factors associated with cultured meat engagement include the unnaturalness of cultured meats. Previous research on public understanding of science has examined and discussed the perceived unnaturalness of biotechnology and new food technology, which is one of the key factors leading to technology neophobia (Aizaki et al., 2011; Marcu et al., 2015; Siegrist and Sütterlin, 2017; Bryant and Barnett, 2018; Siegrist and Hartmann, 2020a; Wilks et al., 2021). The present study clarified the explanatory power of unnaturalness using the AIC index, which measures the explanatory value of a specific variable when compared with other variables for cross-sectional analysis.

The results showed a non-linear association between perceived naturalness and receptivity; cognition of the unnaturalness of

TABLE 3 Contingency table constructed using the subset of explanatory variables for agreement with "would like to try cultured meat" (AIC = −727.2).

		Definitely no	Probably no	Unsure	Probably yes	Definitely yes	Sum	N
Agreement with "CM is unnatural" (X2)	Agreement with "CM will be able to solve world famine problems" (X3)							
1	1	55.6	0.0	5.6	22.2	16.7	100.0	18
1	2	10.0	30.0	0	20.0	40.0	100.0	10
1	3	9.1	9.1	0	27.3	54.5	100.0	11
2	1	10.5	17.8	47.3	19.0	5.4	100.0	427
2	2	2.0	12.4	37.8	39.3	8.5	100.0	201
2	3	1.2	3.7	19.5	47.6	28.0	100.0	82
3	1	20.1	38.2	29.3	11.2	1.2	100.0	259
3	2	8.8	33.7	29.5	26.0	2.0	100.0	407
3	3	4.8	20.2	19.4	37.9	17.7	100.0	124
4	1	62.4	22.9	9.3	3.4	2.0	100.0	205
4	2	41.3	34.2	14.2	7.1	3.2	100.0	155
4	3	41.6	15.8	14.9	17.8	9.9	100.0	101
Total		19.5	24.2	28.6	21.3	6.4	100.0	2,000

The CATDAP-02 searched for the optimal categorization of the continuous values, and the results were as follows: in X2, 1 = "strongly disagree," 2 = "disagree" and "unsure," 3 = "agree," and 4 = "strongly agree," and in X3, 1 = "strongly disagree," "disagree," and "unsure"; 2 = "agree"; and 3 = "strongly agree." The values with a gray background (rows 2–4 in X2) are more than 10 points higher than the percentages of the total distribution.

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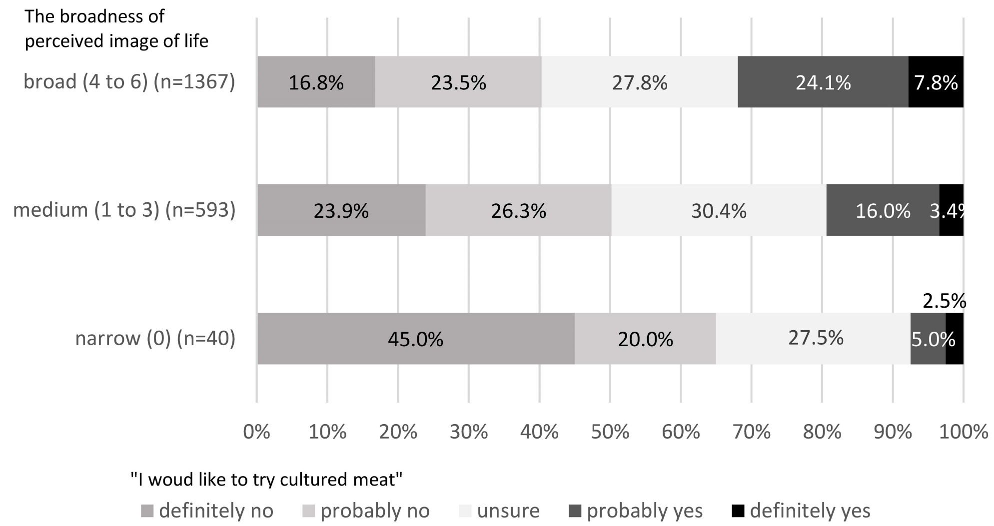

FIGURE 2
Association between number of objects perceived as animate and willingness to try cultured meat (AIC = −43.2).

cultured meat was associated with an unwillingness to try it. On the contrary, the cognition of naturalness is related to both willingness and unwillingness. Why are perceived unnaturalness and naturalness asymmetrical? Is it difficult to improve public acceptance of cultured meats by emphasizing the naturalness of technologies? The critical point may lie in the fact that people might use the term "unnatural" as an expression of aversion. Here, it is synonymous with "I don't want to eat it," and it is conceivable that the two constitute the same feeling, which is grounded in affective mechanisms such as disgust, fear (Wilks et al., 2021), and distrust (Marcu et al., 2015). Conversely, "nature" was mobilized by respondents as the usefulness of cultured meat to "the natural environment and ecosystem." A study of lay and expert arguments regarding "naturalness" (Ditlevsen et al., 2020) found that laypeople see synthetic vaccines as unnatural, suggesting a connection between risk evaluation and objects.

Moreover, it is considered that the plural meanings of "naturalness" affects polarized receptivity. Of the respondents, 16.3% answered that they thought cultured meats respected nature, which was higher than those who said it was "natural" (6.4%). A significant percentage of respondents think that cultured meat itself is unnatural but that it respects "nature." Among the respondents who gave such answers, their logic may be that cultured meat is *not natural* because it is an artificial product. However, when it comes to nature as a global ecosystem, cultured meat can *contribute to nature*, although this interpretation is limited to the Japanese context.

Although naturalness was the most important factor for public receptivity to cultured meats, we should note that other factors, such as the possibility of solving world famine problems and improving animal welfare, were highly ranked in the AIC. An agreement to solve famine is an especially important factor in the discussion of cultured meats, as there was a linear relationship between this variable and acceptance. In addition, this variable showed the strongest explanatory power in combination with the perception of naturalness. In other words, it may suggest that the rejection of cultured meat is associated with perceived unnaturalness, whereas its acceptance comes from recognizing the social significance of environmental issues. Policymakers can utilize a global food system framework with environmental issues to contextualize cultured meats, although implicit faith in food productivism should be unpacked carefully (Iles et al., 2016).

5.2. The role of cultural value: The perceived animacy of non-human lifeforms among the Japanese

What is interesting from our analysis is that the Japanese public's willingness to eat cultured meat is strongly associated with how they perceive non-human life forms. Those who perceive animacy in non-human life forms are also willing to try cultured meat. This result might seem strange to those who think that people should avoid eating all lifeforms and can be interpreted as follows. It is significant that the tolerance of ambiguity (Furnham and Marks, 2013) of artifacts is critical to the formation of public acceptance of cultured meat in the Japanese context. In other words, how people organize semantic classifications among objects, which includes boundary entities, affects their evaluation of cultured meats. There are those who view clear distinctions between animated and unanimated objects, and they might have negative perceptions of cultured meats because the boundary entity between natural and unnatural, or between living and non-living things, does not have a position in their meaning system. In contrast, those who view a continuum between animated and unanimated objects have a positive perception of cultured meats. This is because a new entity can have any meaning for those with such continuous views, even if it includes ambiguity. As described before, in Japan, the concept of life forms a continuum with non-living things and includes the fate of exchanging life and the "emotions" (Sagara, 1994; Kimura, 2002; Takeuchi, 2011). The results of the present study significantly reflect the uniqueness of Japanese culture. A previous survey on public perception of genome-editing techniques and synthetic biology provided similar findings: the depth of understanding of the perceived body image, including components other than the physical body, led to a positive evaluation of emerging life science technologies (Hibino et al., 2019).

The impact of social attributes such as education, income, and occupation, as noted in several previous surveys, were found to be relatively small. This study also found an association between age and sex; however, it suggested that the effect was small when compared with other items. Similar results have been found in previous Japanese surveys. In recent years, the preference for advanced technologies has not been determined by the evaluation systems of social classes or groups, but rather by the feeling of objects rooted in body perception.

5.3. How to cope with the unnaturalness of new food technologies

Studies on public perception of cultured meats have clarified the critical role of perceived unnaturalness in attitude formation, which has been well discussed in previous studies on emerging food technologies. The implications of this study in the Japanese context are as follows: First, it is considered that the framework of social significance and environmental sustainability, in this case, could assist in the discussion and decision-making process for the social implementation of cultured meats, although the perceived unnaturalness of emerging food technologies is strongly associated with public rejection, and such a feeling could not be easily dissolved. Considering that the public receptivity of cultured meat is strongly affected by the configuration of perceived naturalness and world famine problems, it is *inadequate* to appeal directly to the public regarding the "naturalness" of emerging technology to increase its acceptance. As Wilks et al. (2021) discussed, although the perception of "unnaturalness" influences the rejection of cultured meats, it does not mean that the concept of "naturalness" is an antidote to acceptance problems. Marcu et al. (2015) clarified the importance of dialogue; for instance, it is important to promote questions concerning any proposed facts or refer to the management aspect of a new production system. The possibility of discussing emerging technologies seems to expand perspectives, and not simply the literacy improvement of laypeople.

Second, the findings of this study indicate that important factors unique to a specific country emerge in the early phase; such an understanding that is based on cultural frameworks can possibly overcome the dichotomy between the naturalness and unnaturalness of emerging food technologies. For Japanese people, the salient logic of Japanese respondents that focuses on the interrelationships between living things is strongly associated with the acceptance of cultured meats. Interestingly, the perceived animacy of non-human lifeforms are associated with acceptance, although this local framework can also be associated with public rejection. Its *interdependency* addresses the acceptance of new and artificial food technologies, providing another pathway for discussion. What should be noted here is that when evaluating emerging technologies, it is important to have a dynamic perspective wherein the culturally unique framework provides a system of meaning for unfamiliar objects, and the framework itself can be changed gradually.

5.4. Conclusion

This study aims to clarify how the unnaturalness of cellular agricultural products can be familiarized with society, taking the case of the Japanese public's receptivity to cultured meats. It clarified that the perception of unnaturalness showed strong explanatory power for rejection of cultured meats. Furthermore, it showed that the configuration of the explanatory factors of attitudes, eating habits, and perception of non-human life forms played a critical role in the receptivity to eating cultured meats. The important results of our study show the empirical strength of the numerical AIC index with cross tables. One problem to consider is that our findings were derived from the case of cultured meat, so the broad issues in cellular agricultural products should be examined in future research. The study also examined culturally specific framework for life in Japanese, which also relates to the ethical perspective of cellular agriculture; hopefully, this will be verified in international comparative studies in other cultural contexts, including Asia. This multi-layered approach can be seen in public awareness, and is necessary when examining a reasonable response to it in policy discussions and communications.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the Research Ethics Committee of the Faculty of Humanities and Social Sciences, Hirosaki University. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

AH, FN, MF, and ST conceived and designed the study and acquired the data. AH analyzed the data and drafted the manuscript. FN, MF, and ST substantially revised the manuscript. All authors made a substantial contribution toward the development of the final manuscript and approved its publication.

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Conflict of interest

FN and MF are employed by Nissin Foods Holdings.

The remaining 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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1129868/full#supplementary-material

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EDITED BY
Rachel Bezner Kerr,
Cornell University, United States

REVIEWED BY
T. Anukiruthika,
University of Manitoba, Canada
Gaetano Chinnici,
University of Catania, Italy

*CORRESPONDENCE
Lisa Jordan Powell
✉ lpowell@sbc.edu

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Perceptions and acceptance of yeast-derived dairy in British Columbia, Canada

Lisa Jordan Powell[1]*, Zsofia Mendly-Zambo[2] and Lenore Lauri Newman[3]

[1]Center for Human & Environmental Sustainability, Sweet Briar College, Sweet Briar, VA, United States, [2]School of Health Policy & Management, York University, Toronto, ON, Canada, [3]Food and Agriculture Institute, University of the Fraser Valley, Abbotsford, BC, Canada

Yeast derived-dairy (YDD) produced using cellular agriculture technologies is already available for purchase in the United States, though there has been little study of public understanding of these products. Our pilot study explored consumer perception and acceptance of YDD and yeast-derived agriculture (YDA). The study employed a questionnaire consisting of Likert scale, multiple-choice and open-ended questions, which was disseminated to vegans and the food-interested public in the province of British Columbia, Canada. Quantitative data was analyzed using SPSS 27.0, and qualitative data was collected and analyzed (in English) using thematic analysis. A binary logistic regression model indicated that among our participants, being vegan or 35years of age or older negatively predicted having positive feelings towards YDA [chi-square (10)=29.086, p=0.001]. Vegans were less likely to try or purchase YDD than non-vegans. Consumers in our study shared concerns regarding the health and safety of YDD with many viewing it as non-vegan and a highly processed product. Although vegans receive a disproportionate amount of media attention with regards to cellular agriculture, our pilot study suggests this group may be unlikely to accept or consume YDA or YDD. Rather, our preliminary work indicates non-vegans and individuals under the age of 35 may be a more receptive market. Across groups, confusion about YDA processes may be a barrier to adoption.

KEYWORDS

yeast-derived dairy, cellular agriculture, vegan, consumer perception, British Columbia

1. Introduction

Consumption of dairy products across the globe is changing. Plant-based milk sales increased 61% between 2012 and 2017 in the United States (Mintel, 2018), while almost a quarter (23%) of individuals in the UK consumed plant-based milks in 2019 (Mintel, 2019). In Canada, consumption of milk and dairy has steadily decreased over the past decade (Statistics Canada, 2017). The removal of the dairy section from the Canada Food Guide further illuminates these shifts, as dairy products have been a long-standing staple of Canadian diets (Health Canada, 2019). Concerns surrounding ethics, environmental impact, health, and safety have all helped fuel the shift away from conventional dairy toward plant-based alternatives. New varieties of plant-based milk and dairy alternatives from various nuts, oat, hemp, pea and coconut are indicative of the rapid growth and expansion potential of this market.

New technologies also hold the potential to further change the landscape of dairy consumption in Canada and across the globe. Cellular agriculture refers to a set of technologies used in the production of agricultural products like meat, dairy, eggs, and others using cell cultures rather than relying on animals. It has garnered media and academic attention, particularly since 2012, when the first lab grown beef patty was produced by Mark Post's research group at Maastrict University (Post et al., 2020 discusses this in detail). Although lab-grown meat is still likely years away from widespread commercial availability, another application of cellular agriculture, yeast derived-dairy (YDD), is already producing biologically equivalent dairy and milk products for market in the United States. Perfect Day, a San Francisco-based company, has successfully created and marketed their fermentation-derived dairy proteins, now available for purchase in ice-cream made by Smitten. Perfect Day has also expanded to create their own ice cream company, Brave Robot.

Although consumers are already able to enjoy "milk without the moo" (Pandya, 2014), little is known about consumer perceptions and acceptance of this food, particularly among the food-interested public and vegans, of which the latter are often regarded as a key demographic for this novel food (Mendly-Zambo et al., 2021). A 2018 market research study in Great Britain led by a private sector firm gave some insights into consumer interest in YDD (Perkins, 2018), and a study based on focus group conducted in 2021 with 42 participants across Germany, the United States, and Singapore was published as this article was in the late stages of preparation (Broad et al., 2022). Additional research is needed, particularly in regions like Canada, not covered by these studies. The aim of our study was to contribute to addressing this gap in knowledge by collecting information regarding consumer attitudes and perceptions of cellular agriculture technologies, particularly YDD, in the Canadian province of British Columbia (BC). As this was a pilot study, our aim was both to gain preliminary data for analysis, and to use this to inform our team's future research on YDD.

1.1. Overview of cellular agriculture and cellular dairy

Cellular agriculture refers to a set of technologies used in the production of traditionally animal-derived meat, dairy, fish, and eggs, without relying on sentient animals. Unlike the ubiquitous and growing dairy alternatives, including nut, soy, and oat milks, which aim to be viscerally equivalent to dairy, YDD, and other foods produced using cellular agriculture technologies are biologically equivalent and therefore have the same eating and cooking experience as foods produced from animals (Stephens et al., 2018).

Cellular agriculture has two main avenues of production, cellular and acellular. YDD is made by a process of acellular production which uses recombinant microorganisms to produce milk proteins (casein and whey) through a process of fermentation (Tuomisto et al., 2017). Isolated and purified milk proteins are combined with specific ratios of plant-sourced fats, minerals, sugar, and clean water to create biologically equivalent milk (Pandya, 2014) that is described as "animal-free dairy" by companies currently producing it, such as Perfect Day (2020b). As yeast is used in this process, this novel dairy is referred to as yeast-derived dairy, or fermentation-derived dairy, although nomenclature is not yet consistent. Although a novel application, the techniques used in acellular production, which may be broadly framed as yeast-derived agriculture (YDA), are not new, and have already been used for decades in the processes of making insulin and rennet, and more recently in the production of leghemoglobin, a key ingredient responsible for the flavor and aroma of cooked meat in the Impossible Food's Impossible Burger (Shapiro, 2018).

1.2. Consumer acceptance and perceptions of cellular agriculture

Numerous consumer perception and acceptance studies on cellular agriculture have been conducted worldwide (for review see Bryant and Barnett, 2018, 2020); to date, however, these studies have focused primarily on cultured meat production, save for Perkins (2018) and Broad et al. (2022) discussed in Section 1.1. Although yeast-derived dairy and cultured meat have different production processes, they are both foods which are biologically equivalent to animal products and stem from cellular agriculture technologies. Accordingly, both categories of foods raise similar questions about consumer perceptions and acceptance, and we can learn from consumer studies which focused on meat products.

There is a noted lack of uniformity in study design and methods employed in consumer perception studies to date; approaches have included focus groups, surveys, and media analysis (Bryant and Barnett, 2018), as well as examinations of how cellular agriculture technologies are described and the nomenclature used (Bekker et al., 2017; Siegrist et al., 2018; Bryant and Barnett, 2019). As reviewed by Bryant and Barnett (2020), despite this variation in study design, a few key groups stand out as more accepting of cultured meat, including younger men (Wilks and Phillips, 2017; Slade, 2018), individuals with higher levels of education (Gómez-Luciano and de Aguiar, 2019; Mancini and Antonioli, 2019; Weinrich et al., 2020), individuals who are of left leaning political orientation (Wilks and Phillips, 2017; Bryant et al., 2019), and urban city dwellers (Tucker, 2014; Shaw and Iomaire, 2019). Furthermore, familiarity with cultured meat has also been a predictor of acceptance (Bryant et al., 2019). The relationship between income and acceptance of cultured meat, however, is less clear, with some studies finding that those in lower income brackets were more willing to try cultured meat (Wilks and Phillips, 2017), while other studies found the opposite (Bryant et al., 2019; Gómez-Luciano and de Aguiar, 2019). Lastly, although they receive a disproportionate amount of media attention on the subject of cellular agriculture (Hopkins, 2015), prior studies have indicated vegetarians and vegans are less likely to try, eat, or purchase cultured meat as compared to omnivores (Wilks and Phillips, 2017; Bryant et al., 2019; Valente et al., 2019; Arora et al., 2020).

2. Methods

2.1. Study overview

The purpose of this pilot study was to gauge sentiments of food-interested consumers, including vegans, toward YDA and YDD in the province of British Columbia, Canada. Data collection for this research was collected via survey, hosted on web platform SurveyMonkey. The survey consisted of a mix of Likert scale questions, multiple choice as well as open ended questions, providing a rich mixture of quantitative and qualitative data. The survey also included information explaining what cellular agriculture is and how it is produced, through an "explainer" document developed by the study team (see Supplementary information). The study team asked several individuals to review the document for clarity and ease of understanding before the survey began.

2.2. Participants and recruitment

Recruitment of both general food-interested consumers and vegans and others who avoid eating dairy took place through multiple channels, including listservs, social media outreach (e.g., Twitter and Facebook), and direct outreach, all focused on British Columbia, Canada. We also recruited participants using the BC Food Systems Network and Canadian Association for Food Studies listservs. Additionally, we recruited undergraduate students for the study via email to class listservs. Responses to the study were collected between May and July of 2019. We acknowledge the sample for this pilot study was not representative of the general population (for example, in education level); however, it can provide some preliminary insights which are useful both for building an understanding of how consumers perceive YDD, and to help develop strategies for future, more extensive work.

2.3. Quantitative analysis

Data analysis of the consumer survey was conducted in software SPSS 27 (IBM). In this study, 5-point Likert scales were used for the majority of questions. To simplify the data analysis, variables used in statistical analysis were transformed from a 5-point scale into a 3-point Likert scale using SPSS. Specifically, "very likely" and "likely" became "likely," "neither likely nor unlikely" became "neutral," and "very unlikely" and "unlikely" became "unlikely." The same process occurred for "agree" and "disagree" Likert scale questions.

Attitudes towards and perceptions of yeast-derived agriculture were examined through eight different statements pertaining to yeast-derived agriculture, and a series of Mann–Whitney tests were conducted to determine if vegans and non-vegans' likelihood of agreeing with those statements were significantly different. In addition, a series of Pearson Chi-square test statistics were conducted to examine if there was a difference between vegans and non-vegans' likeliness to try, purchase, incorporate and replace milk or cream and ice cream with yeast-derived dairy alternatives.

A binary logistic regression model was conducted to explore what factors predicted individuals having positive feelings towards yeast-derived agriculture. The dependent variable for this regression was binary, either "agree" (containing strongly agree and agree) or "disagree" (containing neutral, disagree and strongly disagree) to the statement "Overall, my feelings towards yeast-derived agriculture are positive." The binary variable was computed from an ordinal variable for simplicity using SPSS, a process has been shown to not significantly impact statistical outcome (Manor et al., 2000).

To achieve parsimony in our analysis, levels of predictor variables were also collapsed using SPSS (Lund and Raimi, 2012). For diet, survey participants were classified as being either vegan, or not vegan (which was an umbrella variable for every other dietary option, including "other," on the survey). Age was also made into a binary variable for those who were 34 years of age and under, and those who were 35 years of age and over. Income was categorized as those who had a household income less than $49,999 per year, those between $50,000 and $99,999 per year, and those who earned $100,000 or over per year. Knowledge of the food system was categorized as those "having excellent" or "very good" knowledge of the food system, those who had "good" or "fair knowledge" and those who had "poor" or "no knowledge" of the food system. Finally, education categories taken from Statistics Canada census data were reduced from six to four categories with "No certificate diploma or degree" grouped together with "Secondary school diploma" and "Some undergraduate coursework" grouped together with "Undergraduate degree (e.g., B.A., B.Sc.)." Demographics, including frequency and percent, are presented in Table 1 for these variables.

TABLE 1 Respondent demographics.

Demographics		%	*n*
Age	34 years or younger	38.3	44
	35 years or older	61.7	71
Gender	Male	19.10	22
	Female	78.30	90
	Prefer not to say	1.7	2
Education	No certificate diploma or degree and or Secondary school diploma	7.8	9
	Apprenticeship or trades certificate or diploma	8.7	10
	Some undergraduate coursework and or Undergraduate degree (e.g., B.A., B.Sc.)	54.8	63
	Graduate degree (e.g., M.S., M.A., M.B.A., M.D., Ph.D.)	27.0	31
Annual household income (CAD)	Less than $49,999	29.6	34
	Between $50,000 - $99,999	35.7	41
	$100,000 and above	33.0	38
Diet	Vegan	38.3	44
	Non-vegan	61.7	71
Knowledge of the food system	Excellent and Very good	51.3	59
	Good and Fair	40.9	47
	Poor and Unfamiliar with the term 'food system'	6.1	7

2.4. Qualitative analysis

Open-ended responses from the consumer survey were collected in two separate questions in the survey, including the question "I would be more likely to consume yeast-derived dairy if it…" and at the end of the survey when respondents were asked to express any comments, questions or concerns regarding cellular agriculture and or yeast-derived dairy that they may have. Responses from these written questions were collected and analyzed (in English) using thematic analysis as described by Braun and Clarke (2006). To do this, responses were collected in an Excel sheet; words were generated from the content of the responses. Next, responses were sorted based on these codes, and themes were identified across the codes. Two researchers reviewed the sorting and made adjustments as necessary.

3. Results and discussion

A total of 127 people responded to the survey. After removing participants who either did not meet the inclusion criteria, or those who did not answer a sufficient number of questions, 115 survey participants remained in this study. Of these 115 respondents, 78.3% were women, 61.7% were 35 years of age or older, and 38.3% followed a vegan diet (Table 1).

Compared with the general Canadian population, our sample population was well-educated and wealthy. Nearly a third of respondents indicated having a graduate degree (27%), well above the population rate for Canada (6.1%; Statistics Canada, 2017). A total of 67% of all respondents earned a household income of $50,000 or over, much higher than the rate within the Canadian population of 33%. Lastly, 51.3% of respondents reported having excellent or very good knowledge of the food system, 40.9% reporting having good or fair knowledge, and 6.1% had either poor knowledge or no knowledge of the food system.

3.1. Familiarity

Approximately 56% of participants responded that they had heard of cellular agriculture, and 34.8% of respondents said that they had heard of it and understood what it was. The remaining 44% of participants had not heard of cellular agriculture prior to this study. Our questions were phrased similarly to questions outlined in Verbeke et al.'s, 2015 study on consumer acceptance of *in vitro* meat for comparability. In their study 13% of respondents had heard of *in vitro* meat and knew what it was, where 36.0% had heard of it but did not know what it meant, and 51% had never heard of *in vitro* meat (Verbeke et al., 2015). While numbers from our survey and theirs are quite different, their survey was conducted several years before ours, when there was substantially less media discourse around cellular agriculture.

Of those respondents to our survey who indicated familiarity with YDA, a majority were aware that meat was being produced using cellular-agriculture technologies, followed by dairy, leather, wood and "other." They were given the option to specify what "other" was and respondents listed organs, insulin, rennet, and seafood (salmon).

3.2. Openness to yeast derived dairy

In the survey questionnaire, participants were asked how likely they would be to try, purchase, incorporate and replace milk or cream and ice cream with yeast-derived dairy alternatives (Table 2). A total of 43.5 and 38.3% of participants indicated they would be either likely or very likely to try milk/cream or ice cream. Overall, survey respondents indicated more willingness to try and or to purchase milk/cream or ice cream, compared with incorporating it regularly into their diet, or replacing their current consumption altogether. This trend is consistent with consumer *in vitro* meat studies (Wilks and Phillips, 2017; Mancini and Antonioli, 2019; Weinrich et al., 2020) suggesting that overall, consumers are currently less likely to regularly consume or entirely replace their consumption of animal derived-foods with ones derived using cellular agriculture technologies.

Furthermore, compared with non-vegan respondents, vegan respondents in this pilot study were less likely to try, purchase, incorporate and replace milk/cream or ice cream with YDA products altogether. Pearson Chi-square test statistic (Table A1) revealed that the difference between vegans and non-vegans' willingness to replace milk or cream ($x^2 = 6.973$, $p = 0.008$) and ice cream ($x^2 = 8.755$, $p = 0.003$) was significantly different, as was willingness to try ice cream ($x^2 = 3.8777$, $p = 0.049$) with vegans again being less likely to do so in all cases. Other consumer perception studies have also shown that vegetarians and vegans find *in vitro* meat less appealing compared to meat-eaters (Wilks and Phillips, 2017; Valente et al., 2019; Arora et al., 2020). Men and individuals under the age of 35 in this pilot study also indicated a higher willingness to try YDA at 54.5 and 52.3% respectively, compared with women (40.0%) and those 35 years of age or older (38.0).

3.3. Perceptions of yeast derived agriculture

To examine attitudes toward and perceptions of yeast-derived agriculture, survey respondents were asked to indicate whether they agreed, disagreed, or were neutral with regards to eight different statements pertaining to yeast-derived agriculture (Table 3). Majorities of respondents perceived YDA as contributing to factors typically associated with sustainability; 65.2% agreed

TABLE 2 Likelihood to try, incorporate, and replace milk or cream and ice cream with yeast-derived dairy alternatives.

Food type		All % (*n*)	Vegan % (*n*)	Non-vegan % (*n*)
Milk or Cream	Try	43.5 (50)	34.1 (15)	49.3 (35)
	Purchase	31.3 (36)	25.0 (11)	35.2 (25)
	Incorporate	25.2 (29)	8.2 (8)	29.6 (21)
	Replace	15.7 (18)	4.5 (2)	22.5 (16)
Ice cream	Try	38.3 (44)	27.3 (12)	45.1 (32)
	Purchase	27.8 (32)	20.5 (9)	32.4 (23)
	Incorporate	20.0 (23)	11.4 (5)	25.4 (18)
	Replace	17.4 (20)	4.5 (2)	25.4 (18)

*Data shows respondents who were either 'very likely' or 'likely' to try, incorporate, replace and purchase yeast derived milk or cream, and ice cream.

TABLE 3 Perceptions and attitudes towards yeast-derived agriculture.

		Agree & strongly agree % (*n*)	Neutral % (*n*)	Disagree & strongly disagree % (*n*)
Yeast-derived agriculture is a technology that will have positive impacts on the environment	All	65.2 (75)	28.7 (37)	6.1 (7)
	Vegans	63.6 (28)	34.1 (15)	2.3 (1)
	Non-vegans	66.2 (47)	25.4 (18)	8.5 (6)
Yeast-derived agriculture is a technology that will have positive impacts on the well-being of animals	All	68.7 (79)	26.1 (30)	5.2 (6)
	Vegans	72.7 (32)	22.7 (10)	4.5 (2)
	Non-vegans	66.2 (47)	28.2 (20)	5.6 (4)
Yeast-derived agriculture is an environmentally sustainable alternative to traditional dairy	All	64.3 (74)	30.4 (35)	5.2 (6)
	Vegans	66.9 (29)	34.1 (15)	0 (0)
	Non-vegans	63.4 (45)	28.2 (20)	8.5 (6)
Yeast-derived agriculture is a technology that will have positive impacts on the health and well-being of humans	All	26.1 (30)	50.4 (58)	23.5 (27)
	Vegans	15.9 (7)	54.5 (24)	29.5 (13)
	Non-vegans	32.4 (23)	47.9 (34)	19.7 (14)
Products made using yeast-derived agriculture technologies are: 'animal free'	All	42.6 (49)	34.8 (40)	22.6 (26)
	Vegans	29.5 (13)	38.6 (17)	31.8 (14)
	Non-vegans	50.7 (36)	32.4 (23)	16.9 (12)
Products made using yeast-derived agriculture technologies are: vegan	All	27.0 (31)	42.6 (49)	30.4 (35)
	Vegans	20.5 (9)	40.9 (18)	38.6 (17)
	Non-vegans	31.0 (22)	43.7 (31)	25.4 (18)
Products made using yeast-derived agriculture technologies are: vegetarian	All	50.4 (58)	33.0 (38)	16.5 (19)
	Vegans	50.0 (22)	29.5 (13)	20.5 (9)
	Non-vegans	50.7 (36)	35.2 (25)	14.1 (10)
Overall, my feelings towards yeast-derived agriculture are positive	All	46.1 (53)	35.7 (41)	18.3 (21)
	Vegans	38.6 (17)	40.9 (18)	20.5 (9)
	Non-vegans	50.7 (36)	32.4 (23)	16.9 (12)

with the statement "Yeast-derived agriculture is a technology that will have positive impacts on the environment"; 68.7% agreed with a similar statement about the wellbeing of animals; and 64.3% agreed with the statement that it was a sustainable alternative to traditional dairy. Only 26.1% of respondents in this pilot study, however, agreed that this technology would have a positive impact on the health and well-being of humans. A majority of respondents (50.4%) indicated they were neutral on this statement. A low value was observed for the statement that YDA was "vegan," with only 27% agreeing. In contrast, 50.4% percent of participants agreed with the statement that YDA was vegetarian and 42.6% considered it "animal-free." Further research examining the difference in perceptions between what makes a product vegetarian, vegan and animal-free with regards to YDA is needed, particularly as Perfect Day, the company currently making YDD products, describes their products as both "animal-free" and "vegan." Lastly, 46% of respondents indicated having positive feelings towards YDA. Predictors of having positive feelings towards YDA are explored further in binary regression analysis discussed below.

Broken down by diet, both vegans and non-vegans agreed similarly that YDA would have positive impacts on the environment and on the well-being of animals. They both agreed that YDA is an environmentally sustainable alternative to traditional dairy, with vegans agreeing at a slightly higher rate, although this difference was not statistically significant. Vegans in this pilot study were less in agreement (16%) compared to non-vegans (32%) that YDA would have a positive impact on the health and well-being of humans. More vegans disagreed with the statement that products made using YDA technologies were vegan (38.6% compared with 25.4% for non-vegans), as well as with the statement that YDA technologies were "animal-free" (31.8% compared with 16.9% for non-vegans). For the latter, a Mann–Whitney test showed that this difference in responses between vegans and non-vegans was statistically significant ($U = 1172.50$, $p = 0.016$; Table A2). Lastly, fewer vegans in this pilot study reported having positive feelings towards YDA, and vegans overall did not see YDA as fitting within their ethical code regarding food production and consumption, but these differences were not statistically significant.

3.4. Positive feelings

A binary logistic regression model was conducted to test what factors predicted respondents in our pilot study agreeing (including strongly agree and agree) with the statement "Overall, my feelings towards yeast-derived agriculture are positive"

TABLE 4 Binary logistic regression for positive feelings towards yeast-derived agriculture.

Binary logistic regression	B	S.E.	Wald	df	*p* value	Exp (B)	95% CI Lower	Upper
Independent variable								
35 years of age or older	−1.893	0.611	9.602	1	0.002*	0.151	0.045	0.499
Vegan	−1.068	0.515	4.298	1	0.038*	0.344	0.125	0.943
No certificate diploma or degree + Secondary school diploma			3.529	3	0.317			
Apprenticeship or trades certificate or diploma	0.703	0.972	0.523	1	0.470	2.020	0.300	13.587
Some undergraduate coursework + Undergraduate degree (e.g., B.A., B.Sc.)	−0.212	1.017	0.044	1	0.834	0.809	0.110	5.929
Graduate degree (e.g., M.S., M.A., M.B.A., M.D., Ph.D.)	0.916	0.559	2.683	1	0.101	2.499	0.835	7.478
Knowledge of the food system: Excellent and very good			3.828	2	0.147			
Knowledge of the food system: Good and fair	0.121	0.941	0.016	1	0.898	1.128	0.178	7.134
Knowledge of the food system: poor and unfamiliar with the term	1.024	0.963	1.131	1	0.288	2.784	0.422	18.379
Female	−0.063	0.595	0.011	1	0.915	0.939	0.293	3.012
Income: less than $49,000			5.078	2	0.079			
Income: between $50,000 and 99,999	−1.653	0.742	4.963	1	0.026*	0.192	0.045	0.820
Income: $100,000 or more	−0.387	0.541	0.511	1	0.475	0.679	0.235	1.962

*Denotes significance.
Dependent variable is 'agree' to the statement "Overall, my feelings towards yeast-derived agriculture are positive."
Two participants indicated 'prefer not to say' for gender and were not included in this regression analysis

TABLE 5 Response (% and *n*) to question "I would be more likely to consume yeast-derived dairy if it…"

Statement	%	(*n*)
Provided environmental benefit	61.7	71
Improved animal welfare	60.0	69
Provided dietary or health benefit	49.6	57
Was cost saving	39.1	45
There was no discernible difference in taste or mouthfeel compared to animal-derived dairy	33.4	39
Other	32.2	37

(Table 4). Adjusting for all other predictors (gender, knowledge of food systems, education), this analysis showed that being 35 years of age or older, and being vegan, were negatively associated with having positive feelings towards yeast-derived agriculture (chi-square (10) = 29.086, $p = 0.001$). Being age 35 years or older had the odds-ratio of 0.151 (95% CI: 0.045, 0.499) and being vegan had the odds-ratio of 0.344 (95% CI: 0.125, 0.943). Furthermore, individuals in this pilot study with a household income between $50,000-99,999, compared with individuals with household income of $49,999 or less, were also negatively associated with having positive feelings towards YDA and had an odds-ratio of 0.192 (95% CI: 0.045, 0.820).

3.5. Factors contributing to consumption of yeast-derived dairy

Survey respondents were asked to complete the following sentence "I would be more likely to consume yeast-derived dairy if it…," and they were able to choose more than one option (Table 5). From these responses, we can see that taste and mouthfeel were not as important as other factors such environmental benefit or animal welfare.

Survey participants who selected "other" were able to leave a comment about what factors they saw as influencing their decision to consume YDD. The comments made by survey respondents ranged but were predominantly concerned with issues related to diet and to health and safety. For example, one person wrote "[If] I felt confident that it is a safe substitute from a personal health perspective; that it does not have some potential negative health impact."

A small handful of respondents indicated that they would likely consume YDD if it was vegan. For example, one person wrote "[If] it did not involve animals at all (including breeding, housing, and slaughtering them to collect their proteins)." Comments like this indicate the possibility that some participants may either be misinterpreting the information provided about the YDD production process, or may be holding on to preconceived ideas despite that information. To recapitulate, YDD is made via a process of fermentation using recombinant microorganisms inserted with 3D printed bovine DNA that produces casein and whey milk proteins; animals do not need to be raised specifically for this process.

Some respondents in this pilot study indicated under "other" that they would be more likely to consume YDD if the taste and experience of it were either similar or better than current animal-derived dairy, despite this having been an answer option to select. Others indicated that they would "…never consume food grown in a lab," and another wrote that they would be likely to consume YDD, "If the technology and its profits could have equitable benefits and not just profit increases for large agri-food companies."

Only one person indicated that they would consume YDA if it "Did not involve genetic modification," while another person indicated they were "wary of cellular level interventions" because of its similarity to genetic engineering. Instead, a majority of participants in this pilot study focused on YDA as a processed food. For example, one person wrote "I do not think I'm interested at all. I prefer to eat food that is more whole grains/veg/fruit/etc. and less processing… I just do not think we need to be 'producing' fake dairy in a lab," indicating that some individuals viewed this more as a processed food rather than as a genetically modified organism (GMO). The theme of processed foods emerges again in the following section.

Our pilot study results echo the findings from the meta-analysis of Bryant and Barnett (2020). They note that perceived benefits of cultured meat and cellular agriculture technologies include benefits to the environment and animal welfare, health and food safety as well as potential to increase global food supply. Despite the numerous perceived benefits, they note there still exist numerous possible barriers to acceptance including concerns regarding price, safety, feelings of disgust and unnaturalness, as well as food neophobia.

3.6. Additional comments on the topic of yeast-derived agriculture

Survey respondents were asked to express any comments, questions or concerns regarding cellular agriculture and or yeast-derived dairy that they may have had but were not previously addressed in the survey.

Only a handful of comments from participants in this pilot study were overly positive about YDA, with some saying they were excited and eager to purchase it, while some were positive, but said they would likely only consume it if it were lactose or allergen free. The majority of comments were from respondents indicating that they would not be interested in consuming YDA. Many of these comments indicated they did not like the concept of YDA because they viewed it as a highly processed food. As one person wrote "It sounds weird and highly processed." And another wrote "I am on a whole plant based diet and do not eat processed food if I can avoid it." Therefore, it appears that YDA was perceived by survey respondents as a processed food, rather than a natural, or whole food like dairy milk, despite being biologically equivalent. This finding was surprising as we had anticipated arguments against YDA to be related to associations between GMOs and cellular agriculture technologies, despite the products themselves containing no GMOs (Milburn, 2018).

Many respondents in this pilot study had mixed feelings about YDA. For example, one person wrote:

> "It feels "icky" to me, perhaps in the same way that any new technology feels unfamiliar/scary to somebody who doesn't know much about it, or what it's capable of. If the technology is used responsibly, doesn't have any terrible unintended consequences, or end up causing cancer or something, then it could be a great alternative (from an animal welfare standpoint) to existing dairy products."

Although they felt that YDA was "icky," the respondent indicated that they could warm up to the idea given the right circumstances. This was noted several times in the responses with individuals liking the idea or one aspect of YDA but being uncertain about another aspect about it. Often participants were concerned about health implications, ethical treatment of animals involved, and environmental implications. For example,

> "… If I didn't have an allergy, I would definitely be more interested in eating yeast-derived dairy than animal-dervied [sic] dairy, mainly for environmental reasons…"
>
> "My main concern is that there would still be animals bred raised and kept in order to have access to proteins…"

Some respondents in this pilot study appeared to be ambivalent about YDA, seeing both the positive and negative aspects of it. For example, one respondent said, "I do not yet have a strong opinion about it, but it seems like a more realistic prospect (with fewer ethical questions) than cellular meat production."

Other respondents indicated that they had questions regarding the process of YDA, with some comments indicating that the process was not fully understood, despite having been provided with information about the process during the survey (see Supplementary information). For example, one person wrote "If it does not have the side effects of yeast," despite no yeast being in the final product. Another person wrote, "Many questions regarding how the base materials ie. stem cells are produced," and "Will the products be cholesterol free? How will the animals from whom the cells are taken be maintained?" In addition to this, some participants in this pilot study noted that they simply did not have enough information to make an informed decision.

Another theme that emerged was regarding the topic of agriculture and farming practices. Some participants wrote that they did not think YDA was the right direction in which agriculture should go. Rather, there was a desire to shift focus towards natural foods and sustainable agriculture, and to move away from industrial agriculture. For example, one person wrote, "The best good for humans is made by nature. Please get our agricultural system back to growing health food, using sustainable practices." Another wrote, "This seems like an unnecessary innovation when we COULD be simply creating agricultural policies for healthier farms integrated into living and built environments."

Environmental concern was also present in these comments, sometimes in the context of agriculture policy like the quote above, or others expressing uncertainty regarding the environmental impacts of YDA. Some indicated they wanted long-term studies on how it impacts the environment and soil conservation. For example, one person wrote: "If we had studies on the long term effects it has on the environment, and if I knew more about the manufacturing process-are the materials for the equipment sustainable? Or are we taking one problem and trading it for another at the expense of our dairy farmers' livelihoods?…"

Lastly, three separate respondents indicated this was a product more suited to non-vegans than vegans. Surprisingly, only one person indicated the need for labeling YDA products.

3.7. Vegan perception and acceptance of YDA and YDD

Our pilot study indicates that vegans may be less likely to try or purchase yeast-derived dairy products and may be less likely to replace or incorporate them into their diet compared with non-vegans. We saw this indicated in responses to multiple questions across the survey. Although vegan participants agreed that YDA would have positive impacts on the environment and for animals, they did not view YDA as being animal-free or vegan. Furthermore, they did not see it as something which would have positive impacts on the health and well-being of humans. Our pilot research is consistent with other cellular agriculture research, specifically with regards to cultured meat, which has observed that vegans and vegetarians were less likely to try or purchase these products compared with meat eaters (Bryant and Barnett, 2018; Bryant et al., 2019). As noted by Hopkins (2015), vegans and vegetarians are the recipients of a disproportionate amount of media attention on the subject of cellular agriculture. Further research with larger sample sizes is needed to gain more understanding of whether vegan response to YDD does indeed mirror their response to cultured meat.

While our pilot study results indicate that vegan respondents did not consider YDD to be vegan, this contradicts the claims of YDD producers. Perfect Day uses the term "animal-free" in much of its marketing, and in the FAQ section of its website, there is a question "Is your protein vegan?" to which Perfect Day has posted the response "Yes! Flora-made dairy protein is made without the use of animals and zero compromise on taste and nutrition. Our animal-free dairy protein is completely vegan as well as lactose-, hormone-, and antibiotic-free." The answer to the FAQ goes on to state, "However, because it's identical to the proteins from cows, it does contain milk allergens, which are labeled on products made with Perfect Day, "Contains: Milk Protein" (Perfect Day, 2020a). In the absence of laws or other means of regulating what can and cannot be labeled "vegan," this tension between vegan consumer perception and corporate claims is likely to continue.

4. Conclusion

Yeast-derived agriculture allows for the production of dairy products which are not derived from animals. Our pilot study provides preliminary insights and suggests directions for future research into how these novel foodstuffs may be received by consumers, in particular vegan consumers; consumer attitudes toward YDD will play a significant role in what impacts these products have on dairy farmers and processors. Our team has also surveyed and interviewed dairy industry stakeholders as part of this area of research; those results form the basis of an article in preparation.

The results of our pilot study suggest that there is a good deal of interest in both trying and purchasing yeast-derived dairy. Our preliminary findings indicate that consumers are unlikely at this point in time, however, to incorporate these products into their daily routines or replace their current option entirely. This reluctance may be overcome, or at least reduced, when the product becomes available for purchase or more information is readily available on the topic of cellular agriculture technologies.

Furthermore, our pilot study indicated that participants who are vegans, and individuals 35 years of age or older are also less likely to try yeast-derived agriculture products, as indicated by the binary regression analysis where being vegan or being over the age of 35 had decreased odds of having positive feelings towards YDA. Limitations of this pilot study include having a small sample size; also, the narrow demographics we chose to study make extrapolation of our findings to the wider population difficult. This pilot study, however, lays the groundwork for a larger national survey which will be disseminated to a wider, more demographically diverse audience, or for additional studies targeting larger groups of particular segments of the population (e.g., vegans).

Some of the survey comments suggested that there may be confusion or misinterpretation regarding how YDD is made, even after a detailed explainer was provided; alternatively, survey respondents may have been holding on to preconceived biases. Further research on this topic may need to go to greater lengths to explain the process as part of engaging with study participants and to account for bias. Similar to the findings from Broad et al. (2022) the results from this pilot study suggests that any company wishing to sell this product in British Columbia, and likely other areas as well, will have to do extensive marketing and education campaigns to not only inform consumers of what it is, but also to inform consumers about its safety for those with allergies and other dietary restrictions. While our research provides data linking demographic characteristics to perceptions of and willingness to try, it also indicates this data may be shaped by perceptions of cellular agriculture that do not align with the framing of the YDD production process by the industry. Our pilot study indicated that vegans are less likely to consume the product than non-vegans, in part because they do not perceive it as being vegan, which contradicts claims made by Perfect Day and other companies. In the absence of some sort of international arbiter of the vegan label, it is unclear how these contradicting views may be resolved.

Despite questions and reservations on the part of consumers, companies bringing YDD products to grocery stores and to online retailers are unlikely to slow their pace. As they become more available, ongoing research about perceptions and acceptance toward these products will be necessary to understand the role they are playing in both diets and food systems as a whole. In particular, surveys of broader audiences will provide key sources of data on how YDD is being received.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by University of the Fraser Valley Human Research Ethics Board, protocol #1156G-19, on April 18th 2019. The patients/participants provided their written informed consent to participate in this study.

Author contributions

ZM-Z performed data collection and statistical analysis. LJP and ZM-Z drafted the manuscript. LLN supervised the project. All authors contributed to the article 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.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1127652/full#supplementary-material

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Appendix

TABLE A1 Chi-Square test statistics examining differences in responses between vegans and non-vegans for likelihood to try, incorporate and replace milk or cream and ice cream with yeast-derived dairy alternatives.

Food type		Pearson Chi-square	df	*p* value	Cramer's *V*
Milk or Cream	Try	2.777	1	0.096	0.156
	Purchase	1.561	1	0.211	0.118
	Incorporate	2.114	1	0.146	0.137
	Replace	6.973	1	0.008*	0.248
Ice cream	Try	3.877	1	0.049*	0.184
	Purchase	2.195	1	0.138	0.139
	Incorporate	3.736	1	0.053	0.183
	Replace	8.755	1	0.003*	0.280

*Denotes significance.

TABLE A2 Mann–Whitney tests for perceptions and attitudes toward yeast-derived agriculture.

	Mann–Whitney U	*p* value	Mean rank Vegan (*n*=44)	Mean rank non-vegan (*n*=71)
Yeast-derived agriculture is a technology that will have positive impacts on the environment	1,558.00	0.978	58.09	57.94
Yeast-derived agriculture is a technology that will have positive impacts on the well-being of animals	1,460.00	0.469	55.68	59.44
Yeast-derived agriculture is an environmentally sustainable alternative to traditional dairy	1,477.50	0.563	56.08	59.19
Yeast-derived agriculture is a technology that will have positive impacts on the health and well-being of humans	1,251.50	0.051	65.06	53.63
Products made using yeast-derived agriculture technologies are 'animal free'	1,172.50	0.016*	66.85	52.51
Products made using yeast-derived agriculture technologies are vegan	1,296.00	0.102	64.05	54.25
Products made using yeast-derived agriculture technologies are vegetarian	1,503.50	0.712	59.33	57.18
Overall, my feelings towards yeast-derived agriculture are positive	1,378.00	0.251	62.18	55.41

*Denotes significance.

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EDITED BY
Rodrigo Luiz Morais-da-Silva,
Federal University of Paraná, Brazil

REVIEWED BY
Rebecca McLaren,
Johns Hopkins University, United States
Julie Guthman,
University of California, Santa Cruz,
United States
Charlotte Biltekoff,
University of California, Davis, United States

*CORRESPONDENCE
Russell C. Hedberg
✉ rchedberg@ship.edu

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Bad animals, techno-fixes, and the environmental narratives of alternative protein

Russell C. Hedberg*

Department of Geography and Earth Science, Shippensburg University of Pennsylvania, Shippensburg, PA, United States

In the last decade animal agriculture has received significant scrutiny for its many negative environmental consequences. In response to these myriad concerns a wide range of voices have advocated for diets that include less animal products (meat, dairy, eggs), often arguing that animal-based diets are inherently more resource intensive than those based on plants. Prominent in this discourse is a narratives formation developed by a slew of venture capital-backed food technology startups known as alternative protein that I refer to as the bad animal narrative. This narrative argues that livestock are fundamentally bad technology, and the solution to the many environmental problems of animal agriculture is to replace livestock with novel technologies to produce animal product alternatives that will satisfy consumer demand while also solving one of the fundamental environmental challenges of modern agriculture. In this paper I use discourse analysis frameworks from political ecology and science and technology studies to examine a large corpus of publicly available text that includes alternative protein company websites, mission statements, blogs, and connected media pieces, as well as life cycle assessment reports documenting the environmental impacts of alternative protein products as well as conventionally and alternatively produced livestock. This analysis finds that the bad animal narrative places blame on livestock without clearly providing evidence, and it rests on a set of problematic assumptions about the current food system and its possible futures. Analysis of life cycle assessment statistics finds that the industrial system, rather than livestock themselves, is the chief driver of the environmental problems of animal agriculture. The paper concludes with a consideration of the future food system envisioned by the bad animal narrative and its implications for sustainability.

KEYWORDS
alternative protein, animal agriculture, cellular agriculture, discourse, future of food, life cycle assessment

Introduction

> "Livestock are the most environmentally destructive technology ever created by humans. My goal is to make that technology obsolete." – Dr. Patrick Brown, founder and CEO of Impossible Foods

The first decades of the Twenty-First Century brought with them significant public attention to the environmental problems associated with industrial food systems (e.g., Pollan, 2006; Kenner, 2008; Vermeulen et al., 2012; Campbell et al., 2017; Hawken, 2017). Animal agriculture and the consumption of animal source foods (ASF) like meat, milk, and eggs are commonly cited as the chief drivers of food-system-driven environmental degradation, particularly as discussions of climate change have become more common in the media. To be sure, these problems are well documented, with animal agriculture fairing particularly poorly. On climate change alone, animal agriculture is, by some accounts, directly responsible for around 5% of anthropogenic greenhouse gas (GHG) emissions and indirectly responsible for another 10–15% (Mottet and Steinfeld, 2018; IPCC, 2019). As public concern has increased, so too has public discourse focused on potential solutions to these issues. Interestingly—and I would argue, problematically—much of this discourse focuses on the nature of livestock species rather than the social/political/economic systems that use livestock to produce food.

The primary way the environmental problems of animal agriculture maniest as established knowledge, and thus shape public discourse, is in the form of life cycle assessment (LCA) statistics. LCA are computational models that quantify the various environmental costs of consumer goods and other economic activities across their production, distribution, use, and disposal. Importantly, LCA models are constructed such that they can proportionately attribute environmental impacts such as GHG emissions to particular stages of the life cycle. Likewise, models can be scaled to quantify the impacts of units as large as an entire industrial sector or as small (and tangible) as a gallon of milk. These features make LCA well suited for comparative analysis, and in recent decades LCA have been widely used in many contexts, including academic analysis, corporate accounting, and by environmental organizations like the Intergovernmental Panel on Climate Change (IPCC) and the Food and Agriculture Organization of the United Nations (FAO).

LCA can be a highly useful too, and model results have understandably shaped public discourse on the environmental problems of animal agriculture and their possible solutions. Perhaps unsurprisingly, a significant stream of discourse takes a decidedly neoliberal tack, arguing that individual consumers should solve these problems by shifting their diets away from ASF and toward foods with comparatively lower LCA scores (Tilman and Clark, 2014; Vergunst and Savulescu, 2017; Wang, 2017; Montague, 2019; Willett et al., 2019). The logic of this argument is that decreased consumer demand will lead to decreased production of ASF, thus alleviating the environmental problems.

Recently, the proponents of a food technology sector often called *alternative protein* (AP) have introduced a new narrative formation, also heavily reliant on LCA, into this public discourse that I refer to as the *bad animal narrative.* This narrative still focuses on consumer choice, but rather than reducing ASF consumption, the bad animal narrative argues that we should stop using livestock to produce ASF and instead use a raft of new biotechnologies to produce versions of these foods that look, feel, and taste the same while still performing better on LCA. In other words, as the quote that begins this paper so clearly states, animals are a bad technology for producing food. If we upgrade our technology, we will solve the environmental problems of animal agriculture.

The AP sector, which encompasses a broad range of food products and manufacturing techniques, functions in many ways like a other technology sectors (Chiles et al., 2021; Fairbairn et al., 2022), and as such, the bad animal narrative is a specifically technological discourse. It is also a narrative that is well suited to LCA assessment and comparison. If livestock are understood to be a technological component of a manufacturing system, then an LCA of that particular system can attribute environmental impacts directly to that technology and comparing that LCA with an LCA of an AP system that removes the animal as a technology can demonstrate the savings. There may well be environmental benefits to AP products, just as there surely are environmental benefits to diets that include fewer ASF. There are broader concerns with AP and the bad animal narrative, however, that deserve greater scrutiny from academics, journalists, policy makers, and the general public engaged in this discourse. First, this narrative offers a bold vision for a future food system reoriented around myriad novel industrial technologies and with little to no livestock—a vision that has far greater implications than the simple swapping of technologies would suggest. Secondly, AP is a major player in the new agriculture and food tech sector that attracted more than $100 billion in capital investment from 2015–2020 (AgFunder, 2021), and that level of economic power confers the ability to profoundly shape discourse. Given that much of this investment is either from venture capital or corporate investment from major multinational players in the current ASF industry (Howard et al., 2021), attention should be given to the extent to which this discourse is in service of investor profit instead of (or in addition to) environmental concerns. Lastly, the bad animal narrative further pushes discourse toward technofixes that can work to obscure questions about structural problems in our food system and the role livestock could play in sustainable food futures.

In this paper I pursue a critique of the environmental claims of AP through analysis of the bad animal narrative using discourse analysis methods common to the fields of political ecology and science and technology studies. After situating my analysis in the broader literature on AP and a brief discussion of methods, I present three lines of inquiry. First, I examine the language used by AP to construct this narrative, including the key assumptions embedded in the narrative. I then consider the role of LCA in this narrative formation with two goals in mind: to give additional scrutiny to the environmental claims of AP, and to consider whether LCA models do condemn livestock as a technology or instead offer other possible interpretations. Lastly, I consider the environmental and sustainability implications for the food future envisioned by the bad animal narrative that are obscured by this discourse.

Defining alternative protein

AP is an umbrella term used to refer to food products (and the companies producing them) that use plant-based ingredients, fungi, or lab produced tissues to produce or simulate ASF like meat, dairy, and eggs. It should be noted at the outset that AP does not attempt to offer a substitute, like tofu, but rather an alternative means of producing foods that are functionally and esthetically equivalent to animal-derived products. There is some evidence to suggest that many consumers would be willing to try AP products in the future (Bryant et al., 2019), yet relatively little is known of who is currently consuming AP products or how they fit into their diets. It may well be that in practice currently available AP products are consumed mostly by vegetarians and flexitarians that would otherwise eat tofu to decrease ASF consumption. This possibility, however, is not in keeping with the promotional efforts of the AP sector. Following the discourse deployed by advocates, AP *are* meat, dairy, and eggs produced by alternative means, and consumers should change their purchasing rather than the structure of their diets (e.g., see Broad, 2020).

Abbreviations: AP, alternative protein; ASF, animal source food; LCA, life cycle assessment.

Under the umbrella of AP, the sector can be segmented based on the primary technologies used to produce food products: cultivated alternative protein (often called *cellular agriculture* or *clean meat*), plant-based alternative protein, and fermented alternative protein (Good Food Institute, 2022).[1] There are important convergences and divergences among these subcategories, and a full accounting of the diversity of forms and technologies in AP is beyond the scope of this paper. For the purposes of the arguments presented here, the key distinction among these technologies is *how* they aim to remove livestock from the food system.

Plant-based AP replaces proteins and other nutrients and flavor compounds derived animals with those from plants and uses new processing technologies to produce food products that simulate ASF. Similarly, fermented AP replaces animal-sourced proteins and nutrients with those produced through fermentation—either whole biomass such as fungi, or through genetically modified yeasts that produce things like whey protein as a biproduct of their metabolism.[2] The approach among these two sub-categories for removing animals from the food system is similar to that of veganism: eat plants and fungi, not animals. Yet unlike veganism, plant-based and fermented AP do not advocate that consumers change the types of foods they eat (e.g. beans instead of burgers), but simply buy different versions of their current diets that are not sourced from animals.

Cultivated AP employs technologies from the biomedical sciences to replicate animal tissue cells in bioreactors and aggregate them into familiar forms like chicken tenders, burger patties, or steaks. This approach seeks to remove animals from the *process* of producing foods rather than as a source of ingredients. Indeed, cultivated AP would require that some quantity of livestock remain in the food system as a source of donor cells. Since virtually all extant food products in this sub-category of AP are still in development (and not commercially available), it is not yet clear how many animals would be needed to support large scale production.

The bad animal narrative examined here is common across the AP sector, and for much of the paper I will use the term AP to discuss environmental narratives and discursive tactics that are broadly deployed. When it is relevant, I will also use the terms noted above to differentiate between the subcategories of AP. My primary goal in making these distinctions is to add nuance to the analysis below.

Alternative protein futures

The AP sector emerged relatively recently, but there is already a diverse academic literature on the subject, and an exhaustive review is beyond the scope of the analysis presented here. Indeed, a recent review article by Lonkila and Kaljonen (2021) included 123 articles from the social sciences alone. Here I briefly review three important themes in AP scholarship to better situate the analysis that follows among those examining the world-making ambition of AP, the phenomenon of green capitalism in AP, and broader discussions of the environmental impacts of ASF and AP.

The promissory discourse of AP

One of the most prominent themes in the emerging AP literature is the analysis of promissory narratives and other discursive practices deployed by AP companies and their advocates (Lonkila and Kaljonen, 2021). In particular, scholars have focused on the ways in which language is used build a base of public support (i.e., consumers) for AP and to attract financial investment. Several scholars have explored the metaphors and other discursive tools used by AP to project their products as edible, wholesome, and variously equivalent or superior to traditional ASF (Jönsson, 2016; Sexton, 2018; Jönsson et al., 2019; Sexton et al., 2019; Broad, 2020; Clay et al., 2020). This research has noted consistent narrative devices employed by AP to molecularize ASF (Sexton, 2018) into common sets of nutrients and flavor compounds that can be combined to "make" meat, milk, and eggs through processes that do not require animals (Broad, 2020), including from mundane resources with scant environmental impact (Guthman and Biltekoff, 2021). Others have observed that AP discourses, as well as some techno-futurist narratives of the livestock sector, produce a biopolitics of food system responsibility (Sexton, 2018; McGregor et al., 2021) whereby the solution to the negative impacts of animal agriculture is the disciplining of bodies, whether it be cattle or human consumers of ASF. At the same time, scholars have also observed that these AP narratives divert attention away from structural problems and over-consumption of ASF and toward questions of brand loyalty (Ormond, 2020; Clay et al., 2020), arguing that the problems of the food system can be solved through consumption rather than social, economic, or political reforms.

The arguments in this paper contribute to this literature in two ways. First, this analysis focuses on environmental narratives in AP, which have received far less attention in the literature. This paper also extends the discursive analysis to consider how statistics are folded into AP narratives to validate and mobilize the AP framing of food system problems and solutions. Secondly, this paper moves beyond the present narrative to consider the future ramifications of the AP environmental narrative. As other scholars have noted, AP not only offers new food products but a clear vision for remaking the food system that may or may not be the best path forward (Metcalf, 2013; McGregor and Houston, 2018; Jönsson et al., 2019; Guthman and Biltekoff, 2021).

Green capitalism

The academic literature has also offered significant consideration to the ways in which AP—both the technologies and the incumbent discourses—fit within broader developments often referred to as green capitalism (Goldstein, 2018). Research in this area has argued convincingly that despite paradigm shifting narratives, AP largely offers incremental market reforms tailored to corporate-dominated food systems (Broad, 2019; Clay et al., 2020; Fairbairn et al., 2022). Likewise, scholars have noted that AP generally reinforces the neoliberal subjectivity of individual responsibility that fits well within current capitalist framings of market-based sustainability (Sexton

1 Some framings of AP include insect-based proteins, but I have excluded such products from my analysis for two reasons. First, the narrative framings used by insect-based AP differ to some extent since they tend not to style their products as analogs of ASF. Secondly, since insects are animals, these companies are not arguing for the de-animalization of the food system, which is a core tenet of the bad animal narrative.

2 Some AP products use multiple methods to produce ingredients, perhaps most well-known is the heme compound in the plant-based *Impossible Burger* that is produced using fermentation.

et al., 2019; Ormond, 2020; Clay et al., 2020). Others have noted that the AP sector is best understood as part of the venture capital driven technology sector that is the hallmark of the 4th industrial revolution (Chiles et al., 2021; Guthman and Biltekoff, 2021; Fairbairn et al., 2022). Fairbairn et al. (2022), for instance, observes that narratives used by AP and other food technology start-ups frequently simplify the problems of the food system to both create a sense of urgency and cast their products as ideal investments that will remake the food system and provide significant financial returns. Furthermore, Guthman and Biltekoff (2021) note that many of the environmental claims made by AP companies are cloaked in secrecy to protect intellectual property and ensure return on venture capital investments. I contribute to this research here by assessing the ways in which the environmental futures proposed by the bad animal narrative may entrench existing power structures in the food system and thus offer little ecological benefit.

Environmental impacts of livestock and AP

Given that much of the narrative work of AP focuses on environmental sustainability, I find it useful to consider AP in the context of the broader academic literature on the ecological impacts of animal agriculture, particularly cattle. There are relatively few peer-reviewed publications directly considering the environmental impacts of AP, particularly in comparison with the streams of scholarship reviewed above. Several scholars have used modeling approaches to compare various AP technologies with conventional and vegan diets (Alexander et al., 2017; Lynch and Pierrehumbert, 2019; Van der Weele et al., 2019; Santo et al., 2020). These analyses find that while AP products do reduce certain environmental impacts, the magnitude of improvement is highly dependent on the comparisons being modeled. For instance, Alexander et al. (2017) found that AP-based diets have significantly lower environmental impacts than industrial beef, but they are roughly equivalent to diets based on chicken and eggs and may offer less benefit than diets that focus on reducing food waste and overall consumption of ASF. Numerous scholars have also been critical of the ways in which LCA are used in the assessment of animal agriculture. These scholars have noted that LCA frequently offer incomplete (and potentially misleading) assessments of environmental impacts (Freidberg, 2015; Sevenster et al., 2020), and that they are highly dependent on production practices to the extent that meaningful comparisons can be difficult (Head et al., 2014; Mottet et al., 2017; Stanley et al., 2018; Lynch and Pierrehumbert, 2019; Rowntree et al., 2020).

The analysis that follows contributes to this literature in two ways. First, I offer needed scrutiny to the environmental claims made by AP with particular attention to the ways in which LCA statistics are used to validate and propel the bad animal narrative. Secondly, I place the social scientific literature on AP discourse in dialog with the potential environmental consequences of the food future envisioned by AP.

Methods

The focus of this analysis is on discursive practices used by AP to shape public debate on the environmental problems and solutions of animal agriculture, particularly in wealthy countries. To that end, the data used here is drawn from publicly available sources published in English, namely the mission statements, websites (including official blogs, news releases, etc.), and promotional materials of AP companies and boosters. Many AP companies included in this data set provide direct links to news articles, podcasts, and interviews from outlets across English language media, and these articles were also included in the corpus of material for this discourse analysis.

Companies were initially identified for inclusion in this study from the investment portfolios of venture capital funds devoted to new food technologies and food tech incubators investing in AP start-ups. Additional sources were identified from a thorough review of the academic literature on AP, as well as references from media reporting on the AP sector. I developed a database of AP companies from these various sources to support this discourse analysis based on two criteria. First, all included sources use novel technologies to produce analogs of traditional ASF as outlined earlier in the paper, and second, all included sources must be producing or developing consumer products. Thus companies that produce traditional vegan food products are not included in this analysis despite significant overlap in vegan and AP environmental narratives (Mouat and Prince, 2018). Similarly, food tech companies that are developing processing equipment and systems for AP production or producing wholesale ingredients for other AP companies are not included in this database, even though many of these companies are rightly considered part of the broader AP sector. This sorting resulted in a database of 55 AP companies, including 16 producing cultivated AP, 24 plant-based AP companies, nine fermented AP operations, and seven AP producers that combine plant-based AP with either cultivated or fermented approaches.

The examination of LCA draws on a set of publicly available LCA reports commissioned by AP companies included in the compiled database. While other AP companies report that they have conducted LCA for their products, or publish comparative statistics consistent with LCA, relatively few actually make these reports freely available. For instance, Zero Egg, an Israeli plant-based AP company, notes in their sustainability statement that their environmental claims are based on a comparative LCA conducted by the consulting company Sher, but the report itself is not available. Given these limitations, the analysis of LCA conducted here is limited to six publicly available LCA commissioned by AP companies representing four plant-based products and two fermented products (Table 1). Also included is an aggregate LCA of cultivated AP conducted by the Dutch consulting firm CE-Delft and commissioned jointly by the European animal rights group GAIA and the AP thinktank and incubator The Good Food Institute (Sinke and Odegard, 2021). This report provides the only available LCA on cellular agriculture that includes data provided (and anonymized) by companies developing cultivated AP products.

The discourse analysis employed here utilizes methods common to the fields of political ecology and science and technology studies. These methods pay particular attention to how language and is used to identify the drivers of environmental degradation and propose solutions, as well as the political and institutional context in which particular narratives come to be seen as true and to what ends (Hajer, 1995; Forsyth, 2003; Goldman et al., 2011). Source material is read with particular attention to the language used by AP to frame the environmental problems of AP and how scientific knowledge in the form of LCA statistics is used to present these problems as true, urgent, and only solvable through the adoption of an AP-based food system. Narrative practices and themes were identified and assessed iteratively through the practice of qualitative memoing. I provide

TABLE 1 Life cycle assessment statistics for a range of AP and ASF products.

Product	Product category	Functional unit	GHG emissions	Water use	Land use	Geographic location	Source
Impossible burger	PBAP	1 kg ground product	3.5 kg CO_2e	106.8 L	2.5 m^2/y	USA	Quantis
Beyond burger	PBAP	1 kg ground product	3.53 kg CO_2e	28.84 L	3.97 m^2	USA	University of Michigan
Oatly oat mylk beverage	Plant-Based AP	1 kg packaged product	0.27 kg CO_2e	NA	NA	Sweden	CarbonCloud
Ripple mylk beverage	Plant-Based AP	kg protein/l mylk product	24.467 kg CO_2e	4,855 gal	NA	North America	Life Cycle Associates, LLC.
Quorn mycoprotein	Fermented AP	1 kg mycoprotein	1.137 kg CO_2e	35 L	1.8 m^2	UK/EU	Carbon Trust Advisory
Perfect day whey protein	Fermented AP	1 kg whey protein powder	2.71 kg CO_2e	73.9 L	NA	NA	WPS
Cultivated AP aggregate[b]	Cultivated AP	1 kg ground type product	13.6/2.5 kg CO_2e	42/56 L	1.8/1.7 m^2	EU	CE-Delft
Diversified regenerative beef[a]	ASF	1 kg beef	−3.5 kg CO_2e	NA	NA	Georgia, USA	Quantis
Multispecies regenerative composite	ASF	1 kg carcass weight	4.2 kg CO_2e	NA	NA	Georgia USA	Rowntree et al. (2020)
Adaptive rotational grazing beef	ASF	1 kg carcass weight	−6.55 kg CO_2e	NA	NA	USA Midwest	Stanley et al. (2018)
Conventional chicken	ASF	1 kg ground meat	3.025 kg CO_2e	40 L	6 m^2	EU	CE-Delft
Conventional pork	ASF	1 kg ground meat	5.225 kg CO_2e	46 L	4.6 m^2	EU	CE-Delft
Conventional beef	ASF	1 kg beef	48.5 kg CO_2e	2558.24 L	47.4 m^2	USA	Thoma et al. (2017)
Conventional dairy beef	ASF	1 kg ground beef	18.51 kg CO_2e	165.79 L	24.69 m^2	Northeastern USA	University of Michigan
Conventional cow milk	ASF	1 kg protein in fluid milk	30.9–79.4 kg CO_2e	1970–5620 L	NA	NA	WPS
Tofu	Vegan	1 kg product	0.95 kg CO_2e	27 L	1.8 m^2	EU	CE-Delft
Wheat-based meat substitute	Vegan	1 kg product	0.425 kg CO_2e	2 L	0.2 m^2	EU	CE-Delft

Where necessary, statistics were converted to reflect a common functional unit of 1 kg of product. Comparisons made between products are useful but should be considered reasonable approximations in cases where they are derived from different LCA models.
[a]The farm case study used for this study is the same case used for the multispecies LCA of Rowntree et al. (2020).
[b]This LCA calculated the impacts of cultivated AP with a modeled electricity supply based on conventional and 50% renewable energy, with both statistics shown.

quotes that exemplify the development of the bad animal narrative. These are representative quotes of a discourse common to the corpus of sources used in this analysis, and I endeavor to use diversity of sources in quotations.

Bad animals, good technologies

The bad animal narrative can be subtle at times, and it exists as one of several streams of discourse deployed by the AP sector to argue the urgent need for their products. Here I document the main narrative beats of this particular discourse as well as the unspoken assumptions on which the bad animal narrative depends.

AP companies begin their discursive formation with an established fact. As Giuseppe Scionti, founder and CEO of the plant-based AP company Nova Meat, states in video on the company YouTube channel, "The current livestock system is unsustainable for the environment, and it's important to find a solution to this urgent problem (Novameat, 2019)." Understanding that the "current livestock system" referenced here is the industrial livestock system, this statement is demonstrably true. AP companies commonly support this by providing headline statistics on the water use, land use, and carbon emissions associated with animal agriculture taken either from IPCC reports or the United Nations Food and Agriculture Organization (FAO) report *Livestock's Long Shadow* (Steinfeld et al., 2006). However, on this foundation AP frames the environmental problems of (industrial) animal agriculture systems on one particular aspect of the livestock system, the animal itself. In some cases this framing is quite explicit, as in the case of the plant-based AP company Impossible Foods in a 2018 blog post,

> "Unless we act quickly to reduce or eliminate the use of *animals as technology in the food system*, we are racing toward ecological disaster (Brown, 2018, emphasis added)."

However, this discursive framing is often more subtle, with AP companies proposing a singular solution that implies a particular driver of the environmental problems of animal agriculture. Consider the following declaration by Just Food on their website in reference to their plant-based egg:

> We separated the egg from the bird to end the unsustainable mass production of one of the world's most common foods. Because the industrialized egg system sucks for our bodies, for the earth and, let's be honest, it's not a party for the birds either.

This framing posits that the solution to the ills of industrial egg production is to remove chickens from the system, which implies (perhaps subtly) that the chief problem of the industrial egg system is that eggs come from chickens. This narrative tactic relies on implicit logic: livestock must be the source of these established environmental problems or removing the animal from the system would not be a credible solution.

Thus framed, the AP sector identifies two particular problems with livestock as a technology. First, AP argues that livestock are inherently destructive. As Mosa Meat, a cultivated AP company based in the Netherlands, argues on their website:

> [O]ur burger, [doesn't] need to draw as much water from the rivers; cut down rainforests to create pasture and animal feed; use as much energy; or work with chemicals which can run-off into our oceans."

Keeping with this narrative, as demand for ASF increases, we must destroy more land and release more greenhouse gases. Animal technology requires it. Even companies developing AP seafood products contribute to this narrative of destruction in their own way, despite the fact that they endeavor to address a very different set of environmental concerns, such as over-fishing, by-catch, and plastic pollution. The plant-based seafood company Oceanhugger Foods documents the central question that motivated their founding after visiting a Tokyo, Japan, fish market:

> [We] saw two football-field sized warehouses full of tuna sold in one morning. [We]… saw the incredible volume of tuna sold every single day, and asked [ourselves]: "How can the oceans ever keep up?" The answer is "they can't."

And shortly following this, they offer their solution:

> to create a plant-based alternative that would offer people the experience of eating their seafood favorites, without adding pressure on the oceans.

Here Oceanhugger follows the discursive pattern of demonstrable degradation and tidy AP solution that implies a particular source of environmental destruction: so long as seafood is sourced from the bodies of ocean animals, issues like over-fishing will persist.

Secondly, this narrative argues that livestock are inefficient. Pat Brown, for instance, explicitly states that "cows, pigs, chicken and fish did not evolve to be eaten. They're terribly inefficient at turning plants into meat (Brown, 2018)." While the environmental destruction narrative is fairly consistent across different forms of AP, there are subtle differences in the efficiency argument between plant-based and cultivated AP that are worth noting. The plant-based AP argument for efficiency is essentially the same environmental argument that vegans and vegetarians have been making for decades: livestock consume more feed (generally expressed in kilograms) than the quantity of ASF they produce. The fundamental metric used here is referred to as the feed-conversion-ratio (Mottet et al., 2017), and so long as the ratio is greater than one, it is more efficient for humans to simply eat the plants. Plant-based AP modifies the vegan narrative by arguing instead that people eat their AP products, which use more efficient technologies to convert plants into meat, milk, and eggs. Cultivated AP tends to focus less on feed conversion and more on the efficiencies gained by removing the messiness and biological needs of animal bodies. Tissue cells, the argument goes, can be fed more efficiently in a bioreactor than in the body of a cow. As the Israeli firm Aleph Farms notes on their website, "we are skipping the cow part, not the steak part." Plant-based and cultivated AP firms often express this efficiency similarly in terms of land use, water withdrawals, and the like, even if the basis for efficiency claims is different. The plant-based company Just Food and the cultivated AP company Mewery, for instance, both offer engaging interactive web pages that combine dynamic visuals and statistics to demonstrate the increased efficiency of their products. Additionally, cultivated AP argues that culturing cells streamlines the supply chain. For example, SuperMeat—an Israeli firm producing chicken via cellular agriculture—argues that with their process "[n]o [disassembly] or cleaning of birds is needed, decreasing expensive labor and risk for zoonotic diseases. Target tissues are grown and harvested directly, resulting in 100% edible chicken meat." Despite these divergences, both cultivated and plant-based AP narratives converge in their conclusions: AP technologies solve the efficiency problems of livestock.

The bad animal narrative favored by AP is straightforward and compelling, yet it is also notable for its numerous unacknowledged assumptions. This style of simplistic problem framing is common in the technology sector (Fairbairn et al., 2022), and as Jönsson (2016) argues, these silences are an equally important part of discourse. I find it useful to acknowledge several critical assumptions in the bad animal narrative here as they create openings for analysis and discussion of both the LCA statistics used by AP and the future food system this narrative envisions.

First, the AP narrative assumes a particular type of industrial livestock production that favors confined animal feed operations (CAFO), which is the most resource intensive and environmentally damaging livestock system. This assumption manifests in many ways in the data analyzed for this research, ranging from frequent mentions of industrial agriculture and factory farms to imagery depicting cattle in feed lots or caged chickens. This assumption is also seen in the comparative LCA provided by some AP companies, which always use an industrial livestock system based in a developed country for comparison. Given the numerous well-documented harms associated with industrial livestock operations, there is clear utility for the bad animal narrative in making this assumption, yet the reality is that livestock production systems are quite diverse (Mottet et al., 2017). Globally, the vast majority of ASF derived from poultry is produced in industrial systems, but for other types of ASF, assuming industrial production can be quite misleading. The majority of pork produced in OECD countries follows the industrial model, but globally industrial pork only represents around 56% of production. For ASF such as beef that are sourced from large ruminants, only 7–13% of global supply derives from feedlot systems—a trend that holds true for OECD and non-OECD countries like (Mottet et al., 2017).

Assuming industrial livestock production serves the bad animal narrative in numerous ways. First, and most apparent, assuming industrial livestock production maximizes the comparative improvement of AP as a replacement for livestock agriculture. This assumption also works hand-in-hand with the implied problem framing structure that is frequently used by AP. It is uncommon in the corpus of sources assessed for this research for an AP producer or booster to explicitly state that livestock *per se* are the drivers of the environmental problems of animal agriculture. Assuming industrial production means that any effort that removes animals from the equation *also* removes the industrial livestock system, which narratively implies that the incumbent environmental benefits are pegged to the animal itself. This assumption then relieves AP of the burden of demonstrating that livestock are clearly the source of problems associated with industrial systems. This type of explicit problem framing would be more difficult for AP, as I demonstrate in the following section on LCA. Acknowledging other modes of livestock production would also create space for a broader dialog about whether or not AP technologies are, in fact, that best or only solution to the environmental problems of animal agriculture. This is the complicated conversation that we *should* be having, but it is not a compelling sales pitch for capital investment or consumer purchasing.

The bad animal narrative also assumes that current very high rates of ASF consumption in developed countries will persist, and that projected increases in global ASF consumption levels are a given. The cultivated AP seafood company Forsea, for instance, posits that, "curbing seafood demand is impossible, so we are using science to create a positive disruption." Similarly, the cultivated AP pork company Mewery declares:

> [T]here will be 10 billion people living on this planet by 2050. Most of them will eat meat to satisfy the need for proteins. Producing meat in the current way is not sustainable and plant-based solutions won't satisfy everyone. That's why our focus lies in bringing clean meat on the table (emphasis in original).

The assumptions that underlie comments like these are that consumer demand is the ultimate driver of ASF production, and that very high levels of production are necessary to feed future populations. Unacknowledged is the fact that for most of human history ASF consumption was drastically lower, and that it is only in the latter half of the Twentieth Century, when new industrial production methods made ASF abundant and cheap, that consumption levels rose to what they are today (Godfray et al., 2018; Bonnet et al., 2020). Relatedly, the bad animal narrative assumes that the primary reason that livestock are produced is to meet growing consumer demand for ASF, and not, for instance, because it is profitable for lead firms directing ASF supply chains, as a result of national economic policy, or a host of other cultural, economic, or food security reasons. There is little reason, in other words, to assume that consumption of ASF will necessarily remain high in the future, or that a future in which humans consume far less ASF is any less possible than one where we mostly consume AP products. This is especially true considering the significant capital investment necessary to transition to an AP-based food system and the significant structural change and policy intervention that will be necessary to transition to a sustainable food system, whether it is based on AP or otherwise (Hayek and Garrett, 2018; Mouat and Prince, 2018; Van der Weele et al., 2019).

Assuming high levels of ASF consumption also offers key support to the bad animal narrative. First, high and rising levels of ASF consumption augment the sense of urgency in the bad animal narrative. In keeping with the narrative of destruction, ever-increasing levels of ASF consumption and production will only compound existing problems, compelling financial interests to invest and skeptical consumers to make the transition to AP-based diets. High and rising ASF consumption also places the bad animal narrative in a very lucrative position as the necessary heir to a global market in excess of $1 trillion U.S. dollars (Howard et al., 2021). I am not suggesting that actors in the AP sector are not genuinely concerned for the environment. I have no reason to believe that the vast majority of people working in the AP sector do not honestly believe that AP technologies are the best solution to the problems of Animal agriculture. It is also true that the viability of the AP solution requires significant capital and selling things to consumers. Following Mouat and Prince (2018), it would be difficult to justify the capital investment necessary to transition to an AP-based food system without guaranteed markets to provide returns on investment. Thus this assumption positions the bad animal narrative as a means of attracting investment, and by omitting the possibility that ASF consumption could decrease, this assumption lends credence to AP as a singular solution (see also: Metcalf, 2013; Mouat and Prince, 2018).

Despite these and other problematic assumptions, the bad animal narrative has received very little scrutiny in the popular media. Painter et al. (2020), for instance, observed that media coverage of cultivated AP in the USA and UK between 2013–2019 was largely positive, with only 3% of articles offering a clearly negative tone. While some scholars have observed that the AP framing on the problems of animal agriculture is only one among many narratives circulating in popular culture (McGregor and Houston, 2018; Mouat and Prince, 2018), other perspectives in this debate are beginning to frame their narratives in terms of efficiency and environmental restoration just like AP's bad animal narrative (Mitloehner, 2018; Moyer et al., 2020; Tickell and Tickell, 2020).

LCA: narrow statistics for a broad narrative

A critical component of the bad animal narrative is the practice used by AP to present their arguments as established science by validating their claims with statistics from LCA models. LCAs in this context are an attempt at comprehensive assessment of the environmental impacts of the production and distribution of ASF and AP food products. LCA have become a hallmark of corporate sustainability in the food system (Freidberg, 2014) as well as the standard package for assessing and reporting the environmental impacts of agriculture for international organizations like the IPCC and FAO (McGregor et al., 2021). The explicit incorporation of LCA statistics in the bad animal narrative thus brings a familiar weight of scientific authority to the discourse. And following Freidberg (2014), the weight of this authority lies directly with the perception of completeness offered by LCA.

LCA can be a highly useful tool, yet for all the claims of completeness they are often highly reductive models (Freidberg,

2015) that are easy to misinterpret without significant context that is often not provided. For instance, the LCA commissioned by AP typically focus only on greenhouse gas emission in CO_2 equivalents (CO_2e), land use (m^2), and water consumption from cradle to retail distribution. In other words, these LCAs are tailor made to focus on just a few of the environmental problems associated with animal agriculture for which animal-free diets tend to perform especially well by comparison (Sevenster and Ridoutt, 2019). LCA also require large amounts of data in particular formats that allow for standardization and attribution to specific components of the life cycle (Freidberg, 2014; Gheewala et al., 2020; Sevenster et al., 2020). The upshot of these data requirements is that LCA have a tendency to mask a great deal of variation in things like agricultural production and they struggle to effectively incorporate complex components of the life cycle that are either difficult to quantify (e.g., social processes) (Freidberg, 2014), or difficult to directly attribute to specific life cycle components, such as soil carbon dynamics (Sevenster et al., 2020). These limitations and challenges are well known in the community of LCA practitioners (Gheewala et al., 2020) and are often noted in the full LCA reports commissioned by AP. These caveats are not part of the bad animal narrative, however, allowing the bare LCA statistics to speak into this silence and maintain their scientific authority.

Many of the AP companies included in this analysis do not have publicly available LCA. In some cases, particularly for cultivated AP, this is partly due to the fact that the technologies and manufacturing processes have not been scaled to production levels that would allow for accurate LCA. Following Guthman and Biltekoff (2021), the dearth of available LCA reports is likely also a reflection of corporate efforts to protect intellectual property. Nonetheless, many of the AP products that retail in major grocery stores have LCAs that are publicly available, and these are the source of their marketing claims. When you read, for instance, on the Beyond Burger promotional materials that it uses 99% less water and emits 90% fewer greenhouse gases, this is directly taken from their LCA. And as I noted above, many AP companies that do not have comparative LCA of their own still use LCA statistics from agencies like the IPCC and FAO to verify their narrative claims.

Given the importance of LCA to the bad animal narrative, I turn this analysis now to the handful of available AP LCA reports noted earlier. My goal here is not to pull apart each statistic, but rather to consider these documents for what they are: models that tell a particular story about animal agriculture. In order to broaden the narrative possibilities of LCA statistics, I also consider LCA of alternative livestock systems and traditional vegan products. Importantly, I find this broader set of LCA to offer a perspective on the environmental problems of animal agriculture that differs from the bad animal narrative—a perspective that is effectively silenced by the problem framing of this AP discourse.

Table 1 presents the primary results for LCA from a number of diverse sources in an effort to provide a broad reference point for what LCA tells us about the environmental impacts of some AP products as well as traditional sources of ASF. In addition to the results from AP-commissioned LCA, included here are LCA results for a range of conventionally produced ASF, three LCA of diversified livestock production that include soil carbon sinks, and two traditional meat substitutes. These additional LCA results are taken either from the peer-reviewed literature or comparative case studies found in AP LCA reports (many of which are drawn from peer-reviewed research). In each case the source of the statistics is noted.

A resource like this data table naturally lends itself to comparison across products in just the way that AP's bad animal narrative presents it. Yet any comparisons made using this table should be tentative. Accurately comparing LCA results requires very careful tuning of the models to control for system boundaries, inputs and outputs counted at various stages of the life cycle, and standardization of the data across cases. For instance, the LCA commissioned by the plant-based AP company Beyond Meat used an LCA of conventional beef commissioned by the National Cattlemen's Beef Association for comparison. Making this comparison required the authors of the report to significantly reconfigure the beef LCA (and thus alter the results) to allow for direct comparison (Heller and Keoleian, 2018)—a process that is not clearly delineated in the report. I have converted the statistics to reflect equivalent functional units so that quantities can be compared. Yet most of the LCA in Table 1 do not have the necessary symmetry for more than approximate comparisons, except in cases that come from the same source document. Again, my point here is not to technically dissect these statistics but rather to draw a broad conclusion about the work of these statistics in the AP discourse. I argue that when considered together, these LCA do not clearly indicate that AP products are more efficient or less environmentally destructive, nor do they provide a compelling case that the central problem is livestock as a technology.

Several trends emerge from the statistics compiled in Table 1. First, the LCA of AP products are generally lower than the LCA of conventional (i.e., industrial) beef. This is a common comparison in the LCA use by AP companies, and in a side-by-side comparison this is a clear win. While AP does perform better than conventional beef, many of these products are generally comparable to conventionally produced chicken and pork. In this broader context, it is reasonable to suggest that simply switching chicken for beef could provide much of the same benefit as adopting AP technologies. Secondly, the inclusion of soil carbon dynamics in LCA, as they are in the alternative livestock production systems represented here, suggest that the carbon footprint of ASF may be greatly reduced in these production systems, possibly becoming carbon-negative for beef. While the literature is not clear on how long soil carbon sequestration will remain positive in these alternative systems, some analyses suggests that these dynamics may persist for decades (Rowntree et al., 2020; Sevenster et al., 2020). The implication, here, of course, is that alternative livestock systems reduce the environmental impacts of animal agriculture, and in terms of greenhouse gas emissions may offer the best alternative. Lastly, traditional vegan substitutes for ASF are comparable or lower than AP products on the metrics typically assessed in these LCA. When considered outside the confines of the bad animal narrative and in the context of other LCA on ASF and vegan alternatives, AP is not clearly the best option in regard to efficiency and environmental impact.

Further scrutiny of these LCA reports beyond the headline statistics also suggests a counter-narrative: that it is not livestock, but modern intensive livestock production practices that are the bad technology. This is the same system of production that the bad animal narrative implies is a necessary component of livestock production—one that is defined by confining animals, concentrating their waste, and feeding them a diet comprised of high quantities of grain that could otherwise be eaten by humans. First, consider that the comparative LCA commissioned by Impossible Foods explicitly states that fully 82% of water use in conventional beef is irrigation used in the production of maize as a feed crop (Khan et al., 2019). Furthermore, the only land use the Beyond Meat LCA associates with beef is the land for growing feed grain (Heller and Keoleian, 2018). The LCA of cultivated AP conducted by CE-Delft offers additional insight on the problems of CAFO through its use of an environmental single-score metric that aggregates the various LCA statistics into a single index. The single score in this study indicates that for all cases, the primary factor contributing to higher environmental impacts for conventional ASF is the emission of fine particulate matter associated with ammonia emissions produced from waste concentrated in animal houses and feedlots found in CAFO operations (Todd et al., 2008; Sinke and Odegard, 2021). Recall from earlier that the assumptions and implied problem framing structure used by the bad animal narrative allows AP to credit all of the environmental benefits of AP production systems to the removal of animals without needing to indicate which variables in the industrial livestock system actually explain the improvement. In each case noted here, the clear improvement of AP products over their ASF counterparts are direct reflections of livestock practices that result from industrial systems (which are also agricultural technologies) and not the bodies of livestock. And when considered in conjunction with the potential environmental benefits of alternative livestock systems, the bad animal narrative becomes even more tenuous.

Most of the LCA reports considered here are publicly available, and the handful of peer-reviewed LCA that are not open-access publications could, at the very least, be easily obtained by curious journalists through straight-forward database searches. Yet the complexities that emerge from closer consideration of LCA reports are, perhaps unsurprisingly, not even implied in the AP discourse that produces the bad animal narrative and seem largely absent from mainstream coverage of AP in the media (Painter et al., 2020). Perhaps, as others have noted, adding these nuances would make for less compelling fund-raising efforts for AP start-ups (Guthman and Biltekoff, 2021; Fairbairn et al., 2022). Indeed, adding caveats to the bad animal narrative clearly suggests that AP technologies may not be the best and only solution to the environmental problems of animal agriculture, and thus a risky investment.

In addition to a fundraising strategy, this silence in the bad animal narrative makes good business sense for AP for an additional reason: changing livestock production practices would likely reduce consumption of ASF in many countries. Domesticated animals have been a part of the human food system for around 10,000 years, yet industrial livestock systems did not become a significant mode of production until the latter half of the Twentieth Century (Martinez, 1999; Montefiore et al., 2022), and even today the dominance of these practices is varied and geographically specific (Mottet et al., 2017). This period of the Twentieth Century precisely aligns with significant observed increases in global ASF consumption (Godfray et al., 2018). I do not wish to assign too much explanatory power to industrial livestock practices, only to note that the coincidence of increased consumption and new technologies that made ASF abundant and cheap are likely related. Modelling suggests that eliminating industrial livestock practices would greatly reduce production of ASF in wealthy countries (Eshel et al., 2018; Hayek and Garrett, 2018), likely making these foods more expensive and reducing consumption. The trouble here is that AP products are not marketed as substitutes for ASF that could support reduced consumption, but rather as the genuine article. The cultivated AP company Meatable, for instance, describes their product as, "identical [to ASF] on every level, without any of the drawbacks." Furthermore, AP promotional materials commonly claim that their products allow consumers to continue to eat their favorite foods without the environmental cost. The plant-based AP company Nobell plainly declares that their cheese product is, "sustainable decadence for everyone…everyone deserves a righteous mozza dripping pie and a planet that is not on fire." In other words, suggesting the possibility that human diets could or should shift away from ASF is bad business for AP. The bad animal narrative implies that the goal of the AP sector is for people to keep eating the same kinds of foods and simply change which products they purchase. This may help explain why many of the dominant multi-national corporations that profit from the current livestock system are investing heavily in the AP sector (Howard et al., 2021).

Framing sustainable food systems: questions un-asked

The bad animal narrative frames the environmental problems of ASF on destructive and inefficient technologies that necessitate AP solutions. Not only does this discourse gloss over important nuances like the ones mentioned above, but its silences also render certain questions about the future of the food system unaskable. In closing, I briefly consider two such questions that deserve more attention in public discourse on the future of livestock in the food system.

Can livestock contribute to an environmentally efficient food system?

The bad animal narrative presents livestock as necessarily inefficient because they require more land and water than AP, emit more planet-warming gases, and consume more feed than they produce in food. Stepping back from the dueling LCA statistics presented by the AP sector, it is fair to say that the industrial food system is environmentally inefficient. A critical question is whether livestock can be an important part of a more efficient food future. To this question I offer two observations.

First, the primary inefficiency levelled against livestock is the so-called feed-conversion-ratio, with many metrics noting that the weight of feed consumed by livestock is generally greater than the weight of ASF that is produced. Yet this is only an inefficiency in so far as the feed consumed by the livestock could otherwise be consumed directly by a human. An extensive global survey of feed conversion in livestock indicates that most of what livestock around the world eat is not human-edible food—especially for cattle which are often considered to have the largest feed-conversion-ratio (Mottet et al., 2017). Furthermore, when this conversion is adjusted to account only for human-edible protein, rather than total mass, global livestock actually produce more human-edible protein than they consume, particularly in non-industrial systems (Mottet et al., 2017). Other studies have found that livestock actually increase land-use efficiency by converting marginal lands and waste streams into human-edible foods, thus reducing pressure on global croplands that only represent around 30% arable land (Van Kernebeek et al., 2016; Alexander et al., 2017).

Secondly, livestock (can) play an important role as nutrient cyclers in agricultural systems, thus reducing reliance on non-renewable resources. Billen et al. (2012), for instance, found that sustainably localizing the nitrogen supply for agriculture in the Seine River watershed in France would require, among other things, increased stocking rates of livestock to provide manure fertilizer. Similarly, sustainably managing phosphorus fertility in the U.S. requires the regional recycling of livestock waste as fertilizer to break cycles of dependence on non-renewable mineral phosphates (Metson et al., 2016; Hedberg, 2020). And LCA of mixed crop and livestock systems suggest that they require fewer external inputs and produce more total food per hectare than current industrial monocropping practices (Costa et al., 2018).

What would an AP-based food system actually look like?

The bad animal narrative presents itself as a relatively straightforward yet profound change to the food system. I agree with others that read into this narrative significant world-making ambition (Metcalf, 2013; Guthman and Biltekoff, 2021). Yet what would actually change? The obvious, if unspoken, answer is that this food future looks just like the food system we have now, even if there are no livestock.

This is a food system dominated by large scale monocrops, albeit with a slightly different handful of varieties. Evan cultivated AP would remain dependent on industrial copping systems for several key feedstocks (Sinke and Odegard, 2021). There may be no more CAFOs, but these facilities will be replaced with others that produce pea protein isolate and house bioreactors for cultivated AP. They could probably even use some of the same buildings! This is a system reliant on synthetic fertilizers, herbicides, pesticides, and patented seed technologies. This is a system that exploits labor, decimates rural livelihoods and indigenous knowledge and lifeways. And to boot, research suggests that a food future that eliminates livestock without otherwise changing the food system will only reduce global greenhouse gas emissions between 2.5–5% (Teague et al., 2016; Mottet and Steinfeld, 2018).

Perhaps most importantly, this AP food system is one that still uses food production as a means of generating profit that concentrates with a cadre of major corporations and their investors, which is a major reason that industrial livestock production is currently so destructive. Following Ormond (2020), in silencing this critical question, the bad animal narrative directs our attention away from the systems that produce, distribute, and profit from our food and onto the products themselves. The juiciest irony of the bad animal narrative is that it likely offers, as with many green capitalist initiatives, very little disruption at all (Goldstein, 2018).

Conclusion

Throughout this paper I have analyzed the ways that the AP sector has constructed and circulated a narrative formation that blames the biology of livestock bodies for the environmental problems of animal agriculture and presents AP technologies as the necessary solution. In so doing, this discourse simplifies many of the environmental problems in the food system in a way that favors techno-fixes, entrenches existing power imbalances, and forecloses the possibility of alternative food futures.

I am no apologist for the livestock sector. My primary concern is not that AP products exist, or even the notion that these technologies could play a role in a sustainable food system, for indeed they may. The real danger of the bad animal narrative is the growing dominance of its totalizing argument, amplified by its multi-billion dollar megaphone of venture capital (AgFunder, 2021) and unchallenged by a media environment that seems all too willing to believe the hype. My fear is that public debate on the future of the food system will be distilled into a battle of LCA statistics. LCA have their uses, but they cannot tell us what our food system should look like—no model can. An environmentally efficient, sustainable, and socially just food system is within reach, but it will require the messy and maddening work of political, economic, and social change. I suspect that this future food system will still have at least a few animals in the mix.

Data availability statement

Publicly available datasets were analyzed in this study. The corpus of data used for this discourse analysis is gathered from many public websites and other media sources. A database of web addresses that are not included in the references section of the paper can be provided upon request from rchedberg@ship.edu.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

Conflict of interest

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

Publisher's note

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EDITED BY
Evan Bowness,
Trent School of the Environment, Canada

REVIEWED BY
Garrett M. Broad,
Rowan University, United States
Angela McIntyre,
Simon Fraser University, Canada

*CORRESPONDENCE
Varsha V. Rao
✉ varshavinayrao@gmail.com

†These authors have contributed equally to this work and share first authorship

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The role of natural scientists in navigating the social implications of cellular agriculture: insights from an interdisciplinary workshop

Varsha V. Rao[1*†], Bianca Datta[2†] and Kai Steinmetz[3†]

[1]Department of Chemical and Biological Engineering, BioFrontiers Institute, University of Colorado Boulder, Boulder, CO, United States, [2]Ronin Institute for Independent Scholarship, Montclair, NJ, United States, [3]Department of Biological Sciences, Riddet Institute, University of Auckland, Auckland, New Zealand

The emerging field of cellular agriculture uses cell culture to create animal products, potentially mitigating climate and health risks associated with conventional animal agriculture. However, cellular agriculture products are poised to enter the food ecosystem without an understanding of the long-term consequences and social implications. While these discussions have begun among social scientists, dialogues are lacking among natural scientists and engineers, perpetuating a disconnect between those progressing new technology and those most directly impacted by it. To begin to bridge this gap, an interdisciplinary workshop was organized by the Food and Agriculture Institute at the University of the Fraser Valley in collaboration with the Arrell Food Institute, New Harvest, and Cellular Agriculture Canada. At his workshop, representatives from cellular agriculture companies, STEM research labs, dairy farms, animal rights organizations, and Indigenous communities convened to discuss the social implications of cellular agriculture. Specific topics of interest were food security, labor, and employment, power relations and governance, and animal ethics. In this commentary, the authors highlight critical learnings from the workshop as natural scientists, namely the relationship between food and identity, the variety of human-animal relationships, and implications for nutrition and health. We believe that for a just transition of our food systems, the development of cellular agriculture needs to include communities as collaborators from the outset. While this work is difficult in the current environment of market capitalism, it has the potential to improve the culture of research and development to benefit the broader society. To this end, we provide resources, examples, and invitations to natural scientists and researchers interested in engaging with this work. As we rapidly approach a food system that includes products created with cellular agriculture, we encourage readers to consider which individuals and populations need to be involved in this growth, and how they can work together to promote a sustainable future for all.

KEYWORDS

cellular agriculture, cultured meat, social implications of technology, community based practice, cultivated meat and dairy

1. Introduction

As we face increasing climate, economic, and social pressures, rethinking our food production has become a necessary endeavor. Cellular agriculture aims to use biotechnology to create meat, dairy, eggs, and other animal-derived products without harming animals, providing exciting avenues for meeting the increasing food demand while improving planetary and human health outcomes. Proponents of cellular agriculture emphasize potential climate mitigation, animal welfare benefits, and theoretic reductions on our dependence on animals, land, and water to provide protein for human consumption (Tuomisto and Teixeira de Mattos, 2011; Post, 2012; Bhat et al., 2015). As natural and physical scientists interested in cellular agriculture, much of the visible focus of our field has centered on technological feasibility, yet food systems are situated in an interconnected network of complex influences; culture, community, geography, infrastructure, and regulation all shape what we eat and where it comes from. While cellular agriculture products have the potential for significant impacts on existing food systems, they are poised to enter the market without a clear understanding of social implications. As cellular agriculture calls for the reinvention of food as we know it, the shifting landscape allows us to imagine a systematic restructuring that prioritizes equitable resource allocation, food security, and food justice. Achieving this will require critical commentary from communities affected by every stage of food production, specifically but not limited to topics of labor conditions, cultural traditions, and economic opportunities and constraints.

The three authors of this paper entered the field of cellular agriculture as scientific researchers in academia, working to develop cell lines, materials, and protocols to support the creation of cell-based products. Thus far, our formal training has not centered on considerations of the communities and cultures impacted by this technical work. Like many other people, our values draw us to the promises of cellular agriculture, but we often experience a disconnect between these values and the daily practices and incentives of scientific work in existing academic and industrial structures. A lack of explicit training in sociology or the history of science in natural science curricula makes value-based decision-making abstract and leaves out the context of historical examples. Traditionally trained scientists and engineers are rarely armed with the toolkits needed to meaningfully navigate the reality of the nuanced sociological factors that contribute to technology adoption in a socially minded manner. Often, this knowledge is only gained through practical experience over the course of an extended career. While this observation is not new, we highlight opportunities for natural scientists to engage in socially minded decision-making within the field of cellular agriculture in this manuscript as part of a broader call for public engagement and socially responsible innovation.

We explore this challenge anchoring ourselves in the principles of responsible research and innovation (RRI)—a process of research that contextualizes scientific endeavors within a broader ecosystem of society and the environment that aligns with public interest (Framework for Responsible Research and Innovation, n.d.; KLF Tools, n.d.). Key tenets of RRI include (a) anticipating (considering the economic, social, and environmental impacts of the work), (b) reflecting (considering the motivations, biases, and unknowns involved in doing the research), (c) engaging (involving diverse stakeholders), and (d) acting (applying these processes to the research and innovation process) (Framework for Responsible Research and Innovation, n.d.; KLF Tools, n.d.). Beyond anticipating, reflecting, engaging, and acting, others argue that RRI provides a framework in which stakeholders are mutually responsive and responsible to each other (von Schomberg, 2013). Further, reducing barriers to public understanding through direct engagement helps promote general discussion around new technologies and enables trust building. Often, showing novel performance is not enough to ensure widespread acceptance, especially if new options do not conform to existing standards for an established field (Smith, 2007; Jenkins et al., 2020; Gentemann, 2023). As cellular agriculture is in its early stages, we have an opportunity to incorporate these principles as a fundamental part of the infrastructure of the field.

To begin to address these disconnects in cellular agriculture research, various stakeholders were invited to participate in an interdisciplinary workshop in collaboration with the Food and Agriculture Institute (FAI) at the University of the Fraser Valley, the Arrell Food Institute, New Harvest, and Cellular Agriculture Canada, to discuss the potential social implications of cellular agriculture. In addition to representatives from these organizations, representatives from cellular agriculture companies, STEM and social science research groups, dairy farms, animal rights organizations, and Indigenous communities came together to outline ways in which the incorporation of cellular agriculture products into the food system may impact food security, labor and employment, power relations and governance, and animal ethics. Below we highlight our key takeaways from this workshop from our perspective as natural and physical scientists. Specifically, we discuss concerns surrounding how the introduction of cellular agriculture products into the food system might impact animal welfare and human/animal relationships. We also highlight concerns around the nutrition, safety, and health that participants had when considering consuming these novel products. Finally, we draw attention to the gaps in cost and accessibility, both in producing and buying cellular agriculture products and in accessing the technology, for those currently involved in food production and the general public.

The systemic questions discussed at this workshop and in this special issue are broad and complex. While it can be overwhelming to consider the social and economic implications of scientific decisions and communications, the impact they have is undeniable. In this piece, we illuminate specific areas of research, such as cost, nutrition, health, and safety considerations, that technical scientists can engage with and improve communication around. We also provide examples of current models and frameworks, such as responsible research and innovation practices, community engagement guidelines, and food and energy justice frameworks, intended to help natural scientists and engineers be cognizant of the social implications of cellular agriculture. However, we acknowledge that the resources we highlight are in no way exhaustive and intend this piece to mainly spark conversations and encourage the sustainable and socially responsible development of cellular agriculture.

2. Motivation

Exploring the viability and sustainability of cellular agriculture requires considerations of location, population, and community. It is increasingly evident that marginalized communities, specifically rural communities and small-scale farmers, will be heavily impacted by changing natural environments in a disproportionate manner (Benevolenza and DeRigne, 2019). For example, anthropogenic warming has already caused diminished crop yields for farmers through the greater frequency of extreme weather events and changing precipitation and temperature patterns, impacting rural and subsistence farmers. A 2019 IPCC reports with high confidence that climate change will greatly affect food security, particularly in indigenous, rural, and low-income communities worldwide (Food Security, n.d.). Just and holistic solutions require a deep look at processes for development, rather than only economic outcome measures.

In addressing such grand challenges, technical performance is not sufficient. Not everything developed in a lab is widely adopted or accepted by the public. A relevant example is the development of genetically modified organisms (GMOs), which demonstrated many pitfalls to avoid. In part due to a lack of transparency around genetically modified crops, many members of the public are widely unaware of their scientific foundation, their safety, and their prevalence—even today, almost 20 years after their introduction into our food systems. This lack of information has contributed to negative consumer attitudes and restrictive policies, despite many potential food system benefits of GMOs (Funk, n.d.). Negative attitudes have additionally been stoked by the control of GMOs by big, multi-national corporations. Patenting from these corporations has restricted the autonomy of farmers regarding seed saving and reselling and less affluent farmers, unable to afford GMO seed, in the resulting, highly concentrated seed market, are being locked out from competing, resulting in loss of livelihoods (Fischer et al., 2015). Some farmers who chose to abstain and use native seeds have found themselves liable for patent infringement due to cross-contamination of their crops from neighboring farms (Daño, 2007). Cross-contaimination has also resulted in a devastating losses of biodiveristy, both in farmed crops and native plants (Daño, 2007). It is not only the scientists' responsibility to educate the public about their work, but also to take into account how their work is being used: failing to address systemic issues surrounding the conception and implementation of GMOs has ultimately discredited a technology that might otherwise contribute to the benefit of everyone (National Academies of Sciences, Engineering, and Medicine; Division on Earth and Life Studies; Board on Agriculture and Natural Resources; Committee on Genetically Engineered Crops: Past Experience and Future Prospects, 2016).

Cellular agriculture, both the technology and the industry, is still in its early stages. However, its development is being largely driven by venture capitalists, rooted in profit-driven decision making such as IP protection. Furthermore, cellular agriculture products are poised to enter an unequal and globalized food system, where most of the control and influence lies in the hands of a few multi-national corporations. There is already concern among social science scholars that the trajectory of GMO products is poised to repeat itself with those created using cellular agriculture (Mohorčich and Reese, 2019; Khan, n.d.). This technology will impact and perhaps disrupt food systems, not only in the intended ways, but likely in unintended and completely unpredictable ways. Now is the time to think about these downstream implications.

Motivated by this timing and by the challenging nature of these questions, the authors attended the workshop described below. We wanted to better understand the concerns of communities involved in animal rearing and activism and of social scientists focused on food systems and food justice. By interrogating these in collaboration with social scientists and involving relevant communities in the development process, thus making them participants rather than bystanders, we aim to not only promote transparency but also fundamentally integrate public good rather than private interest into the very structure of this emerging technology.

3. Integrating cellular agriculture into our food systems: unaddressed concerns and opportunities for technical researchers

In April 2022, a group of partners led by the FAI convened a learning exchange entitled "Social Implications of Cellular Agriculture." The organizers brought together cellular agriculture entrepreneurs, scientists, and NGOs, along with animal rights advocates, farmers, educators, social science researchers, and Indigenous Peoples and Elders to discuss the potential societal impacts of cellular agriculture in the US and Canada. Plainly, the workshop was unlike anything the authors had experienced as STEM scientists and engineers. Most time was spent in a large circle sharing our expertise, stories, and anxieties about integrating cellular agriculture into our food systems. We focused mainly on how these cellular agriculture technologies could disrupt, for better or for worse, traditional ways of living and being, and how they could live up to their environmental and social promises. The primary concerns were: (i) the role of food in identity and human/animal relationships, (ii) nutrition and health, and (iii) the cost and accessibility of cellular agriculture products.

3.1. The role of food in identity and human/animal relationships

The different communities in the agricultural system and beyond have distinctly unique relationships with other living beings. For example, Indigenous communities regard animals as their relatives, a relationship that is critical to their identities as individuals and communities (Kimmerer, 2013). At the workshop, members of the Stó:lō Nation, the River People who have inhabited the Fraser Valley in present day British Columbia since time immemorial, explained how salmon are their brethren, relatives that are respected and honored for giving their lives to nourish their Nation (Carlson, 2008). Without over generalizing, this relationship is an extension of a broader worldview held by Indigenous Peoples, which is characterized by the interdependence of all living beings, where humans are not separate from or superior to other animals, plants, or the land itself (Carlson, 2008). For many farmers, on the other hand, animals represent their livelihoods and are commodities that require specific inputs and outputs for economic viability. This relationship is based on covering the animals' basic needs such as feeding, shelter, protection, and veterinary care. For animal rights activists, factory farming perpetuates mass production of animal goods at the expense of or any regard for livestock quality of life, contributing to a greater abstraction of food products away from their animal origins. Most consumers experience a complete disconnect between animal-derived products and the animals themselves. Furthermore, we may hold multiple of these identities simultaneously.

At first glance, the values driving cellular agriculture overlap with those of animal activists. Many companies started with the explicit goal of ending industrialized animal agriculture by offering an indistinguishable replacement, both in price and taste. However, many recent conversations imagine cellular agriculture products as just another option for consumers, on future shelves next to animal-derived products (Dutkiewicz and Rosenberg, 2021). Projected increases in meat consumption in the near future predict higher demands for animal products, perhaps made both through conventional and cellular agriculture (Ritchie et al., 2017; Godfray et al., 2018). Established companies in the factory farming industry, such as Tyson and Cargill, are investing heavily in cultivated meat companies (Byrd, n.d.) and the first approved cell-cultured chicken was produced with fetal bovine serum (FBS), thus necessating the use of animals in its production. With this increased demand and clear partnership with industrial agriculture, it remains to be seen if cellular agriculture will decrease the use of animals in our food systems or ease the burdens for wild caught ones. Economic and scaling pressures may shift individual perspectives, ultimately furthering the objectification and commoditization of animals (e.g., cell source). Furthermore, decoupling the animals from the food they produce may be in contradiction with the interconnected worldview of Indigenous Peoples and the experience of many farmers, and potentially further alienate the consumer from food production and sourcing.

While exploring these types of questions is not often in the research purview of natural scientists, they are nevertheless important to query. Collaborative efforts with social scientists should be conducted to investigate and understand how food identity and relationships to animals might be impacted with the introduction of cellular agriculture products into food systems to adapt scientific communications and, potentially, technological processes to better reflect the values driving the industry.

3.2. Nutrition and health

Many workshop participants, including proponents of cellular agriculture, were concerned about the nutritional benefits and health effects of cultivated products. In particular, they voiced concerns about how "natural" or "processed" these products would be, whether cellular agriculture products will have the same nutrition as their conventional counterparts, and their long-term health impacts. Specific questions surrounding cancer risks of eating immortalized cells (sometimes derived from cancerous sources in biopharma) were also asked.

First, it is important to note that the term "natural" is difficult to define in the context of animal agriculture. For example, deliberate selective breeding has created chickens with disproportionately large breasts, over three times the size of their predecessors, that are unable to support their own weight (Kateman, n.d.). To the next point, scientists are actively researching the nutritional similarities between cellular agriculture and animal-derived products. Academic studies have shown similar fatty acid profiles and protein content between cultivated and conventional fat and meat (Dohmen et al., 2022; Yuen et al., 2022). A premarket submission by Upside Foods, a US-based cultivated meat company, to the Food and Drug Administration (FDA), describes similar macronutrient profiles between their cultured poultry meat and conventional chicken (Schulze, n.d.). Specifically, regarding the use of immortalized cell lines, leading cancer researchers have pointed out that, as the cells are not human and are being eaten, it is highly unlikely that any transmission events will occur (Fassler, 2023). However, this information is often inadequately communicated to the public. This is crucial, as health benefits are a key driver of dietary changes (Rolland et al., 2020). While there is no evidence that the consumption of cellular agriculture products would cause any health issues, further research and, particularly, long-term human health studies are yet to be conducted (Holmes et al., 2022). Clear explanations by technical researchers to the public and potentially novel ways of communicating this information are necessary as well.

3.3. Cost and accessibility

Another main concern was the economics of cellular agriculture. While there has been much discussion surrounding the techno-economic feasibility of cellular agriculture technology (Risner et al., 2020; Humbird, 2021; Odegard and Sinke, n.d.), there is little discussion of how food economies will be affected and who will stand to benefit from its introduction. Currently, the economic ecosystem of cellular agriculture relies heavily on venture capital ~$4 billion USD investment in private companies in the past decade (Cellular Agriculture Investment Report, 2021), which incentivizes closed intellectual property protection. Historically, technological development, rooted in colonial and settler regimes, have been at the expense of Indigenous Peoples livelihoods, sovereignty, and local food systems. Stemming from this history, several Indigenous scholars and community members were concerned about the accessibility of patented, proprietary technology and whether their family members could make and eat cultivated salmon in future generations, given its central importance to them. Given the previously mentioned ties to animal agriculture and growing world populations, it remains to be seen if the emergence of cell-based salmon would result in a net increase of the wild salmon populations or in any economic or ecological benefit for the Indigenous communities that rely on them.

In addition to possible patent restrictions, the accessibility of knowledge for cellular agriculture became a key concern for several scientists present at the workshop, including the authors of this perspective. Understanding the basics of cellular agriculture requires prior knowledge of fairly advanced cell biology, including concepts of stem cells and recombinant organisms at a minimum. This is likely prohibitive to many farmers and Indigenous community members who are interested in cultivating products.

The hardware and resources needed to cultivate products, such as bioreactors, cell lines, cell culture media, and post-processing equipment, are also often both financially and physically inaccessible. As the field grows, companies are building this infrastructure in isolation. For a farmer interested in incorporating cellular agriculture into their operation, the costs of getting involved are unclear and may be prohibitive, and know-how on how to do so is scarce.

An organization called RESPECTfarms is currently building a bridge between farms and cultivated meat scientists in the Netherlands and aims to assist farmers in cultivated meat production on their farms. Still, it is unclear whether this will be a viable option for farmers within existing systems. Shojin Meat Project, a citizen science organization based in Japan, has protocols for DIY cellular agriculture, including making cell media from electrolytes and salts and cell incubators from towel warmers. There are clear opportunities here for technical researchers to create bioreactors and downstream processing systems designed to be incorporated on farms and operated by farmers.

There are several efforts for deconvoluting cellular agriculture and increasing the scientific literacy of the process. Non-profit organizations, including New Harvest, the Good Food Institute (GFI), Cell Agri, and Cellular Agriculture Canada and Australia, provide information on their websites about the production and science of cultivated meat and dairy. Student groups, such as the Alt Protein Project and Food Tech at MIT, and independent labs, such as the Kaplan lab at Tufts University, have created in-depth educational material openly accessible online. However, there are still significant gaps in scientific communication around cultivated meat. These discussions highlight the need for clear communication and public engagement efforts from technical scientists.

3.4. Workshop summary

In summary, participants were concerned about the effects of cellular agriculture on the relationship between animals and humans, the nutrition and health impacts on consumers, and access to the technology—physically, financially, and intellectually. Industrial food production has largely led to an alienation of people from the source of their food, especially animals, and it is not clear how a further abstraction like cellular agriculture may shape this relationship. The publicity around the cellular agriculture industry has largely been driven by overenthusiastic media coverage that lacks nuance, with messaging geared more toward investors than consumers, already leading to a track record of broken promises and missed milestones (Philpott, n.d.). Transparency is further hindered by the need to secure IP in tandem with the extreme costs associated with starting an industrial cellular agriculture operation. Combined, this leads to reasonable fears around a further concentration of food production in the hands of a few companies with the necessary access to capital, which could ultimately perpetuate shortcomings of existing food systems (Howard, 2022). To further exacerbate these challenges, the accurate information that is currently available about cellular agriculture is often inaccessible, relying on specialized knowledge and vocabulary that is often not translatable across disciplines, presenting challenges for collaboration and open inquiry.

While informative, this workshop was just a first step into having necessary conversations with some of the voices and groups currently missing from the cellular agriculture community. Solutions to the concerns discussed above will require new, creative ideas around community engagement in the research and development process, funding models, and interdisciplinary research in this emerging field, especially from non-STEM disciplines. In the next section, we highlight some examples of existing barriers and resources with which to approach this field.

4. Discussion

Cellular agriculture may provide an opportunity to decouple food supply from current industrialized and heavily subsidized agricultural systems that often exploit workers, animals, and consumers. To achieve this potential, it will need to reach, or surpass, price parity with conventional agricultural outputs. While present research and early prototypes are far from this vision (Fassler, n.d.), the infancy of this industry does present an opportunity to be proactive and consider locality, environment, cultural traditions, and community engagement at each step of the process.

Developing the field of cellular agriculture may fundamentally change how we define food; integrating these products will be intertwined with culture, storytelling, and community practices. Therefore, as detailed by the RRI framework, it is crucial that scientists strive to pursue continued cross-disciplinary investigation, and collaborate between industry, non-profits, and community and government organizations. The existing paradigm of scientific research often neglects collaborations with social or public organizations until after technology has fully matured, making it difficult to adapt processes and operations toward beneficial outcomes for affected communities which can even lead to harm. While many technologists aim to contribute to sustainable and equitable outcomes, not all designed solutions proliferate sustainability in practice, and failing to conduct impact assessments early on can allow for oversights around environmental or health hazards, energy and resource usage, and social and economic justice (Datta et al., 2022).

For cellular agriculture, this might look like involving specific communities and social scientists in the development and impact assessment of culturally relevant products. For example, scientists and companies could involve community representatives in species selection, cell isolations, and iterative tastings. Other areas for collaboration may include determining societal effects of material inputs used in the research process, sourcing and transporting raw materials, and selecting the location of production facilities (Risner et al., 2020; Humbird, 2021; Odegard and Sinke, n.d.). Natural scientists, social science researchers, and community members together could actively anticipate the future impact of the introduction of novel foods on the current food systems and adapt processes if necessary to meet agreed upon social and economic goals.

Translating these technological advances beyond a laboratory setting is challenging on multiple levels: beyond the technical feasibility and access to scientific equipment, engaging with a broader community deviates from traditional protocol-based workflows common in scientific disciplines. Solving complex problems with expansive implications like food system restructuring requires convergence at all scholarship and community levels, from education and training to technology transfer and local stewardship. Historically, there has been an "engagement education gap" (Harsh et al., 2017) between students studying potential solutions and the communities which hope to benefit from them. While in-depth multi-day workshops are resource-intensive and difficult to scale, early research is underway on the potential impact of including community-based work as part of formal engineering education (Harsh et al., 2017), and the authors found this kind of in-depth interaction (namely the FAI workshop) to be deeply valuable and enriching. Supporting the growth of an industry centered on food will require scientists and engineers to recognize that community is "an interdependent web of systems [with] 'economic, technological, social, cultural factors'" (Schneider et al., 2008; Harsh et al., 2017).

Organizations such as the American Association for the Advancement of Science specifically provide tools to help scientists advocate and communicate with their communities and policymakers on local, state, and national levels (AAAS home, n.d.). Furthermore, as more open source and student-run initiatives emerge (such as the Tufts Cell Ag Course, Food Tech at MIT, and other initiatives mentioned above), promote open innovation and communication between scientists and potential consumers through awareness and outreach. To encourage nontraditional research practices that emphasize community-led collaborations, we must begin by broadening scientific training (Batchelor et al., 2021). Employing a more socially directed approach to technical research and development early on will better prepare upcoming scientists to tackle nuanced contemporary issues, mitigating potential harm to people and the planet (Datta et al., 2022). For early-stage scientists, participating in responsible research can start with carefully considering which authors to cite to ensure diversity of opinion and background, inviting a broader range of speakers to events, or speaking directly with intended users of research outcomes to develop mutual interest. For scientists in industry, advocacy may also involve talking to leadership about impact assessments or incorporation of RRI principles at the company level.

As scientists understand the specifics of developing relevant technology, we are well-positioned to inform policy that is grounded in scientific evidence. The potential far-reaching impact of such policy is immense, and scientists have an opportunity to provide the general public with the information and tools needed to engage meaningfully with policy and legislation around the field. In doing so, researchers and practitioners can actively elevate the perspectives of underserved and highly impacted populations, allowing for the co-production of knowledge, policy, and communication outputs. NASA and other federal agencies have prioritized open science for 2023, explicitly setting the goals of (a) developing a strategy for open science, (b) improving transparency and equity of reviews, (c) accounting for open-science activities in evaluations, and (d) engaging under-represented communities (Gentemann, 2023).

Many of the incentives driving cellular agriculture overlap with climate-oriented efforts, including energy transitions and climate engineering (Cusack et al., 2014; Jenkins et al., 2020), so researchers can draw inspiration from recent efforts toward incorporating societal considerations in these fields. An example is the framework of energy justice and energy democracy, which engage with energy policy, consumption, and production as it intersects with activism, security, and socioeconomic factors (Burke and Stephens, 2017). These endeavors explicitly link considerations of justice and societal impact to technical advancements (Burke and Stephens, 2017) and recognize that existing energy challenges (much like existing challenges in industrial agriculture) provide opportunities for change and transition toward a new system (Szulecki, 2018). Overcoming these challenges depends on our ability to determine equitable principles for restructuring, determine future pathways, and imagine new realities (Burke and Stephens, 2017). Researchers may also draw inspiration from circular economy work, where incentives are aligned to provide sustainable solutions that allow communities to thrive economically. Energy transition researchers identify workshops, community outreach, and interdisciplinary, multi-method, contextually sensitive approaches as opportunities for early stakeholder engagement with the development of research agendas toward the co-production of knowledge and impact (Hoolohan et al., 2018; Jenkins et al., 2020). Food justice principles may also be useful resources to incorporate values of equity into cellular agriculture. Broad and Chiles argue that values of racial and social justice, place-based economic development, equitable labor practices, and climate and environmental justice can inform the evolution of the cellular agriculture sector (Broad and Chiles, 2022).

For these frameworks to be enacted, researchers, community members, activists, and practitioners will need practical partnerships, shared terminology, and goals (Jenkins et al., 2020). Such work will require an understanding of both the populations impacted by these transitions (Jenkins et al., 2020) and of the historical factors and social forces that shaped the existing systems and challenges (Burke and Stephens, 2017). Learnings from these efforts may encourage researchers to consider a "fundamentally different approach" to research, wherein direct social engagement is an explicit goal (Jenkins et al., 2020; Datta et al., 2022).

More specifically to the participants in attendance at this workshop, engagement between scientists and Indigenous communities has historically been exploitative and extractive. Decades of scientists participating in unethical or culturally insensitive behaviors have sown distrust (Harmon, 2010; Genetic Researcher Uses Nuu-chah-nulth Blood for Unapproved Studies in Genetic Anthropology, n.d.) Furthermore, novel technological development, such as cellular agriculture, historically has been created to solely benefit colonial and settler regimes, not the Indigenous Peoples. Proponents of cellular agriculture readily tout the potential decrease in use of, e.g., land and water, a natural resource that has been systematically stripped from Indigenous communities in the past, yet there are no explicit efforts underway to ensure that they will benefit from the purported advantages of cellular agriculture. Claw et al. (2018) details principles for Indigenous engagement in genomic science rooted in values of reciprocity, respect, equity, and beneficence which might help ensure they do. Concrete examples of these values in action include building cultural competency of tribal traditions and sovereignty before engagement, engaging with tribal members throughout the research process, cultivating a practice of transparency, developing a plan to disseminate findings in community-accessible formats, and building scientific research capacity in the community to ensure tribal scientists can lead research in the future. To this last point, Native-led research efforts are extremely important to empower and support (McOliver et al., 2015). In food research specifically, engaging with Indigenous communities also creates many opportunities for western scientists to understand and weave principles of Traditional Ecological Knowledge into their decisions and practices (Whyte et al., 2016; El-Sayed and Cloutier, 2022).

New technology is sometimes posed as a wholesale (or "benevolent") solution to existing challenges, but in reality, technology alone is often deeply unsuccessful and fails to acknowledge the existing systems and people who will have to accept and incorporate it. We envision an iterative process where community members are collaborators, and in which listening, observing, and understanding are central. This type of respectful collaboration, grounded in cultural competency and meaningful relationships, will take time and effort, which is difficult in the current fast-moving and competitive cellular agriculture field. Despite these difficulties, we hope that others with ambitions of improving the status quo will embrace these challenges to strive for an ecological, equitable, and just transition of food systems, and help transform the culture of research and development to benefit broader society.

5. Conclusion

The workshop, focused on the social implications of cellular agriculture, provided a unique convergence of interests relevant to cellular agriculture as an emerging food system. It highlighted presently under-researched areas: (i) the role of food in identity and human/animal relationships, (ii) concerns around nutrition and health, and (iii) the cost, safety, and accessibility of cellular agriculture products and technology. As this field is only just gaining traction, we have an opportunity to incorporate these broader social implications and complex questions at the onset. Doing so will allow us to collectively build the field with community impacts and collaboration at the forefront.

The technical developments and social pressures of the past few decades have brought us to a unique moment in history, where we face mounting climate crises, supply chain obstacles, and economic and social disparities exacerbated by wars and an ongoing pandemic. Technological developments promising improvement in human quality of life have proliferated unchecked without the scientific community fully engaging with the potential unintended consequences. As cellular agriculture has far-reaching implications, we cannot afford to simply let market forces decide how this technology should evolve.

Food is inherently community-based, from the production and growth, the types of dishes we prepare, to the people with whom we share our meals. Perturbations can be immense as they do not just change what and the way we eat, but the way we interact with the earth and life in general. Thus, as scientists, we have a responsibility to engage deeply with communities around the emergence of cellular agriculture and to collectively create a pathway for the responsible development of this field. While the focus for scientists and engineers is often on research outputs and objective or technical contributions, researchers in cellular agriculture have the ability to contribute as individuals as well. Beyond technical engagement, we can contribute through local civic engagement, community organizing, political action, scientific outreach, and public education. Most critically, the approaches needed to sustainably develop this field expand far beyond the scope of this paper – the main body of work is what lies ahead.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

VR, BD, and KS originated the ideas for, wrote, and revised the manuscript. All authors contributed to the article 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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*CORRESPONDENCE
Varsha V. Rao
varshavinayrao@gmail.com

†These authors have contributed equally to this work and share first authorship

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Corrigendum: The role of natural scientists in navigating the social implications of cellular agriculture: insights from an interdisciplinary workshop

Varsha V. Rao[1*†], Bianca Datta[2†] and Kai Steinmetz[3†]

[1]Department of Chemical and Biological Engineering, BioFrontiers Institute, University of Colorado Boulder, Boulder, CO, United States, [2]Ronin Institute for Independent Scholarship, Montclair, NJ, United States, [3]Department of Biological Sciences, Riddet Institute, University of Auckland, Auckland, New Zealand

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Shippensburg University, United States

*CORRESPONDENCE
Alesandros Glaros
✉ alesandros.glaros@ufv.ca

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

Alesandros Glaros[1,2]*, Robert Newell[3], Evan Fraser[1] and Lenore Lauri Newman[2]

[1]Department of Geography, University of Guelph, Environment and Geomatics, Guelph, ON, Canada, [2]University of the Fraser Valley, Food and Agriculture Institute, Abbotsford, BC, Canada, [3]Royal Roads University, School of Environment and Sustainability, Victoria, BC, Canada

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 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.

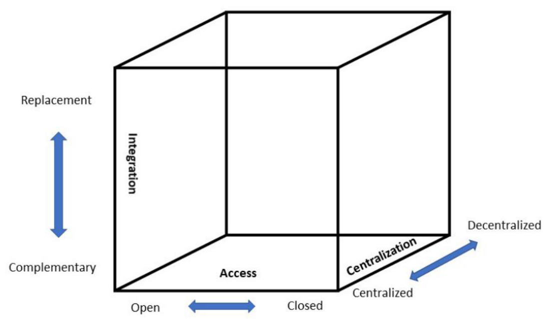

FIGURE 1
Framework to assess cellular agriculture futures.

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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EDITED BY
Evan Bowness,
Trent School of the Environment, Canada

REVIEWED BY
Russell Hedberg,
Shippensburg University, United States
Patrick Baur,
University of Rhode Island, United States

*CORRESPONDENCE
John J. Dooley
✉ john.dooley@rau.ac.uk

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Threat or opportunity? An analysis of perceptions of cultured meat in the UK farming sector

Louise Manning[1], John J. Dooley[2]*, Illtud Dunsford[3], Michael K. Goodman[4], Tom C. MacMillan[2], Lisa C. Morgans[2], David C. Rose[2] and Alexandra E. Sexton[5]

[1]The Lincoln Institute for Agri-Food Technology, University of Lincoln, Lincoln, United Kingdom, [2]Royal Agricultural University, Cirencester, United Kingdom, [3]Cellular Agriculture Ltd., Felin y Glyn, Llanelli, United Kingdom, [4]Department of Geography and Environmental Science, University of Reading, Reading, United Kingdom, [5]Department of Geography, University of Sheffield, Sheffield, United Kingdom

Background: The environmental and social impacts of cultured meat, and its economic viability, are contingent on its implications for food production and for agriculture. However, the implications of cultured meat production for farmers have not yet been thoroughly investigated and are poorly understood. The aim of this research was to engage with the farming sector in critically assessing cultured meat as a technology which could profoundly affect future farm livelihoods, land use, rural and farming communities and agricultural value chains. Ensuring farmers' voices, and potential 'counter-narratives' inform the development of cultured meat is not only inclusive, but could identify unexpected impacts of this emerging technology and contribute to the framing of the social license of the industry developing them.

Methods: Six focus groups were undertaken with 75 UK farmers from a variety of farming sectors and regions. Questions focused on what the term 'cultured meat' means to farmers, the potential impacts of cultured meat, and potential business scenarios arising for farmers. All meetings were recorded, transcribed, and thematically analyzed.

Results and discussion: Farmers expressed complex and considered reflections on cultured meat, raising several perceived opportunities and risks associated with the themes of 'ethics and affective' narratives, 'environment-based' narratives, and 'socio-economic' narratives. Aspects of foci of power, food system control and transparency associated with cultured meat emerged from the conversations, as well as cultured meat's potential impacts on the environment and on jobs, farming/rural communities and connecting with the land.

Conclusion: Globally, meat production underpins the livelihoods of many rural communities, so a transition to cultured meat is likely to have deep-seated ethical, environmental, and socio-economic impacts. Within the discourse on cultured meat the voices of farmers are often lost. While not claiming to be representative of all UK farming, this study engaged UK farmer perspectives as a way of starting the substantive process of greater stakeholder inclusion in cultured meat innovation pathways, and which should underpin responsible technology transitions in agriculture.

KEYWORDS

cultured meat, farmer, attitudes, perceptions, meanings

1 Introduction

There is growing concern over the negative externalities of the global production of meat and dairy products (Funke et al., 2021). Between 1961 and 2009, the global average availability of animal-based protein per person increased by 59%, compared with a 14% increase in plant-based protein, and consumption of animal-based food is expected to rise by nearly 80% between 2006 and 2050 (WRI, 2016). Traditionally, meat derived from animals is an important food for humans because, although substitutable in the diet, it is a nutritionally dense, rich source of bio-available high-quality protein, fat, a range of vitamins, minerals and other essential nutrients including iron and vitamin B12 (Fraeye et al., 2020; Li et al., 2022). Additionally, eating meat is a very significant identity-defining cultural and culinary practice across the world (Potts, 2017).

Meeting the global demand for meat is land-intensive compared to crop production (Smith and Myers, 2022). Methods of meat production range from extensive ruminant grazing systems to intensive industrial-level livestock production, where concerns arise with regard to environmental impact, animal welfare, and food safety (Reis et al., 2020). While meat from grazed ruminants generally requires more land and natural resources (Chen et al., 2022), grazing systems turn those resources (land, soil, water, plants), where crop production is unviable, into nutrients that would otherwise not be accessible to humans. However, livestock production has significant environmental impacts including associated greenhouse gas emissions, deforestation and air and water pollution due to nutrient run-off (Specht et al., 2018). Life cycle assessment studies have been undertaken for cultured meat showing lower land use and higher energy use compared to beef production (Tuomisto and Teixeira de Mattos, 2011; Mattick et al., 2015; Smetana et al., 2015; Lynch and Pierrehumbert, 2019; Delft, 2021)[1], but Risner et al. (2023) raise concerns based on a life cycle assessment that the environmental impact of near-term animal cultured meat could be "orders of magnitude" higher than median traditional beef production.

Concerns have been raised in some quarters over the global politics of meat 'boosterism', food safety and animal welfare concerns, the health consequences of meat-intensive diets (Lescinsky et al., 2022), and the concentration of red, white and processed meat production into fewer corporations (Howard et al., 2021; Sievert et al., 2022), while the ability to significantly increase productivity and efficiency with current methods of livestock meat production have been stated as limited (Post, 2014; WEF, 2019).

In the quest for more sustainable food systems, various 'game-changing technologies' (Klerkx and Rose, 2020) have been proposed as part of a so-called 'revolution' in food production. A range of new technologies are heralded as being part of Agriculture 4.0 (Lezoche et al., 2020), including drones, artificial intelligence, robotics, and gene editing, as well as novel production systems such as vertical farming and the production of alternative proteins derived from fungi or algae (Klerkx and Rose, 2020). These technologies offer promises to increase food production, while having less impact on land, soil, air, water, and biodiversity, and maintain profitable farm businesses. However, they would cause disruption to existing food production systems. Whilst disruption is an important part of sustainable transitions (de Boon et al., 2022), the potential impacts – both positive and negative – on people, production, and the planet must be considered in the round (Rose et al., 2021). For all the promised potential positive impacts, concerns have been raised over the unintended consequences of new technologies (Klerkx et al., 2019), including on jobs and the nature of work in the agri-food sector (Rotz et al., 2019), negative impact on farmers and farming communities (Wilks and Phillips, 2017; Bryant, 2020; Bryant and Barnett, 2020), the weakening of farmer autonomy and control in the food system (Brooks, 2021; Gardezi and Stock, 2021), the further consolidation of power in companies who control development of, and access to, new technologies (Duncan et al., 2021; Bronson and Sengers, 2022; Goodman, 2023), unequal benefit (Klerkx et al., 2019), data ownership (Wiseman et al., 2019), further intensification of production (Miles, 2019; Daum, 2021), and increased energy use (Streed et al., 2021). Cultured meat production could take the pressure off intensive livestock production, creating business opportunities for higher-welfare, higher-price, extensive traditional livestock products (Sexton et al., 2019). Bryant et al. (2020, 11) state that farmers may also see opportunities with the development of cultured meat, which may "address the mass demand for affordable meat, enabling them to move away from intensive industrial production systems and return to more traditional systems, which are more harmonious with environmental and animal welfare outcomes." Indeed, the high level of differentiation of meat production systems from highly intensive, forage or feed based to regenerative meat production systems (see Dyer and Desjardins, 2021) mean that the implications for greenhouse gas emissions and land use need to be considered according to the individual meat production system, its context and its location.

Alternative meat production is one area of technology identified as having game-changing potential and around which 'promissory narratives' (Sexton et al., 2019) have been forged. Alternative meats range from analogs derived from plants, fungi or algae, to cultured animal cells. As the most direct substitute for meat, and a focus of significant private and public investment, cell-cultured alternatives warrant particular attention. Cultured meat is estimated by Gasteratos (2019) to require less land than cattle production (99%) and poultry production (66%) and less water (cattle, 98%, poultry, 92%). Warner (2019, 3041) states that the drivers for increasing cultured meat production include: "food security, environment and sustainability, consumer and public health/safety and animal welfare problems associated with meat production, but not all of these challenges will be met by a move to industrial scale cell-based meat." The potential for cultured meat to mitigate the negative impacts and externalities of meat production includes reducing foodborne illness, pathogens and zoonoses (Gilchrist et al., 2007; Hsi et al., 2015; Gasteratos, 2019) and reducing antibiotic resistance (Gilchrist et al., 2007; McEachran et al., 2015; McCrackin et al., 2016). Chriki and Hocquette (2020) highlight a number of technical and other criteria that need to be addressed if cultured meat is to achieve these goals. As set out in the following section, however, closer scrutiny of the sustainability credentials (i.e., productivity, environmental, social) of cultured meat is required in the context

1 It is important to note that the public availability of data on commercial large-scale cultured meat production has been limited to date, and so existing LCA studies have typically been based on hypothetical inputs and production processes. As such, the findings should be viewed as anticipatory rather than indicative of the environmental footprint of industrial cultured meat.

of wider social science work on Agriculture 4.0 that has raised social and ethical concerns.

For agricultural sustainability transitions to be just, ethical and responsible, the views of all affected stakeholders should be heard and included in the setting of trajectories (Klerkx and Rose, 2020; de Boon et al., 2022). We have seen recent examples of poorly managed agricultural sustainability transitions (e.g., livestock farmer protests in Netherlands and Ireland) in which people have not felt included, which has led to conflict and controversy. The development of cultured meat may have significant implications across the supply chain, meaning that agri-food stakeholders (including producers, retailers, consumers etc.) should be included in decision-making. Farmers are one group of important stakeholders, but the implications of cultured meat production for farmers have not yet been thoroughly investigated in the literature and are poorly understood.

The aim of this research was to engage the farming sector in critically assessing cultured meat as a technology which could profoundly affect future farm livelihoods, land use, rural and farming communities, and agricultural value chains. Ensuring farmers' voices, as well as potential 'counter-narratives' (Sexton et al., 2019) and/or alternative narratives are heard in the development of cultured meat is not only important to the industry players and interests surrounding their production and consumption, but potentially also to identifying unexpected impacts of these emerging technologies, and their social license.

2 Perceptions and positioning of cultured meat

2.1 Technical positioning of cultured meat

Cultured meat is produced through *in vitro* animal cell culture techniques involving the steps of animal cell isolation, cell proliferation or expansion, cell differentiation, cell harvest, and then cell processing in an aseptic laboratory or factory environment (Ben-Arye and Levenberg, 2019; Ong et al., 2020; Wang et al., 2020; Li et al., 2021; Treich, 2021). Currently, the stem cells used in the process are taken from live skeletal muscle from the animal via a biopsy and then the stem cells are grown in a media containing fetal bovine serum (Catts and Zurr, 2014; Post, 2014; Post, 2017) in a bioreactor (Datar and Betti, 2010). However, genetically modified immortal cell lines could be produced that only require animals as the source of the original cells (Genovese et al., 2017) meaning considerably fewer animals would be used in cultured meat production (Stephens et al., 2018; Soice and Johnston, 2021). The use of fetal bovine serum can be inconsistent, there is the potential for contamination, it is expensive and has ethical implications that could concern consumers of cultured meat, so serum-free production is being investigated (Gottipamula et al., 2013; Garrison et al., 2022). These animal-free growth factors are also a significant cost driver within the media, affecting the economic feasibility of the production of cultured meat (Chen et al., 2022).

Cultured meat can be formed into tissue structure through 3D bioprinting (Li et al., 2021). Bioprinting arranges cellular and acellular components "to construct complex 3D functional living tissues" extending from production of cultured meat to print "muscle cells, fat cells, and extracellular matrix supportive cells" (Handral et al., 2022, p. 273). 3D bioprinting is used in tissue engineering for soft tissue repair, developing artificial blood vessels and organs such as human ears, bones and skin (Mandrycky et al., 2016; Tarassoli et al., 2018; Genova et al., 2020; Li et al., 2021). Scaffolds are the framework for cells to adhere to and move from a 2D sheet to a 3D material (Auluck et al., 2005; Shimizu et al., 2017; Allan et al., 2019; Li et al., 2021) to then allow the development of tissue maturity (Handral et al., 2022). Scaffold materials can include a wide range of plant and other based materials offering opportunities for existing supply chain businesses to provide commodity products which can be modified for cultured meat production, however some of these may impact food safety with respect to allergen labeling.

2.2 Promissory positioning of cultured meat

Nobre (2022) reflects on cultured meat as a promising clean technology and sustainable food innovation and Stephens et al. (2018) state that the technology could lead to reduced emissions, water pollution, reduced water use, and less land use, but note that existing LCA findings have mostly been based on hypothetical models. Chen et al. (2022) argue that the upscaling processes for cultured meat will require high resource input in terms of capital costs related to equipment and facilities, the cell lines and the culture media, resource input to upskilling, knowledge development and training, as well as standards and governance development and dissemination, and increased resources such as water, and energy. There is also a current knowledge gap in terms of understanding the environmental impacts, as well as other potential risks including the long-term human health implications of consuming cultured meat (Wood et al., 2023). New technologies, such as alternative protein production and cultured meat have been promoted as a way of transforming the image of the food production industry, potentially attracting younger and differently skilled people into the sector, including those with STEM expertise. Promissory narratives of 'healthier bodies' through consumption of more nutritious alternative proteins have also been prominent (Sexton et al., 2019).

As with the emergence of other technologies associated with Agriculture 4.0 such as gene editing, robotics, or artificial intelligence, there are social concerns about cultured meat relating to power, inequality and the further erosion of farmers' engagement in food systems. Responsible research and innovation (RRI) requires those designing new technologies, such as alternative protein and cultured meat to design processes and make decisions based not only on what the technology is capable of achieving, but also what the technologies should responsibly be developed and operationalized 'to do' (Owen et al., 2013). Concerns with the consequences of misuse, and who has control of the technology can influence perceptions of the technology itself (Von Schomberg, 2013). Thus, responsible innovation can be considered, through a socially constructed framing, innovation that is socially desirable and socially acceptable, in addition to complying with normative values of integrity, transparency and trust (Owen et al., 2013). Bronson (2019, p. 5) critically asserts that "social actors working in private and public contexts to shape these [technological] innovations hold a narrow set of values about [what it is to be a] good farmer, farming and good technology and their data practices privilege large-scale and commodity crop farmers." Regardless, they suggest

RRI rubrics are essential to ensure the benefits of innovations can be widely shared.

In the context of responsible innovation, Sexton and Goodman (2022) encourage engagement with the ethical, material and spatial implications of cell-cultured meat to consider what is disrupted and what is retained through the development of this technology. Recent studies have found that ‘Big Food’ has placed itself ‘front and center’ of the mission to address pressing issues facing our food production system (Clapp, 2022; Sexton and Goodman, 2022; Goodman, 2023). New technologies, such as cultured meat, are a key part of this framing and should lead us to pose the question of what food systems are for and who makes key decisions (Kneafsey et al., 2021). On these points, Treich (2021, 44) raises a concern that cultured meat could ‘significantly affect market power’ (see also Stephens et al., 2018). He notes that the meat sector is already highly concentrated in the hands of a few actors, and there has been considerable erosion of farmer control and autonomy in the food system over recent decades (Brooks, 2021; Duncan et al., 2022). New ‘alternative’ innovations could create opportunities for new businesses, but the global protein sector could also become more concentrated (Treich, 2021) with particular firms (likely in the Global North: Stephens et al., 2018) controlling supply of cultured meat products, as was operationalized for example, with GM seeds.

Alternative proteins, including cultured meat, have attracted major interest from investors and companies in Silicon Valley as a way to reinvent food (Sexton, 2020; Guthman and Biltekoff, 2021). A consequence of this reinvention is the broadening and shifting of who is involved, and who has ownership, over protein food production. New actors are being brought into the sector (e.g., Big Pharma, tech entrepreneurs and venture capital firms), while large corporations in the midstream of agricultural supply chains (e.g., processing) have greater financial and infrastructural opportunity to buy-in to cultured meat at a time when price points remain prohibitive for smaller producers as a form of ‘big corporate’ lock-in (Goodman, 2023; Hackfort, 2023). Disruption to food markets from alternative protein production in Silicon Valley has been described as lacking in transparency, leading Guthman and Biltekoff (2021) to question whether secrecy is preventing publics from ‘meaningfully’ assessing promises and potential consequences of innovation. Holmes et al. (2023) argue that instead of rushing to achieve market minimum standards needed to scale cultured meat, more work is required to target *mission-based* standards fostered on transparency and collaboration. Thus whilst there are promissory discourses and narratives associated with alternative proteins and cultured meat (Sexton et al., 2019; Painter et al., 2020), concerns over biocapitalisation and the veracity of such narratives also have been articulated (Mouat and Prince, 2018).

Efforts to understand the prospects for this emerging technology focus on commercial, scientific and regulatory developments in a small number of countries. The top five investors in the technology between 2016 and 2022 were the United States, Israel, United Kingdom, Australia, and France (GFI, 2022), although the Netherlands announced $64.6 million of total funding in 2022, which would take it to fourth place, behind the United Kingdom. These countries are also notable for other reasons: the US for attracting more than half of global investment; Israel for its supportive innovation ecosystem; the Netherlands as early scientific pioneers; Singapore for the first regulatory approval; and the United Kingdom for its emerging post-Brexit regulatory and policy environment. Businesses and investors in the sector are interested in the United Kingdom not only as the European market with the second highest (behind Sweden) rate of processed food consumption (Mertens et al., 2022), but also because the government has highlighted its approach to cultured meat in seeking to attract businesses post-Brexit as a high-efficiency, high-trust regulator (HMG, 2022). With United Kingdom agriculture policies simultaneously being reshaped and debated after exiting the EU, the technology’s implications for farming may be especially important to its development in this context.

Morais-da-Silva et al. (2022a) interviewed 35 experts (including one farmer) from the Brazilian agri-food sector about potential social impacts of changing to non-conventional food production. They identified nine social opportunities, ranging from supplying crops for cultured meat production, improved job opportunities, up-skilling, better salary and working conditions for employees, and five challenges including unemployment, the low educational level of the labor force and the high price of cultured meat products. An expansion of this study that included 136 experts, from Brazil, US and Europe found similar opportunities and that the greatest threat will likely be to animal farmers (Morais-da-Silva et al., 2022b). In Newton and Blaustein-Rejto (2021) study, 37 US agri-food sector experts (including two farmers) highlighted loss of income, especially for livestock and animal feed producers, and difficulty breaking into alternative sectors as the greatest threats for US farmers. In contrast, opportunities for farmers included supplying crops and genetic (animal) materials for cultured meat production, developing on-farm cultured meat production, transitioning to new sectors and/or increasing “value-added” to existing enterprises via higher welfare or regenerative farming.

2.3 Perceptions of cultured meat within farming communities

An important stakeholder group who could be disrupted by upscaling cultured meat production is the farming community, with potential threats including market competition and loss of control, and potential opportunities such as supplying materials for cultured meat production or benefiting from greater differentiation of extensively reared meat. As previously stated, there is little research that has explored the perceptions of cultured meat within farming communities. Research has considered farmer perceptions with regard to veganic farming in the US (Seymour and Utter, 2021), insect production with German farmers (Weinreis et al., 2023), and cultured meat with farmers in Finland (Räty et al., 2023). In the United Kingdom, Crawshaw and Piazza (2023) compared the perceptions of livestock farmers and non-farmers toward three animal-free foods and cultured meat. Although both groups agreed these products offered economic and environmental advantages, the farmers’ level of agreement was lower, they identified more barriers to production and they identified a general lack of support and vulnerability of farming communities. Shaw and Mac Con Iomaire (2019) also found that the impacts of cultured meat on farmers and agri-food businesses was of concern to Irish rural consumers. However of the consumers surveyed, approximately 10% were farmers, thus farmers’ voice remains underrepresented in this particular study.

In addition to the work reported here, there are currently several on-going studies investigating the opportunities and threats of cellular agriculture for farming communities in Canada, Europe, United States and the Global South (e.g., Aleph Farms and Federation University Australia, 2023; RESPECTfarms, 2023; University of the Fraser Valley, 2023), so it is anticipated that more data will be published on farmer perspectives of cultured meat in the coming years. Räty et al. (2023) found that farmers perceived the shift to cellular agriculture would be slow and gradual and the production systems were likely to focus on large scale, but low value meat products and questioned what options could be available for hybrid production approaches where meat production and cellular production were aligned.

Building on this existing body of work, the following section outlines our methodological approach for exploring the views of United Kingdom farmers on cultured meat.

3 Materials and methods

The research presented in this paper is an exploratory study using focus groups with farmers from the UK farming sector to determine their perceptions of cultured meat, their existing lived experience as farmers, and their perceived implications of cultured meat on their current farming systems. The study was approved by the Royal Agricultural University Research Ethics Committee.

3.1 Research design

We adopted a qualitative approach discussing multiple topics around cultured meat with farmers in focus groups. Primary data was collected through six focus groups with 75 farmers in the United Kingdom. The profiles of the groups are listed in Table 1.

A convenience sampling approach was followed for the focus groups where existing researcher networks with farmers were utilized to initially contact farmer groups with both location, sector and type of farming enterprise considered. The locations were Northern Ireland, Wales, South West England which predominantly covered the sectors of beef cattle, sheep, dairy, poultry and calf rearing, i.e., livestock producers, a national group that represented pasture fed, and organic livestock production and then the Midlands, East and East Midlands of England who were predominantly protein crops, arable and mixed farming. The questions were structured to facilitate discussion and were the same for all farmer focus groups. The first focus group (i.e., FGA) acted as a pilot group and as there were no changes to the questions or format of the facilitation after the pilot, the data was included in the analysis. The average duration of the focus group was 77 min with a range between 56 to 110 min and the data collection was during the autumn and winter of 2022. Four focus groups were face to face and two were online mainly due to travel logistics. The attendees of the focus groups did not receive any information about cultured meat prior to meeting.

3.2 Focus group protocol

After brief introductions in each focus group, the facilitator asked the farmers: *What does the term cultured meat mean to you?* There was then an open discussion and, if needed, prompts were used to explore who and/or where the farmers had heard about cultured meat. Once all participants had the opportunity to contribute, material including a brief overview of how cultured meat is produced, the key ingredients and a comparison to conventional farmed meat, was shared by the facilitator depending on the farmers' level of knowledge of cultured meat that was demonstrated with the first question. The prompts on cultured meat were a set of slides that provided details including a diagram from the literature that explained cultured meat (see Ng and Kurisawa, 2021).

The group was then asked: *What is your perception toward cultured meat now?* When no further contributions were forthcoming, the discussion moved on to the next question: *What are the potential impacts of cultured meat on farming and farming systems in the UK?* The same process was followed, with prompts from the facilitator to further explore perceived risks and opportunities. The final question was: *What potential business scenarios do you see arising for farmers and cultured meat?* The discussions then closed with farmers having the opportunity to provide any final thoughts that might have arisen during the discussions. All meetings were recorded and transcribed with the transcriptions informing the next stage of the research. All transcriptions were provided to the facilitator to check for accuracy.

TABLE 1 Farmer focus groups.

Focus group ID	Location	Sector(s)	Approach	Number of farmers	Duration (minutes)
FGA	Northern Ireland	Livestock (Beef, sheep, dairy, poultry)	Online	23	105
FGB	Wales	Livestock (Beef, sheep, dairy)	Face to face	11	65
FGC	National	Extensive livestock (Pasture/conservation grazing, organic)	Online	7	110
FGD	Midlands	Protein crop (pulses, beans etc.)	Face to face	13	66
FGE	East/E. Midlands	Arable/Mixed	Face to face	13	62
FGF	South West	Livestock (Dairy, beef, calf rearing)	Face to face	8	56
Total				75	

3.3 Data analysis

This approach followed the work of Braun and Clarke (2021), namely (1) transcripts from all focus groups were read multiple times to ensure data familiarization; (2) systematic data coding with an open content coding approach using Nvivo version 12; (3) the generation of initial themes from the coded data; (4) the development and reviewing themes; (5) refining, defining and naming themes; and (6) writing the analysis. This process iteratively identified themes and categories and the abductive aspects of the process enabled new meanings and interpretations to be explored. As new codes and themes emerged the axial coding drew the open codes together thematically providing analytical interpretations of individual responses, focus groups and as a farming community (Creswell, 2012). A reflexive thematic approach was used, whereby the coding was open and organic, and the themes were the final 'outcome' of data coding and iterative theme development (Braun and Clarke, 2021). This enabled the drawing of conclusions for each of the research questions from the data in the empirical study.

4 Results

Three core narrative themes—and their embedded counter-narratives—arose from the focus group conversations: (1) ethical and affective narratives, (2) environmental narratives, and (3) socioeconomic narratives. All three themes capture the existing ideas the farmers had about cultured meat, including what they had heard about the technology in public discourse prior to the study (e.g., from news media, company narratives, personal social networks) and how they viewed the technology in relation to traditional farming methods. They also capture the range of perceived opportunities and threats of cultured meat to their livelihoods and to broader society.

In this section we provide exemplar quotes for each theme, before turning to a more in-depth analysis of the findings in the Discussion. We have separated the themes in this section for analytical purposes, but acknowledge their overlaps, an outcome of the way conversations unfolded and were co-developed during the focus group setting. Due to this, it has not been possible to attribute all the quotes to individual farmers. Thus, the unit of analysis is primarily at the focus group level. The perceptions derived from the data are differentiated by sector where possible, but only at the level of livestock or non-livestock farmers as the non-representative nature of the sample population means further depth of analysis was difficult.

4.1 Ethical and affective narratives: motivations, power, and 'Americanization'

The focus groups began with the question: *what does the term cultured meat mean to you?* Most of the participating farmers had heard of cultured meat before the study, and had a variety of existing opinions and questions on the subject. One farmer understood the technology as "meat effectively grown in a laboratory" (*FGA, Northern Ireland, Livestock*). This sparked a discussion about technical aspects, including the nutritional makeup of cultured meat products and the feasibility of building the sensory and experiential qualities of 'meat' via cell culture:

> "I don't understand how that achieves the texture and the flavor and the nutrient density or variety, because there's so much in food that we don't think about. There are hundreds and hundreds of chemicals that all contribute to the value of that food. It's not just about protein and fat and carbohydrate, there's lots of other stuff going on in there, and I don't know how that can be replicated and how it can achieve a product that would give people the sort of food that they actually want to eat." (FGA, Northern Ireland, Livestock)

This discussion led to a number of affective responses amongst the farmers toward cultured meat. They used a range of negative language including about the product itself (Frankenstein food, toxicity), and the business processes in which it would be brought to market and remain in the market (cheap, dictate, greed, horrendous, scary). As two farmers commented:

> "Those people aren't going to eat that stuff either. That's a Frankenstein food. What they're trying to create there is like something I'd be trying to wash out of a shed and throw disinfectant on it to try and kill it. No, definitely not." (FGA, Northern Ireland, Livestock)

> "I disagree with it, basically because there'll probably be more additives and more carbon footprint and more toxicity than the natural beef and lamb that we […] are producing" (FGA, Northern Ireland, Livestock)

One farmer who did have more knowledge of alternative protein production, in this case plant-based protein, suggested that the cultured meat production process seemed "a bit weird":

> "It's not like… like recreating something which looks, tastes and smells like meat with a vegetable-based product. Instead it's… actually taking live animal cells and replicating it […] and growing it. And so, in a sense, it still is like flesh and meat in the same sense…it's a bit weird that part of our food chain would be coming from a lab, as opposed to, how we've always known it forever." (FGD, Midlands, Protein Crop)

In contrast, a broadacre arable crop farmer was less disgusted by the 'laboratory' origins of cultured meat,[2] and was open to the prospective benefits this approach could bring for those currently facing food insecurity:

> "I don't know enough about its nutritional makeup, but if it does provide protein and nutrients to a population that can't afford to buy meat, then I think that that could be a good thing." (FGE, East/E. Midlands, Arable/Mixed)

Concerns over power, inequality, control of the food production systems, and IP issues were also discussed (see also Räty et al., 2023). Firstly, concerns were raised about the motivations of the companies

2 See Section 5 for discussion of how the term 'lab-grown' was used during the focus groups.

involved in cultured meat production, the way in which their technological solutions were being framed, and who would most likely benefit in the short and medium terms:

> "I think it's going to be produced for the wrong reason. It's not for the health, it's not for the betterment of the environment." (FGA, Northern Ireland, Livestock)
>
> "I'm experienced enough and old enough not to completely discount it, particularly because there's an awful lot of… of finance being put behind it and some very influential individuals attempting to talk it up as a technology for the future." (FGC, National, Extensive Livestock)
>
> "It's just about profitability for shareholders and, you know, it is competing. It is taking up shelf space, so it is competing against products, but to me…it's really only for the benefit of shareholders." (FGA, Northern Ireland, Livestock)

Secondly, worries were raised over IP and corporate lock-in of the food system:

> "I do wonder if [with] the production of more…cultured protein there are going to be much larger companies that are going to…be pushing for this and they will own the intellectual property, they will own the rights to that, they will own the formulations, and that's something which reinforces a sort of a hegemonic position. If you're interested in agroecology…regenerative farming you're interested in small scale farms, I'm not quite sure where that leaves those farmers." (FGE, East/E. Midlands, Arable/Mixed)

The farmers considered and shared thoughts on the likelihood of unequal benefit across the supply chain where existing power dynamics would continue in a 'business-as-usual' model for cultured meat. Across the focus groups, there was an underlying theme of concentration of power and control within food production, and the US influence or "Americanization" of United Kingdom food production:

> "Then the American influence…. the corn syrup element of putting all of that into food and making [it] tastier…And as a result, it's not fat that's made us fat, it's sugars that's made us fat, but we've then lost like the vitamins and nutrients and everything from a more plant based active diet." (FGD, Midlands, Protein Crops)
>
> "…once you have signed up to [a CM system] that's it, there's kind of no going back because you have lost, you know, you have lost all your pasture land and you do not have animals, you have lost your stock, you have lost your breeding opportunities and you are in the hands of corporations that then can charge you what they will. So I think it's a bit worrying really." (FGD, Midlands, Protein Crops).

Concerns over the cultured meat industry's lack of transparency were also shared, with one participant describing it as being *"shrouded in secrecy" (FGC, National, Extensive Livestock)*. Another farmer felt that "*There's so much money being thrown at it [cultured meat] that we [farming community] cannot afford to ignore it,*" but that too many questions were not being answered by the industry. Some of the uncertainties they highlighted included what the waste products might include and where inputs would be sourced, and they concluded that "*we should be pinning them down on that now and saying look… you are now telling us this is the future, you cannot keep hiding behind commercial confidentiality of your process. You've gotta tell us what… what it means in terms of its inputs and its outputs," (FGC, National, Extensive Livestock).*

There were several conversations across the focus groups about how the food system is currently organized, and whether cultured meat could be a catalyst for positive change, or rather entrenchment of what the participants saw as existing systemic problems. Questions were raised about how cultured meat and other alternative proteins might fit into shortening supply chains and more localized food, as opposed to the corporate centralized model of food production – the latter of which was largely seen as undesirable by the participants. The farmers also saw cultured meat as an unwelcome extension of the increasing monetization of carbon and natural capital in and/or through agriculture.

A further negative impact on farmers' lives highlighted by some participants was the potential for land grabbing – i.e. the mass purchase of land previously used for livestock production by wealthy private landowners, possibly from overseas – and the risk of rural spaces becoming increasingly inaccessible and monetized in ways that may not provide environmental, cultural or socioeconomic benefits at local or national scales:

> *"And so we'd be checking all that lot out if… if we sort of went down the rewilding strategy, but I think redacted [is] just being desperately naive to think that because we do not need the land for food production the only sensible use for it will be to hand it back to nature, and he's completely oblivious to the fact that there will be lots of other very powerful, very wealthy interests that would love to have that land to do something that would be much more remunerative, much more profitable." (FGC, National, Extensive Livestock)*
>
> "With the price of land where it is at the moment, I think it will go one way and become more of an insular industry where it will be run by less and less people because people will give up and the next generation can't afford to take it on." (FGF, South West, Livestock)

In terms of ethical impacts on animals, the current use of animals to derive input materials for cultured meat was perceived to have negative ethical dimensions:

> "We still need cows to have cultured meat because the big ethical issue with the cultured meat is that you have to extract the cells from calf embryos to…to grow the cultured meat in the first place. So that's a really big ethical question there." (FGE, East/E. Midlands, Arable/Mixed)

However, one farmer thought cultured meat offered an opportunity to end the unethical factory-farming of animals:

> "I thought that can't be a bad thing if it were to displace all the factory farm meat which clearly represents the bulk of the meat that people in this country are eating…my guess would be that a lot of the factory farmed stuff isn't that good quality anyway, because the way it's reared." (FGC, National, Extensive Livestock)

4.2 Environment-based narratives: LCAs, land use change and a lack of data

Farmers in the study were open to considering the potential opportunities offered by cultured meat. As a big-picture discussion point, farmers discussed the systemic challenges facing food production (e.g., population, environment, food waste) and tended to agree that 'game-changers' would be needed, though this term was not exclusively associated with technological solutions:

> "What we do know is that we're all doomed unless we find some game changers. I don't think even our pastured movement, I don't think regenerative agriculture is going to save us, we're still fiddling at the edges." (FGC, National, Extensive Livestock)
>
> "We need some big game changes in the next 20 years. So we need to be open and not biased about such things, and I fear we are being biased tonight, obviously because of our backgrounds, our passions, our day jobs, our careers, our culture." FGC (National, Extensive Livestock)

As for whether cultured meat could be an environmental 'game-changer', views were mainly negative. Farmers in one group wondered, for example, whether a move to regenerative livestock systems would be more effective:

> "So, how much better is [cultured meat] than, say, like a regenerative, holistic system where we have animals in nature … in harmony with the land and we're using byproducts and getting meat and having a land-based diet that we are meant to eat rather than a processed factory created nutritional supplement effectively?" (FGD, Midlands, Protein Crop)

Others were skeptical about whether cultured meat is any better for the environment than current products:

> "That's the concern we have for cultured meat is that it's going to be produced by a factory process demanding huge amounts of energy and other inputs, and then it will be marketed as a green source of product, which it's highly likely not to be." (FGA, Northern Ireland, Livestock)

These discussions fed back into the theme raised in the previous section regarding the lack of information on which to base informed views. Environmental aspects of cultured meat that were discussed by the farmers included questions about the environmental impact, the carbon footprint and LCAs:

> "Has anybody looked at the environmental impact that the carbon […] the environmental footprint compared with conventional livestock rearing?" (FGC, National, Extensive Livestock)

> "Livestock farming and arable farming are not separate entities. So if you're going to have land dedicated towards arable as a feedstock into [cultured meat], then given the carbon cost of fertilizers etc. and [the UK's reliance on] importing them, [to redress environmental impacts] you will be relying on livestock producers for those inputs into the arable system, so this is back to that old world of mixed farming perhaps?" (FGC, National, Extensive Livestock)

As well as concerns over cultured meat leading to agricultural land-grabbing, as highlighted above, several farmers noted the risk of land and resources currently being used for livestock farming simply being abandoned in this transition. Participants shared concerns that this could have a negative impact on the land if there was no vision for managing that transition well:

> "[It's a] bit like the vicar went down past the garden when he said to the gardener, "Oh what a wonderful garden you've got […] look how God's hands have helped you". He [gardener] goes "Yeah … you should've seen what it looked like when he did it on his own". And that's what's gonna happen with the countryside. So we have got to be careful. It will be left, our lovely green countryside will go to rack and ruin." (FGF, South West, Livestock)

The issues raised by livestock farmers across this theme echo those identified in the literature as to whether the net environmental benefit of cultured meat would be positive (e.g., Tuomisto and Teixeira de Mattos, 2011; Stephens et al., 2018; Nobre, 2022), whilst others have raised important doubts (e.g., Chen et al., 2022). Farmers recognized the environmental challenges facing the sector, but noted that there are likely to be both technological and systems-based solutions to these challenges.

4.3 Socio-economic narratives: markets, communities and farmer identities

Unsurprisingly, farmers reflected on the socio-economic impacts of cultured meat on their businesses, on the farming sector and on broader society. Again, farmers were open to considering both opportunities and threats offered by cultured meat. Discussions were held about the unsustainable disconnect between communities and existing forms of food production and a criticism of specialization, as well as the system-wide dependence on chemical fertilizers. The important role of 'nature' in delivering healthy diets was also raised:

> "The balanced diet comes from balanced farming and that is part of the agriculture's problem - we've become so specialized because of the drive for labor shortage and no margin, that we really have lost that balanced farm where you would have ploughed an odd field, fed the crop back to your own cattle and everything else." (FGA, Northern Ireland, Livestock)
>
> "I think the biggest disconnect that most people don't understand is that the fertility for the soil comes out the back [end] of an animal, but if you don't want that animal you can't have it in terms of the soil, so you're degrading the soil[…] we've all realized after

> sixty years of chemical fertilizers that actually animals are good on the land." (FGE, East/E. Midlands, Arable/Mixed)

> "I feel like food is a real connection to nature, it's our… people… are already a bit disconnected, we're disconnecting even more and we want to reconnect more… we need nature not just for nutrition but for our, like, souls." (FGD, Midlands, Protein Crop)

The positioning of cultured meat on the market was also discussed, specifically whether it would replace cheaper forms of meat or would be seen as a niche, expensive product (Sexton and Goodman, 2022). Participants discussed how the economic positioning of cultured meat and the value proposition would influence them in different ways, proving both a threat and an opportunity. For example, there could be opportunities for traditionally-produced meat as an alternative to factory-produced cultured meat, although this 'natural' meat may not be financially accessible to all. When describing current methods of production, farmers used words such as 'natural', 'proper', and 'the real stuff':

> "Depends which market they're aiming at? Is it the mincemeat, the cheap end of the market or are they aiming at the steak end of the market? And my first impression is they're probably aiming for that lower end of the market, which means that maybe West Country, grass-fed systems might come [out] a little bit better" (FGF, South West, Livestock)

When discussing perceived threats of cultured meat to farmers, a primary focal point was the loss of existing livestock farming communities, especially in areas of the United Kingdom where the most viable food production option is meat production. As one farmer expressed:

> "It would change the face of farming … especially livestock farming." (FGB, Wales, Livestock)

The threat was considered to be primarily for non-ruminant meat production which was viewed as more easily substituted. Thinking through these large-scale transition scenarios, the farmers considered the potential outcome of mass culling of livestock if they were no longer needed, and the loss of rural employment this would create if meat production switched to factories rather than on farm.

The substitution of meat production with alternatives like cultured meat was also considered more likely to occur in other parts of the world, such as the US or China, where the meat industry is dominated by large-scale livestock facilities and the outputs largely service the processed foods sector. When discussing the global picture of this new industry, the role of food regulation was also raised as an important driver of *where* in the world cultured meat production may develop first. The farmers expressed concerns that the cultured meat industry may seek markets in parts of the world with fewer or less stringent regulations, and/or a lack of existing regulatory frameworks that can apply to cultured meat (a trend that is arguably already happening), and thereby pose a threat to higher welfare farming in places like the United Kingdom, both in terms of price and its marketing as a greener product:

> "We produce hormone-free beef here and in Europe and the reason for that was because of the perceived implications for consumers, and that's the concern we have for cultured meat is that it's going to be produced by a factory process demanding huge amounts of energy and other inputs, and then it will be marketed as a green source of product, which it's highly likely not to be." (FGA, Northern Ireland, Livestock)

While livestock farmers were considered at greatest risk, the discussions highlighted possible opportunities for arable farmers:

> "[I]t's likely to prove an opportunity for arable agriculture, because it will provide them with another market for some of their products in terms of supplying the inputs to the system and we've already said several times that, you know, that there are nutritional inputs to cultured meats, but no one yet is saying where they're coming from and what those inputs are. They've got to come from somewhere…. I think the opportunity is very much in terms of broad scale crop agriculture as supplying inputs to it and very much against the…interests of the vast majority of grassland agriculture in the UK" (FGC, National, Extensive Livestock)

> "As a local food distributor and mixed farmer, I consider it to be a threat, but as an arable farmer, I think that there are opportunistic elements and I think it's important not to deny the existence of the technology, because without the technology there's no progress and it may not end up in the format that it ends up in, it might be something completely different." (FGE, East/E. Midlands, Arable/Mixed)

However, the participants voiced uncertainty about what a transition away from livestock farming could mean for the arable sector, both in terms of livestock's current role in servicing broadacre crops (e.g., via fertilizer/manure) and for the production of other byproducts, such as leather and soap, and whether this may lead to an increased reliance on fossil fuel-based alternatives:

> If you're going down the synthetic routes on food, there's an awful long chain of other synthetic things you're going to have to produce […] leather, soap … the list is endless, isn't it? So not only are you going to have to synthetically produce food, you have to synthetically produce a lot of things. (FGB, Wales, Livestock)

Some farmers were concerned about the potential change in emphasis for livestock if they were reimagined solely as the providers of inputs into cultured meat production. For one participant, the idea evoked a disturbing vision of a future with drastically diminished numbers of livestock animals and smaller-scale food producers:

> "We have a situation, say in 100 years time where food is produced, animals are only kept on a few reserves that are there for cell culture and the future big conglomerates set up huge factories to produce foodstuffs." (FGA, Northern Ireland, Livestock)

Farmers also considered how a possible future of animal-free farmland in the UK, and the loss of cultural heritage and knowledge systems bound up in livestock farming that would accompany this transition, would affect the wellbeing of farmers. This was a particularly emotive topic for the group, and for one participant brought to mind previous events that had threatened the future of farmers' livelihoods and businesses:

> "… and we are going to lose a lot of species and … and knowledge and experience through that… [becomes emotional] and I was involved with the foot and mouth and it was heartbreaking to see the farmers in absolute tears, losing generations of their families' stock. I'm very mindful of what you're saying… we're dealing with trying to feed, you know, our nation and lots of other nations and the globe, but I've just got this feeling that those factories would end up in other countries, far away from us and then we'll be shipping back-and-forth, back-and-forth and where does that actually get us?" (FGD, Midlands, Protein Crop)

On the other hand, others said they would be happy to provide the materials for cultured meat and mentioned possible business models for how such transactions could work: "*If they want to contract animal cells, I'll sell them … There's an opportunity (FGB, Wales, Livestock).*

5 Discussion

The findings of the focus groups represent a rich discourse expressed by the farmers, with complex and considered reflections about the perceptions, concerns and opportunities they associated with cultured meat. We identified three distinct themes from the conversations, noting first the affective reactions that the participants had toward the idea of cultured meat. As other public focus group work on this topic has similarly observed (e.g., Van der Weele and Driessen 2013), initial responses to cultured meat amongst the participants tended toward the negative and skeptical. Doubts were raised about the technical feasibility of cell culture methods replicating the organoleptic experience and nutritional makeup of 'real' meat (Sexton 2016). The perceived 'laboratory origins' of cultured meat elicited some of the strongest negative affective narratives from the participants, and fed into the general concerns over the increasing disconnection from, and corporate ownership over, contemporary food production. To note, the term 'lab-grown' was not used by the research team during the focus groups to describe cultured meat, and the likelihood that future large-scale production would occur in brewery-like factories rather than scientific laboratories was also highlighted. Despite this, it is interesting that the farmers referred to the 'lab' on numerous occasions when trying to make sense of the technology, an outcome most likely due to the persistence of the term in news media over the last decade (Broad, 2020; Painter et al., 2020).

The farmers' affective responses were closely linked with discussions of the ethical implications of cultured meat development, with concerns raised over the actors and business models currently driving this new industry. There was particular skepticism over the motivations and lack of transparency (see Wood et al., 2023) from cultured meat companies. This led many of the participants to worry that cultured meat will lead to further concentration of power within food systems. Indeed, this trajectory is arguably already happening, as regular headlines of cultured meat companies show continued partnerships with agrifood and pharmaceutical conglomerates (e.g., Dutch cultured meat company Mosa Meat partnering with Merck Group and Bell Food Group). Guthman and Biltekoff (2021) argue that corporate secrecy is preventing meaningful engagement by different publics on the subject of cultured meat and Holmes et al. (2023) have called for more transparency and collaboration in the alternative protein space.

Powerful corporations can act like chameleons, framing their technology in line with pressing, but often short-term, societal solutions masking other motivations (Reisman, 2021). This form of greenwashing risks a halo effect of continued profiteering by a handful of large corporations with very little change to the destructive practices of business-as-usual. This study illustrates that no technology, including cultured meat, can be responsibly developed without also acknowledging and addressing the power imbalances that characterize modern food systems and the actors and institutions within it. One opportunity to address this power imbalance is to strive for a multi-voiced vision for food and farming. Such a vision would identify what and who cultured meat and related technologies are for, how they work, who controls them, and who has the power to decide their trajectories – all of which is currently lacking from contemporary discussion of the future of food systems (Sexton, 2020; Holmes et al., 2023). Importantly, due to the context-specific nature of agricultural sustainability transitions (de Boon et al., 2022), these visions may need to be contextualized in the different places and socio-economic circumstances in which they appear.

An interesting and perhaps novel aspect of our findings is that the farmers did not unanimously dismiss the consideration of opportunities offered by new technologies like cultured meat. The majority of participants agreed that big, system-level change in food production was needed to secure a more sustainable and healthy future. While some saw hope in movements from within their own industry – e.g. regenerative agriculture – others shared doubts that such approaches were simply "fiddling at the edges." Cultured meat was viewed as a potential "game-changing" technology that could create cheaper meat products for populations with limited access to affordable and bioavailable forms of protein, with traditional farming either supplying inputs and/or continuing to service niche markets for consumers who still wanted higher-priced, traditionally-reared 'real' meat products.

Yet while acknowledging these potential wins, the farmers were less certain that all types of traditional farming business would be able to survive this technological transition. Livestock farming was viewed as the most at risk. A few livestock farmers were open to the potential business opportunities of supplying the cultured meat industry, including licensing cells from their animals. The greatest opportunities were seen for arable farming, which the participants believed could pivot more easily toward providing cultured meat inputs than livestock farming. For one of the farmers, cultured meat represented both a threat and opportunity to different parts of their business, with their smaller-scale mixed farming operations more at risk than their arable business. This particular comment highlighted that technological transitions are rarely binary, and that, at least in these focus groups, the farmers were keen to think through the nuances of how cultured meat may fit into their existing business models. These findings mirror those from other studies that have considered how different types of farm business may be better placed than others to redirect and/or diversify their current practices toward cultured meat (Newton and Blaustein-Rejto, 2021; Morais-da-Silva et al., 2022b). It was generally agreed among the participants of this study that larger-scale, single-output farms would have a greater early advantage in this transition than smaller-scale, mixed farms.

Linked to the discussion of *who* in traditional farming may come to benefit or not from a transition to cultured meat, the farmers raised concerns over the potential for widespread loss of rural employment, change in rural communities and impact on farmer wellbeing. The future of the United Kingdom countryside was also deemed at risk – both environmentally and in terms of the socioeconomic fabric of rural areas – without sufficient policies in place for managing change in use of former agricultural land. Some in the cultured meat community have imagined much of this land could be used for carbon sequestration and rewilding projects (Verschuuren, 2023).

Doubts were expressed, however, amongst the farmers about the aesthetic and ecological outcomes of rewilding large swathes of United Kingdom countryside. Such responses mirror ongoing tensions amongst rural communities in the United Kingdom on this subject which often evoke emotive responses about what the United Kingdom countryside *should* look like, and what function (e.g., conservation/food production/recreation) it should serve (Mikołajczak et al., 2022). Whether rewilded or not, this particular discussion point highlights the urgent need for rural management plans to be put in place that will ensure any change in land use from traditional to cellular agriculture does not lead to degraded and/or worse sustainability and socioeconomic outcomes.

Collectively, our findings highlight farmers as an important stakeholder group amongst the impacted 'publics' of cultured meat (Guthman and Biltekoff, 2021). The study also reveals the complexity with which the farmers engaged with the subject of cultured meat and its potential impacts. While many of the participants did express negative and skeptical views about the technology, they were also eager to engage with and learn more about the nuances of what a cultured meat transition might mean for them, and for society more broadly. This outcome emphasizes the point that many farmers, as entrepreneurs and business owners, are open to considering the prospects of new technologies like cultured meat, and that their concerns should not be simply dismissed as reactionary and uninformed.

Finally, among the many points the participants raised, a core concern was the lack of opportunity for them to engage with the cultured meat industry in the early stages of its technological development, and that access to information to inform both their opinions and prospective options as business owners was significantly limited. The lack of public data on the environmental footprint of cultured meat production systems was cited as a particular challenge for farmers trying to assess whether the technology offers a more sustainable pathway for their business. Uncertainty over regulations, as well as international cultured meat products undercutting UK farming on price and production standards, were also major concerns of the participants. These points reinforce our recommendation for a multi-voiced vision of food, farming and food systems and an inclusive governance process that facilitates an equitable and just transition to sustainability (de Boon et al., 2022). We outline our recommendations, as well as avenues for future work, in the next and final section of the paper.

6 Conclusion

Cultured meat is a potential technological solution that could form part of future sustainable agricultural transitions. However, for the technology to deliver on its environmental, social and ethical promises, key stakeholders need to be substantively included in decision-making about its future trajectories – a key tenet of responsible innovation (Stilgoe et al., 2013; Rose and Chilvers, 2018; Klerkx and Rose, 2020; de Boon et al., 2022). Owen et al. (2013) argue that to innovate responsibly, i.e., with care and responsiveness, the process must also be *anticipatory* (anticipating impacts and consequences), *reflective* (on purposes of innovation and the values that are anchored into it), *inclusively deliberative* (collectively discussing impacts of innovation, identifying and addressing nuances, areas of conflict and contestation and the trade-offs that arise) and *responsive* (thereby to multi-stakeholder needs and concerns).

Given the range of potential impacts cultured meat poses to traditional farming, we highlight farmers as a crucial and critical key stakeholder group that should have greater inclusion in both the decision-making and technological development of cultured meat. With the core tenets of responsible innovation in mind, potential avenues for progressing this could include involving farmers or farm advisors in reviewing public sector innovation funding applications, or making diverse and inclusive partnerships a condition of public funding, facilitating deliberative dialog with farmers and other farming stakeholders using methods which substantively include participants. Firstly, efforts should be made to include 'harder-to-reach' farmers in dialog by making practical efforts to hold engagement activities in diverse formats, at accessible times of the day and farming calendars, and in accessible places (e.g., online, in-person [e.g. events on-farm]). Secondly, feeding back to farming participants about how their views have influenced decision-making is crucial. Lastly, deciding on the set of methods to enable substantive inclusion, whether through the use of well-facilitated deliberative workshops, on-farm discussion groups, 'listening-in' to existing conversations in farming forums and on social media, or other approaches is crucial (Rose and Chilvers, 2018). We would also encourage greater dialog between the cultured meat industry and other stakeholder groups from agri-food industry, such as workers in abbatoirs and meat processing, to similarly explore areas of opportunity, concern and uncertainty amongst other impacted publics.

As well as greater inclusion of key stakeholders, responsible innovation in food systems also requires *critical debate* on both the opportunities and threats a technology like cultured meat presents to different stakeholder groups (Rose and Chilvers, 2018). Indeed, Von Schomberg (2013) argues that effective governance of innovation must encompass multi-stakeholder involvement to scope the development and application of a technology, and to develop specific binding legislation or voluntary codes of conduct, standards, certification and self-regulation. This is just one specific area in need of further work – e.g. policy and/or legal frameworks to sustainably and equitably manage agricultural land use change – with many more also requiring further consideration. These include, but are not limited to: schemes to support the reskilling of farmers in relevant aspects of cultured meat production; legislation to ensure a level playing field of food and marketing standards across traditional and cell-cultured meat production; and frameworks for supporting knowledge sharing, open science and equitable commercial collaborations between farmers and cultured meat businesses. Economic and mental health supports should also be developed for farmers displaced by cultured meat advancement. Finally, there is considerable scope for social scientists to further explore the potential impacts of cultured meat development at the scale of rural communities and landscapes.

Potential limitations

The limitations of this study are the convenience based sampling method that was employed which means that this study can only be exploratory and does not have powers of generalization. This means that the quotes used are exemplars and can only be considered on that basis.

Data availability statement

The datasets presented in this article are not readily available because restrictions apply to the data which was collected under the understanding that information would be held securely by us, following GDPR regulations. Requests to access the datasets should be directed to the corresponding author, john.dooley@rau.ac.uk.

Ethics statement

The studies involving humans were approved by the Royal Agricultural University Ethics Committee. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

LM: Formal analysis, Investigation, Writing – original draft, Writing – review & editing. JJD: Data curation, Investigation, Project administration, Writing – review & editing, Formal analysis. ID: Conceptualization, Funding acquisition, Writing – review & editing. MKG: Writing – review & editing. TCM: Conceptualization, Funding acquisition, Project administration, Visualization, Writing – review & editing. LCM: Investigation, Writing – review & editing, Formal analysis. DCR: Writing – original draft, Writing – review & editing. AES: Conceptualization, Funding acquisition, Writing – review & editing.

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Conflict of interest

ID is CEO and co-founder of Cellular Agriculture Ltd.

The remaining 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.

Publisher's note

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