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

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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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