Frontiers in Sustainable Food Systems

TYPE Perspective
PUBLISHED 16 June 2023
DOI 10.3389/fsufs.2023.1134100

Check for updates

OPEN ACCESS

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

RECEIVED 29 December 2022
ACCEPTED 16 May 2023
PUBLISHED 16 June 2023

CITATION
Rao VV, Datta B and Steinmetz K (2023) The role of natural scientists in navigating the social implications of cellular agriculture: insights from an interdisciplinary workshop.
Front. Sustain. Food Syst. 7:1134100.
doi: 10.3389/fsufs.2023.1134100

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.

Funding

KS was supported by a New Harvest Fellowship award and VR and BD were supported by New Harvest Dissertation Awards. New Harvest is a donor-funded 501(c)(3) research institute working to maximize the positive impact of cellular agriculture. Open access publication fees for this article were covered by by Arrell Food Institute at the University of Guelph.

Acknowledgments

We would sincerely like to thank all the organizers and participants of the workshop, including members of the Food and Agriculture Institute, the University of the Fraser Valley, Arrell Food Institute, New Harvest, and Cellular Agriculture Canada. We would also like to thank Isha Datar, Yadira Tejada-Saldana, and Evan Bowness for helpful discussions and edits.

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

AAAS home. Available at: http://www.aaas.org.

Batchelor, R. L., Ali, H., Gardner-Vandy, K. G., Gold, A. U., MacKinnon, J. A., and Asher, P. M. (2021). Reimagining STEM workforce development as a braided river. *Eos* 102. doi: 10.1029/2021eo157277

Benevolenza, M. A., and DeRigne, L. (2019). The impact of climate change and natural disasters on vulnerable populations: a systematic review of literature. *J. Hum. Behav. Soc. Environ.* 29, 266–281. doi: 10.1080/10911359.2018.1527739

Bhat, Z. F., Kumar, S., and Fayaz, H. (2015). In vitro meat production: challenges and benefits over conventional meat production. *J. Integr. Agric.* 14, 241–248. doi: 10.1016/S2095-3119(14)60887-X

Broad, G. M., and Chiles, R. M. (2022). Thick and thin food justice approaches in the evaluation of cellular agriculture. *Nat. Food* 3, 795–797. doi: 10.1038/s43016-022-00603-x

Burke, M. J., and Stephens, J. C. (2017). Energy democracy: goals and policy instruments for sociotechnical transitions. *Energy Res. Soc. Sci.* 33, 35–48. doi: 10.1016/j.erss.2017.09.024

Byrd, E. Tyson invests in UPSIDE foods. Available at: https://gfi.org/blog/tyson-invests-in-memphis-meats/.

Carlson, K. *You are asked to witness: the Stó:lō in Canada's Pacific coast history*. Vancouver, BC: Langara College. (2008)

Cellular Agriculture Investment Report (2021). Available at: https://www.cell.ag/cellagri-investment-report.

Claw, K. G., Anderson, M. Z., Begay, R. L., Tsosie, K. S., Fox, K., and Garrison, N. A. (2018). Summer internship for indigenous peoples in genomics (SING) consortium. A framework for enhancing ethical genomic research with indigenous communities. *Nat. Commun.* 9:2957. doi: 10.1038/s41467-018-05188-3

Cusack, D. F., Axsen, J., Shwom, R., Hartzell-Nichols, L., White, S., and Mackey, K. R. M. (2014). An interdisciplinary assessment of climate engineering strategies. *Front. Ecol. Environ.* 12, 280–287. doi: 10.1890/130030

Daño, EC. *Potential socio-economic, cultural and ethical impacts of GMOs: prospects for socio-economic impact assessment*. Penang: Third World Network (2007).

Datta, B., Spero, E. F., Martin-Martinez, F. J., and Ortiz, C. (2022). Socially-directed development of materials for structural color. *Adv. Mater.* 34:2100939. doi: 10.1002/adma.202100939

Dohmen, R. G. J., Hubalek, S., Melke, J., Messmer, T., Cantoni, F., Mei, A., et al. (2022). Muscle-derived fibro-adipogenic progenitor cells for production of cultured bovine adipose tissue. *NPJ Sci. Food.* 6:6. doi: 10.1038/s41538-021-00122-2

Dutkiewicz, J, and Rosenberg, GN. (2021). Man v food: is lab-grown meat really going to solve our nasty agriculture problem? Available at: https://www.theguardian.com/news/2021/jul/29/lab-grown-meat-factory-farms-industrial-agriculture-animals.

El-Sayed, S., and Cloutier, S. (2022). Weaving disciplines to conceptualize a regenerative food system. *J. Agric. Food Syst. Commun. Dev.* 11, 1–29. doi: 10.5304/jafscd.2022.112.003

Fassler, J. (2023). Lab-grown meat has a bigger problem than the lab. Available at: https://www.bloomberg.com/news/features/2023-02-07/lab-grown-meat-has-bigger-challenges-than-the-fda.

Fassler, J. Lab-grown meat is supposed to be inevitable. The science tells a different story. Available at: https://thecounter.org/lab-grown-cultivated-meat-cost-at-scale/.

Fischer, K., Ekener-Petersen, E., Rydhmer, L., and Björnberg, K. (2015). Social impacts of GM crops in agriculture: a systematic literature review. *Sustainability* 7, 8598–8620. doi: 10.3390/su7078598

Food Security (n.d.). Available at: https://www.ipcc.ch/srccl/chapter/chapter-5/.

Framework for Responsible Research and Innovation (n.d.). Available at: https://www.ukri.org/about-us/epsrc/our-policies-and-standards/framework-for-responsible-innovation/

Funk, C. 3. Public opinion about genetically modified foods and trust in scientists connected with these foods. Available at: https://www.pewresearch.org/science/2016/12/01/public-opinion-about-genetically-modified-foods-and-trust-in-scientists-connected-with-these-foods/.

Genetic Researcher Uses Nuu-chah-nulth Blood for Unapproved Studies in Genetic Anthropology. Available at: https://www.hashilthsa.com/news/2013-07-22/genetic-researcher-uses-nuu-chah-nulth-blood-unapproved-studies-genetic.

Gentemann, C. (2023). Why NASA and federal agencies are declaring this the year of open science. *Nature* 613:217. doi: 10.1038/d41586-023-00019-y

Godfray, H. C. J., Aveyard, P., Garnett, T., Hall, J. W., Key, T. J., Lorimer, J., et al. (2018). Meat consumption, health, and the environment. *Science* 361:eaam5324. doi: 10.1126/science.aam5324

Harmon, A. (2010). Indian tribe wins fight to limit research of its DNA. Available at: https://www.nytimes.com/2010/04/22/us/22dna.html.

Harsh, M., Bernstein, M. J., Wetmore, J., Cozzens, S., Woodson, T., and Castillo, R. (2017). Preparing engineers for the challenges of community engagement. *Eur. J. Eng. Educ.* 42, 1154–1173. doi: 10.1080/03043797.2016.1270902

Holmes, D., Humbird, D., Dutkiewicz, J., Tejeda-Saldana, Y., Duffy, B., and Datar, I. (2022). Cultured meat needs a race to mission not a race to market. *Nat. Food* 3, 785–787. doi: 10.1038/s43016-022-00586-9

Hoolohan, C., Larkin, A., McLachlan, C., Falconer, R., Soutar, I., Suckling, J., et al. (2018). Engaging stakeholders in research to address water–energy–food (WEF) nexus challenges. *Sustain. Sci.* 13, 1415–1426. doi: 10.1007/s11625-018-0552-7

Howard, P. H. (2022). Cellular agriculture will reinforce power asymmetries in food systems. *Nat. Food* 3, 798–800. doi: 10.1038/s43016-022-00609-5

Humbird, D. (2021). Scale-up economics for cultured meat. *Biotechnol. Bioeng.* 118, 3239–3250. doi: 10.1002/bit.27848

Jenkins, K. E. H., Stephens, J. C., Reames, T. G., and Hernández, D. (2020). Towards impactful energy justice research: transforming the power of academic engagement. *Energy Res. Soc. Sci.* 67:101510. doi: 10.1016/j.erss.2020.101510

Kateman, B. The meat you eat is already fake. Available at: https://www.fastcompany.com/90808821/the-meat-you-already-eat-is-fake

Khan, A. (n.d.). Cellular agriculture and the Monsanto lesson – CellAgri – medium. Available at: https://medium.com/cellagri/cellular-agriculture-and-the-monsanto-lesson-a18aa6c29e0.

Kimmerer, R. *Braiding sweetgrass: indigenous wisdom, scientific knowledge and the teachings of plants*. Minneapolis: Milkweed Editions. (2013).

KLF Tools. (2015) A practical guide to responsible research and innovation. Available at: https://www.fosteropenscience.eu/sites/default/files/pdf/3646.pdf

McOliver, C. A., Camper, A. K., Doyle, J. T., Eggers, M. J., Ford, T. E., Lila, M. A., et al. (2015). Community-based research as a mechanism to reduce environmental health disparities in American Indian and Alaska native communities. *Int. J. Environ. Res. Public Health* 12, 4076–4100. doi: 10.3390/ijerph120404076

Mohorčich, J., and Reese, J. (2019). Cell-cultured meat: lessons from GMO adoption and resistance. *Appetite* 143:104408. doi: 10.1016/j.appet.2019.104408

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. *Social and economic effects of genetically engineered crops*. Washington, DC: National Academies Press. (2016).

Odegard, I, and Sinke, P. LCA of cultivated meat. Future projections for different scenarios. Available at: https://cedelft.eu/publications/rapport-lca-of-cultivated-meat-future-projections-for-different-scenarios/

Philpott, T. Is lab meat about to hit your dinner plate? Available at: https://www.motherjones.com/food/2021/08/is-lab-meat-about-to-hit-your-dinner-plate/

Post, M. J. (2012). Cultured meat from stem cells: challenges and prospects. *Meat Sci.* 92, 297–301. doi: 10.1016/j.meatsci.2012.04.008

Risner, D., Li, F., Fell, J. S., Pace, S. A., Siegel, J. B., Tagkopoulos, I., et al. (2020). Preliminary techno-economic assessment of animal cell-based meat. *Foods* 10:3. doi: 10.3390/foods10010003

Ritchie, H., Rosado, P., and Roser, M. (2017). Meat and dairy production. *Our World Data Org*. Available at: https://ourworldindata.org/meat-production

Rolland, N. C. M., Markus, C. R., and Post, M. J. (2020). The effect of information content on acceptance of cultured meat in a tasting context. *PLoS One* 15:e0231176. doi: 10.1371/journal.pone.0231176

Schneider, J., Leydens, J. A., and Lucena, J. (2008). Where is 'community'?: engineering education and sustainable community development. *Eur. J. Eng. Educ.* 33, 307–319. doi: 10.1080/03043790802088640

Schulze, E. Premarket notice for integral tissue cultured poultry meat. *Upside Foods*

Smith, A. (2007). Translating sustainabilities between green niches and socio-technical regimes. *Tech. Anal. Strat. Manag.* 19, 427–450. doi: 10.1080/09537320701403334

Szulecki, K. (2018). Conceptualizing energy democracy. *Environ. Polit.* 27, 21–41. doi: 10.1080/09644016.2017.1387294

Tuomisto, H. L., and Teixeira de Mattos, M. J. (2011). Environmental impacts of cultured meat production. *Environ. Sci. Technol.* 45, 6117–6123. doi: 10.1021/es200130u

von Schomberg, R. (2013). "A vision of responsible research and innovation" in *Responsible innovation*. eds. R. Owen, J. R. Bessant and M. Heintz (Chichester, UK: John Wiley & Sons, Ltd)

Whyte, K. P., Brewer, J. P., and Johnson, J. T. (2016). Weaving indigenous science, protocols and sustainability science. *Sustain. Sci.* 11, 25–32. doi: 10.1007/s11625-015-0296-6

Yuen, J. S. K., Saad, M. K., Xiang, N., Barrick, B. M., DiCindio, H., Li, C., et al. (2022). Macroscale adipose tissue from cellular aggregates: a simplified method of mass producing cell-cultured fat for food applications. *bioRxiv*. doi: 10.1101/2022.06.08.495192