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RESEARCH ARTICLE

Prospects of Justice for Cellular Agriculture: A just Transition or Reinvesting in Unsustainability?

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Abstract
Transformation in food systems poses new opportunities for improving environmental sustainability and reducing the use of farmed animals. Discussions about transforming current food systems have been centered mostly on replacing animal source proteins with plant-based alternatives and about how to minimize food waste and loss. Products from cellular agriculture are part of a novel food transition and are presented as new, sustainable alternatives for animal source proteins. However, justice and equity narratives in food system transition discussions concerning cellular agriculture are rare. The aim of this study is to address how cellular agriculture may contribute to a just food system transition and to evaluate the prospects of such foods on this planet by reviewing narratives of cellular agriculture in 36 scientific articles. The data were analyzed using a justice transition framework. The results show that cellular agriculture has a potential to contribute to improving environmental sustainability if developers take justice into account as an important factor. Concerns are that cellular agriculture has the potential to be an exclusive food and may introduce regional variances exacerbating inequalities within the food system. We contribute to the discussion of just food system transitions by highlighting the importance of justice considerations in the context of cellular agriculture. Key aspects include the need for fair distribution along the value chain, global access to cellular agriculture benefits, and the recognition of social transformations in technological solutions. Additionally, transparent decision-making, open data access, and capacity building for stakeholders emerge as critical elements for fostering equitable and sustainable development in cellular agriculture.

Keywords Cellular agriculture · Narratives · Food systems · Justice · Sustainability · Transformation

Introduction

Climate change is one of the most pressing issues facing our planet and it partly originates from unsustainable practices within the current food system (Abbass et al. 2022). One major concern is the extensive environmental degradation caused by industrial agricultural practices. The high demand for meat and dairy products contributes to deforestation as vast

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areas of land are cleared for livestock pastures and feed crops (Theurl et al. 2020). These practices also contribute to greenhouse gas emissions, exacerbating climate change. Moreover, the intensive use of water resources in agriculture further strains already stressed water systems, leading to water scarcity and depletion (Wallace 2000). These negative externalities emphasize the urgent need for more sustainable and equitable food systems that prioritize environmental stewardship, promote healthier diets, and address the social and economic disparities inherent in the current model.

A major step in transforming the current food system toward consumption of more sustainable, healthier, and less environmentally impactful foods, would be the production of those foods remaining within the planetary boundaries (Willett et al. 2019). Planetary boundaries are scientific targets set as bounds for which the Earth system needs to remain within to keep a healthy environment for human well-being (Rockström et al. 2009; Campbell et al. 2017). The Planetary Health Diet (PHD) is an evidence-based diet created by the EAT-Lancet Commission to equally protect human health and the environment and to establish global guidelines for staying within these planetary and human health boundaries (Willett et al. 2019). A shift to sustainable diets is challenging and depends on simultaneous policy, regulation, socio-cultural, and economic measures that promote more sustainable food systems (HLPE 2020).

Reflecting the need for more sustainable, accessible alternatives, novel food production technologies propose a means for producing foods which are healthy and have less environmental impacts. Cellular agriculture (CA) is a novel means of food production that entails bioreactor-grown cellular products made of cells (e.g., animal or plant origin) and acellular products made by cells (e.g., bacterial, fungal, algal) through fermentation (Datar et al. 2016). Previous research has claimed that CA could provide sustainable options as part of future food systems (Parodi et al. 2018; Tuomisto 2019; 2022; Järviö et al. 2021; Smetana et al. 2015; Mazac et al. 2022). The proponents of CA tend to follow a narrative in which they envision that the main goals of CA will be to reduce the agricultural burden on the environment and expand animal welfare outcomes (Mattick 2018; Bryant 2020). However, emphasizing these benefits of CA has led to a situation where the potential justice and equity prospects of CA in the greater food system have been largely overlooked.

One prominent example of novel foods is cell-cultivated products such as cultured meat (Datar et al. 2016). Cultured meat is a product where the cells of an animal are grown in a culture medium in a bioreactor (Post 2012). Cellular products also include microbial and plant cells when the cultured cells are used in the final product. Another form of CA includes acellular products, which are organic molecules and usually fermentation-based such as chicken egg white protein (i.e., ovalbumin) synthesized by microbes (Järviö et al. 2021). An overview of cellular and acellular products is presented in Table 2.

As CA products are developed and prepared for the market, they face both opportunities and challenges. Life cycle assessments show that cultured meat production could reduce land use, water use and global warming potential (Sinke et al. 2023; Tuomisto et al. 2022). However, achieving a significant reduction in environmental emissions at this high level is only possible when cultured meat is produced using sustainable energy sources (Sinke et al. 2023). If CA products are consumed instead of animal source proteins, agricultural land might be freed up for more plant-based protein production or to reduce pressures on deforestation and biodiversity (Tuomisto et al. 2022). Cultured meat could offer significant reductions in global warming potential and land use, and some reduction in eutrophication potential, especially when replacing beef (Sinke et al. 2023; Tuomisto et al. 2022). Nonetheless, there are potential industrial energy use increases with cultured meat production compared to all animal source proteins. Thus, potential environmental impact savings

could be similar if people ate less beef and replaced red meat with mostly poultry (Sinke et al. 2023; Tuomisto et al. 2022). However, his replacement would not solve ethical issues of animal husbandry in the livestock production.

CA could reduce other negative externalities such as animal slaughter or human health issues caused by consuming red meat (Poore and Nemecek 2018). However, one of the major uncertainties around the production of cultured meat is production feasibility. To date, a hybrid product consisting partly of cultured chicken meat and partly of plant-based ingredients has entered the market only in Singapore and the USA (Lucas 2020; CNN, June 2023). The prospects for regulatory approval of CA products in the EU are still unclear.

Beyond the environmental impact reduction potential of CA, there are other systemic considerations and barriers to its expansion. The ethical aspect of centralizing large food production like CA may reduce opportunities for farmers, which is another aspect that needs consideration (IPES-Food 2022; Glaros et al. 2023). Moreover, cultured meat is suspected to trigger neophobia (Dupont et al. 2022) as it is a product that is portrayed as food produced in a laboratory or later in large-scale industrial processes. Previous studies have identified other obstacles to CA adoption, such as consumer acceptance (Bryant and Dillard 2019; Bryant et al. 2020; Wilks and Phillips 2017; Slade 2018; Mancini and Antonioli 2019; Ryynänen and Toivanen 2022); the challenge of how to include farmers (Newton and Blaustein-Rejto 2021; Helliwell and Burton 2021; Räty et al. 2023); the political stakeholders' role (Moritz et al. 2022; 2023; Chiles 2013); and the general transformative potential (Moritz et al. 2022; 2023; Burton 2019; Chiles et al. 2021).

However, acellular products offer an advantage as they already exist in the medical and chemical market and are used in those domains (Burton 2019; Tuomisto 2022). Therefore, products from precision fermentation would not just be alternatives but analogues to producing conventional animal source products without animals and novel foods with potential high consumer value.

Beyond the challenges and prospects of CA to the future food system, Guthman and Biltekoff (2022) discuss about third generation proteins and their attractiveness to invest in. They argue that agri-food tech companies frame novel proteins purposely as *the* solution for future food shortages without addressing the consequences (2022). In the story-telling of third generation proteins, the social and environmental challenges are overlooked (Guthman et al. 2022) and the promissory narratives of new proteins tend to be emphasised (Sexton et al. 2019). These promissory narratives, destructive silences (Helliwell and Burton 2021) and food system justice dimensions are discussed in the next section.

Dimensions of a just Food System Transition

Transformation of the food system has become a common conceptual pathway to realizing sustainability in future food systems. The terminology of transformation and transition is often used interchangeably. A transition describes a smaller scale or different paths of one field, whereas a transformation is used to describe a bigger scale change, such as transforming or replacing a whole system (Loorbach 2017; Hölscher et al. 2018; Geels and Schot 2007). Transition and transformation theories have largely been influenced by Geels and Schot (2007), who first implemented the multi-level perspective to demonstrate among other things the socio-technical interconnectedness of a transition. A socio-technical system is exposed to external pressures such as climate change and the pressures of niche innovations that aim to transform the current system into a more sustainable

one (Geels 2002). The multi-level perspective has been criticized for ignoring the non-linearity and complexity of multidimensional systems (Berkhout et al. 2004; Geels et al. 2016). In response, Geels and Turnheim (2022) propose the need for a great reconfiguration approach, through which a system passes in different stages to change. Their emphasis is on the interconnectedness of socio-political, cultural, historical, and ethical factors that need to be considered by producers of radical niche innovations and by the system itself (Geels and Turnheim 2022).

Justice is a necessary factor in the transition process and has been acknowledged by various scholars as a requirement for sustainability in food systems (Kaljonen et al. 2021; Heffron 2021; Whitfield et al. 2021). Identification of uneven capacities, preconditions and preferences in different regions of the world need to consider justice from various perspectives (Kaljonen et al. 2021). By incorporating justice into food systems and the third generation proteins (Guthman and Biltekoff 2022) research, it globally increases the opportunities to benefit from advancements in food production and distribution, leading to a more equitable, sustainable, and resilient food system. Whitfield et al. (2021) created three lenses through which a food system transformation should be analyzed. The first lens focuses on avoiding reproduction of historical injustices, such as the over-exploitation of natural resources in developing countries. The second lens ensures representational justice by utilizing current knowledge, participating active stakeholders, and combining different perspectives. The third lens elaborates distributional justice by ensuring that future outcomes of the transformation are fairly distributed along the value chain (Whitfield et al. 2021).

In addition to the three lenses by Whitfield et al. (2021), three key dimensions have repeatedly been used by scholars to describe justice in transitioning food and energy systems; distributive, procedural, and recognitive justice (Tribaldos and Kortetmäki 2022; Kaljonen et al. 2021; Williams and Doyon 2019). Distributive justice is defined as the harms or benefits to the environment or involved stakeholders of distributing new goods, in our case the impact implications of innovative foods from CA. Procedural justice refers to diverse and inclusive stakeholder involvement in decision-making and a fair procedure throughout the transition process. Recognitive justice emphasizes the need to recognize historical injustices, intercultural differences, and respect for the values of all stakeholders involved in the transition (Tribaldos and Kortetmäki 2022; Kaljonen et al. 2021; Williams and Doyon 2019).

Kaljonen et al. (2021) as well as Tribaldos and Kortetmäki (2022) added four other justice dimensions to evaluate dietary transition in and beyond food systems. Restorative justice refers to righting previous wrongs through reconciliation, for example, being able to restore or reconcile farmer jobs that could be lost during a transition to CA (Kaljonen et al 2021). Cosmopolitan justice emphasizes the right of all people to food without exception and hence includes a global and intergenerational viewpoint (Kaljonen et al. 2021; Tribaldos and Kortetmäki 2022). Justice for ecological and non-human beings refers to a form of justice that goes beyond anthropocentric outcomes and protects or improves current negative externalities on non-human beings and ecosystems (Tribaldos and Kortetmäki 2022). In the case of CA, justice for ecological and non-human beings would mean consideration of the ecological externalities of emissions caused by food production or complicity in animal harm of livestock production systems. Capacities refers to a justice approach that recognizes the required capabilities of an innovation and ensures equal job opportunities. Oftentimes, energy, environmental, and climate justice approaches are treated separately and thus scholars have different definitions of justice. Hence, studies on justice transitions use different justice dimensions to describe their purposes. For the analysis purpose of this paper, we apply the framework by Tribaldos and Kortetmäki (2022) as it is specifically

designed for food systems and CA is aimed to transform the current food system. Their framework includes six justice dimensions with respective categories that we have adapted to our analysis. Justice frameworks applied to analyze the prospects of novel foods such as CA are largely missing in the extant studies, which tend to focus instead on environmental impacts and consumer acceptance (Post et al. 2020). Considering the perspective of the alternate and otherwise marginalized is needed as the new food technologies are primarily being implemented in developed countries and through the investment of the wealthy and powerful but could have wide-reaching systemic impacts in developing nations or disenfranchised voices in wealthy nations (Mahoney 2022).

A stated original aim of developing novel technologies is to produce "better" foods, reducing the environmental impacts of food production, and feeding the world in developing countries (Tzachor et al. 2021). Such stated aims seem to miss certain aspects of distributional and recognitive justice. For instance, even though societies have purportedly long produced enough food to feed nearly 10 billion—that is 2 billion more than are currently on the planet, the distribution of that food is deficient (Holt-Giménez et al. 2012). Also seldom discussed is procedural and cosmopolitan justice along the whole supply chain, including the effects that new technologies might have on food traditions or rural livelihoods in countries other than EU or North America (Reis et al. 2020). Therefore, a sustainability transition is not just if it excludes the social, cultural, and economic characteristics of the stakeholders in the food system transition.

Data and Methods

To meet the aim of how CA may contribute to a just food system transition, a review of existing research was conducted. We sought to identify, evaluate, and synthesize narratives of cellular agriculture. The aim of our review is to provide a comprehensive summary of the available evidence and draw conclusions about justice for CA. We followed the justice transition framework (Tribaldos and Kortetmäki 2022), adhered inclusion and exclusion criteria, and extracted data from Web of Science and Scopus databases. Through a systematic and transparent approach we aimed at enhancing the reliability and validity of the results and providing evidence-based conclusions that are relevant for research-based decision-making in justice themes of CA.

In total, 927 papers were identified upon the first search on the Web of Science (464) and Scopus (463). The search was conducted in June 2023 using the following search terms:

("cellular agriculture" OR "cultivated meat" OR "cultured meat" OR (("lab-grown" OR "lab-based") AND (agriculture OR meat))) AND (just* OR fair* OR sustainab* OR climate OR livelihood* OR farm* OR (food W/2 chain) OR ((food OR nutrition) W/4 (health OR security OR cultur*)) OR ethic* OR ethnic* OR generation* OR access* OR discriminati* OR participat* OR "well-being" OR resilie* OR "decision making").

This search phrase was specifically constructed to be restrictive and target scientific articles that report studies on the intersection of CA, justice, and sustainable food systems from the social science and environmental impact perspectives. Even though justice was included in the search phrase, the majority of articles addressed topics of sustainability and environmental perspectives of CA without mentioning justice. We limited the search on Web of Science and Scopus as they gave the most comprehensive results, covering the key fields of science. The first search results were further restricted by applying a filter,

eliminating all articles that appeared due to the technical or natural sciences aspects of CA excluding lifecycle assessment (LCA) modelling, which we here count as social sciences. With this filter, papers have been eliminated that have a primary focus on biochemistry, biology, or engineering. Other exclusion criteria comprise articles that were not published after 2000, not written in English, not published in a peer-reviewed journal, and if the papers focused on non-food products.

The first round of exclusion left us with 173 articles, which then in the second round were screened by abstract and if unsure by full-length text. In this process, 147 articles have been excluded as they did not address contributions of cellular agriculture to justice or a just food system transition. Articles that directly addressed the relationship between cellular agriculture and justice were included for further analysis. These exclusion criteria ensured that the selected articles were relevant in addressing the research question and clarified the potential impacts of cellular agriculture on food system justice (Fig. 1). In the last step, the reference lists of the remaining 26 articles were screened to identify additional data valuable for the analysis. Thus, ten articles were added. Seven out of the nine extra articles explain the environmental impact of CA. Finally, 36 articles were included in the data and for reviewing justice in the CA transition.

We analyzed the data using the justice transition framework created by Tribaldos and Kortetmäki (2022). The analysis followed a theory-led approach that allowed us to organize the reviewed literature according to the different dimensions of justice. In the first step of analyzing the literature, we created a table with the key findings of the reviewed literature (see Table 3). In the second step, we performed a content analysis (Mayring 2000;

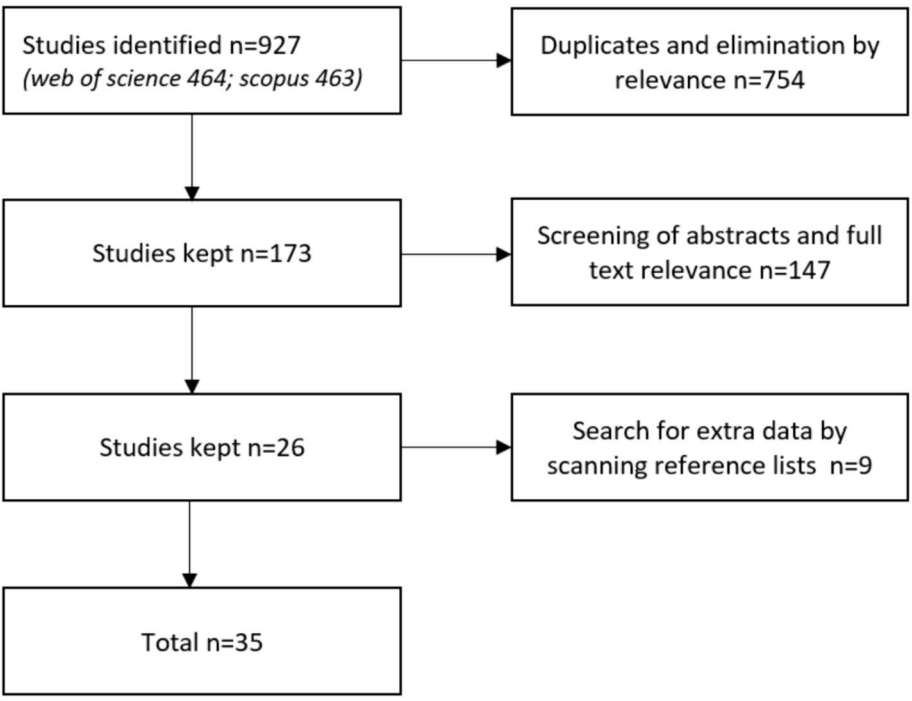

Fig. 1 Process for identifying the relevant literature

Schreier et al. 2012; Schreier 2014) of the included literature aiming to identify which dimensions of justice the authors are addressing; often, papers fit into multiple dimensions. We created a table (see 3Table 3) that summarizes the key message of each justice dimension and added the key findings of each paper to each dimension. Each dimension of justice is further comprised into principles. Justice principles have been evaluated together rather than separately (see Table 1 for overview, p. 17). The results are presented in the following.

Cellular Agriculture Through the Dimensions of Justice in Transitions

Distributional Justice

Distributional justice involves assessing the impacts on various stakeholders in the food system when distributing or developing both tangible and intangible resources. The first principle of distributional justice is the *rights to vital goods* to everyone at any time. Research shows that cultured products will most likely become an addition to the market and stay a niche product that is not accessible to everyone (Moritz et al. 2022). Moreover, cultured products are intended to be a replacement for meat in a diet where meat is not the most important component to a healthy lifestyle (Mazac et al. 2022). Therefore, it seems that CA products are not meant to be a vital good. Thus, they should not be considered a principle for justice but rather products that are already accessible and easily available. That does not mean that CA products should eventually be accessible to all.

The next principle of distributed justice is *labor justice*, which aims at the fair payment and support of established jobs created within the CA industry. As CA is still in the research and development phase, literature about fair payment, labor support, and rights

Table 1 A justice system for cellular agriculture

Justice dimensions	Justice principles	Implications for cellular agriculture
Distributional justice	Rights to vital goods	Avoidance of CA becoming a niche luxury product.
	Labor justice	Fair payment and support of the established jobs created within the CA industry.
	Just food chain structures	Simply more food produced by technology may not be the solution. CA needs to be distributed fairly along the value chain.
	Livelihood opportunities	Inclusion of stakeholders (e.g., farmers) is necessary in the CA transition process.
Cosmopolitan justice	Global fairness	Secure access to food where CA is not developed.
	Intergenerational justice	CA needs to generate food for the future that is also affordable for everyone.
Ecological and non-human beings justice	Ecological integrity	Potential of CA to be significantly more resource efficient if renewable energy sources can be used.
	Justice for animals	CA can reduce harm to animals as production of CA products mostly indirectly involves animals.
Procedural justice	Just processes	The necessity of transparent and inclusive decision-making processes along the CA value-chain that do not generate confusion or ambiguity.
	Access to relevant information	Information on the development of CA need to be communicated to the wider public as for now they mainly come from those who produce cultured meat or from academics who research the topic.
Recognition justice	Respectful pluralism and esteem recognition/ Non-discrimination	Technological solutions such as CA offered for fixing complex systemic problems should recognize the need to include social and gender transformations.
Capacities and justice	Capacity building	Stakeholder groups need to have a capacity to understand what CA is and to anticipate how they could be related to food system transitions.
Technological justice	*Access to open data*	*Create open data platforms to accelerate the development of CA.*
	Funding opportunities	*Dedicated fundings for promising technical developments that are not yet readily available.*

are non-existent. The CA industry consists of startups working with pilot scale production facilities and pre-production patches. There is, however, literature about the *just food chain structures*, which is another principle of distributed justice. The dominance of one system is seldom regarded as beneficial on the global scale. It is argued that simply more food produced by technology may not be the solution, although it does answer the question of how the resources can be distributed fairly (Klerkx and Rose 2020). The jobs that are affected by the development of CA also differ along the value chain. The most affected are the farmers in the traditional livestock agricultural industry. However, farmers seem optimistic that novel food technologies can create new jobs if policy measures and new strategies are supportive enough (Räty et al. 2023). Brazilian farmers seem more optimistic compared to European farmers (Morais da Silva et al. 2022).

The next principle of distributed justice is related to *livelihood opportunities* or access to suitable farmland, retaining livelihoods in rural areas and the same opportunities for all sized food system actors. This approach exceeds the contrasting positions of traditional and alternative system narratives (Newman et al. 2023b) by combining different food production practices including novel food technologies such as CA. A high yield, local agricultural approach would lead to shorter supply chains and decentralization of food systems with the result of less land use and emissions.

Livestock farmers are one group of stakeholders that are anticipated to lose their jobs in the development of CA (Helliwell and Burton 2021). Several attempts have been made to find ways to include farmers in the transition progress, such as a decentralized model where farmers could restructure their farms and be part of the CA development (Newton and Blaustein-Rejto 2021; Soice and Johnston 2021). For some, such a radical restructuring of farms and farming practices towards CA is an unrealistic scenario, whereas others believe that reinventing their jobs is one outcome (Helliwell and Burton 2021; Moritz et al. 2022; Räty et al. 2023).

Cosmopolitan Justice

Cosmopolitan justice is about the right of all people to food without exception and hence a global, intercultural, and intergenerational viewpoint is necessary. The first principle of cosmopolitan justice is *global fairness* and aims to secure access to food where CA is not developed. However, literature suggests that CA has the potential to create global inequity by i) becoming a niche in the luxury sector, ii) by further limiting access to food, and iii) by only supporting big developers who currently keep their patents under disclosure (Mahoney 2022; Howard 2022). CA is portrayed as an opportunity to partly reach the UN Sustainable Development Goals (SDGs) and thus be part of a transition toward more planetary health if certain obstacles can be resolved and if the cosmopolitan justice dimension is not overlooked (Newman et al. 2023a). Therefore, CA developers are encouraged to include all those stakeholders who historically have been deliberately overlooked and disenfranchised in food system transition discussions and thus create equity for people affected in the CA development (Ellis et al. 2022).

Currently, most of the development of CA is centered on the USA, Israel, Singapore, and European countries and therefore mainly excludes other regions. However, from a global point of view, the development of CA needs to focus on each countries' resources. The reason why Singapore is well adapted to novel food technologies is due to their lack of agricultural space and dependency on food technologies (Mok et al. 2020). Where, when, and how CA develops is subject to the future constraints of resources and interests. Food

security depends on centralized, decentralized, and distributed supply systems (Soice and Johnston 2021). CA in a centralized model would lead to the highest economic outcome for only a few and would create bureaucratic and communication burdens for those with lower economic outcomes (Soice and Johnston 2021). Moreover, CA products would have more difficulties meeting the promised ethical standards and could create distrust among consumers (Ellis et al. 2022). An exemplary case would be technology development in the global North and then exporting licensed services to the global South (Ellis et al. 2022). While some state that CA could have a positive impact on the global food system by 2050 (Glaros et al. 2022; Newman et al. 2023a) others emphasize that the focus should be on advancing sustainability in existing agricultural practices (Moritz et al. 2022).

The second principle of cosmopolitan justice is intergenerational justice, which aims to include the well-being of future generations. While CA producers claim to create a better future, the literature suggests that this high confidence contrasts with the feasibility of producing CA products (Glaros et al. 2022). To address the problems of premature technology such as CA production, a multidisciplinary approach is necessary to generate food for the future that is also affordable for everyone (Smith et al. 2022). CA is portrayed as an opportunity to partly reach the SDGs by 2050 and thus be part of a transition towards planetary health if certain obstacles can be resolved (Newman et al. 2023a; Glaros et al. 2022). The promissory narratives of CA suggest that novel food technologies can reduce or even terminate the negative impacts of traditional agriculture without addressing the potential consequences. This partial debate is called creative destructive silences (Helliwell and Burton 2021. It is suggested that CA development will probably produce new monocultures and new environmental problems and hence work against the planet (2021).

Ecological and Non-Human Beings' Justice

Justice aspects covering ecological and non-human beings go beyond anthropogenic outcomes and aims at protecting non-human beings and improving ecosystems. The first principle is about *ecological integrity*, which concerns where the ecosystem's health is to be protected. The second principle is *justice for animals* that could potentially be harmed during the transition toward CA. The commonly used binary narrative of CA builds on the protection of the environment and animals.

Newman et al. (2023a) has analyzed the potential of CA from the perspective of the 17 SDG goals, categorizing them into focus areas; people, the planet, prosperity, and protection of animals. Their main findings include the fact that CA has the potential to provide healthy and nutritional products for a growing world population (i.e., people). CA also can reduce environmental impacts (i.e., the planet) shown by various LCA studies (Tuomisto et al. 2022; Sinke et al 2023). CA could also provide new job opportunities, new global infrastructures and diversify food production systems (i.e., prosperity). Lastly, CA can reduce harm to animals as production of CA products mostly indirectly involves animals (Newman et al. 2023a). The feminist ecological view further emphasizes the importance that the development of CA should not be used as a tool for more dominance but should be considered from an inclusive and ethical perspective. This would mean acknowledging that non-human beings should be valued in the same way as humans (Lee 2018).

LCAs are often used by scholars to support their claims concerning the environmental benefits of CA. However, the LCA data measure the impacts on the environment based on the best estimates of current production systems; such estimates may not be best suited for novel production technologies (Tuomisto et al. 2022). Barriers such as the animal

serum-free culture medium and producing large-scale bioreactors need to be resolved for more accurate LCA results which reflect the prospects of CA production on a larger scale (Tuomisto 2022).

Though CA might be a viable and environmentally beneficial option for replacing animal source proteins in diets, plant-based proteins have lower environmental impacts (Mazac et al. 2022). Simple reductions in overall food intake and animal source proteins intake specifically can achieve similar impact reductions as including CA products in one's diet. Mazac et al. (2022) have shown that optimized vegan and omnivore (with up to 80% less animal source proteins) diets had similar environmental impact reductions as a diet with CA foods, such as microbial protein, cultured milk, or cultured meat when the diets were minimized for either land use, water use, or climate impact. Larger energy use requirements for CA production necessitate a green energy transition and further technology development for environmental impact reductions of diets. Cultured meat production showed an increase in energy use compared to beef, pork, and poultry (CE Delft 2021). The high-energy requirement of cultured meat means a major electricity grid overhaul and green energy transition would be required before the environmental burden would be reduced by swapping animal source proteins for CA (Smetana et al. 2015; Parodi et al. 2018). There are additional uncertainties in the tradeoffs among additional environmental impact categories, such as carbon dioxide impacts and biodiversity, and location-specific differences in emissions and energy use, which may result in less beneficial outcomes for CA (Glaros et al. 2022).

It seems that most LCA studies conclude with the notion that the development of CA is only environmentally feasible if renewable energy sources can be used to produce them (Spiller et al. 2020; Sillman et al. 2020; Kobayashi et al. 2022; Järviö et al. 2021; Tuomisto 2022). The highest ecological and dietary benefits could come from other practices such as controlled environmental agriculture, which are defined as artificial environments for agricultural practices such as vertical farming (Glaros et al. 2022). Moreover, technological, and nutritional challenges seem too challenging within the anticipated time frame of bringing CA products to the market by 2030 (Glaros et al. 2022; Helliwell and Burton 2021). On the one hand Newman et al. (2023a) propose that CA has the potential towards more climate justice through the 17 SDGs. On the other hand the technical and physical challenges as proposed by the various LCA studies seem to weaken the link between climate change mitigation and climate justice drastically.

Procedural Justice

Procedural justice emphasizes the involvement in the decision-making processes of CA development and fair procedure throughout the transition. The first principle is *just processes*, which emphasizes the necessity of transparent and inclusive decision-making processes that do not generate confusion or ambiguity. These processes should be openly presented as technologies capable of mitigating or even replacing the adverse effects associated with traditional agriculture in a relatively short period, without concealing the state of development and potential consequences (Helliwell and Burton 2021). Like Industry 4.0, new food technologies have been called Agriculture 4.0, which simply implies a new era of doing agriculture (Klerkx and Rose 2020). CA is part of Agriculture 4.0 and is acknowledged as having the potential to be disruptive and transformative (Klerkx and Rose 2020; Moritz et al. 2022).

Klerkx and Rose (2020), however, discuss the potential challenges of overemphasizing technocratic solutions and promising advanced global food security. An overemphasis on innovations such as CA and molecular farming potentially draws attention to quick and easy solutions but do not to transformative changes (Klerkx and Rose 2020; Howard 2022). Furthermore, CA as part of the fourth Industrial Revolution could have the power to further concentrate wealth to only certain stakeholder groups rather than addressing inequity and including a wider range of stakeholders (Klerkx and Rose 2020; Chiles et al. 2021).

To further discuss the inclusion of different stakeholders in the procedure of CA development, Broad and Chiles (2022) introduce the concepts of thick and thin food justice. Thin food justice is a solution that includes the benefit of economic growth and calls for collaborations between all stakeholders to minimize the risk of monopoly and job loss in other sectors. An example of thin food justice is that technocratic solutions are doubted but accepted for the greater good (Klerkx and Rose 2020; Broad and Chiles 2022). On the other hand, thick food justice expresses a strong distrust of technologies and in general this form of justice is more radical as it actively requests an economic slowdown. CA production may fall under the thin food justice approach as CA producers are actively involved with the industry to push their innovation forward, but at the same time they promote a narrative of reducing environmental harm and animal suffering (Broad and Chiles 2022). However, even if CA producers which to pursue just the thin food justice, they would need to show a strong commitment to establishing CA as a radical de-growth solution (less economic growth) and to include citizens in the decision-making processes of CA solutions (Broad and Chiles 2022; Chiles et al. 2021).

The thick food justice approach seems to work against CA development. From a utilitarian point of view, the long-term consequences need to be considered. Even if the benefits outweigh the costs compared to factory farming, one moral pitfall is the missing sovereignty: advocates of CA may fail to recognize and communicate the power dynamics that come along with this new development (Moyano-Fernández 2023).

The second principle of procedural justice is *access to relevant information*. Available information comes mainly from those who produce cultured meat or from academics who research the topic. While scientific articles concerning this topic are usually not read by the general public, news articles about the latest developments by companies create attention, including the comment sections, where everyone can publicly announce their opinions on the topic and thus influence the development of CA (Ryynänen and Toivanen 2022). Sometimes it seems that CA is purposely miscommunicated by its producers to attract fundings (Abrell 2023). In addition, technological development is characterized as rather slow to have positive environmental impacts and current investments should have been directed at alternative protein projects (Abrell 2023). For involved stakeholders to have the ability to keep up with the CA transition, transparency and closing current knowledge gaps have been found to be important factors (Moritz et al. 2022). If the knowledge gaps are not addressed early on, the development of CA could suffer as public perceptions might then change in the course of time and become more ambiguous (Stephens et al. 2018; Moritz et al. 2022).

Moreover, it seems that businesses are more equipped to attract funding than universities (Stephens et al. 2018), which could turn into a problem about keeping patents rather than sharing knowledge through open access (Mahoney 2022; Howard 2022; Glaros et al. 2023). As the necessary knowledge is not yet readily available, it is problematic to publicly present CA products as solutions to achieve sustainability in the food system transition (Stephens et al. 2018; Moritz et al. 2022; Rijssenbeek et al. 2022). A multi-faceted approach should instead be promoted, including plant-based proteins and improved food

waste management strategies as well as decision-makers to implement policy reforms to transform the current livestock system and improve food systems (Stephens et al. 2018; Broad 2019). Moreover, it seems that companies might follow a different notion of sustainability (environmental impacts) than would be required to achieve societal change. CA is part of the problem by causing with its practices a new norm of understanding sustainability, if in fact thicker versions of sustainability are needed (Rijssenbeek et al. 2022).

Recognition Justice

Recognition justice emphasizes the need to recognize historical injustices, intercultural differences, and respect for the values of all stakeholders involved in the transition. The first principle is about *respectful pluralism and esteem recognition*, which aims to recognize that there are different cultures and food practices that need to be respected. The second principle is *non-discrimination* in any form. As the two principles align and the literature on this specific topic is limited, these two principles are discussed together rather than separately.

Technological solutions such as CA offered for fixing complex systemic problems should recognize the need to include social and gender transformations as proposed by the ecofeminism point of view (Lee 2018). Different forms of ideas for food systems and how to improve sustainability bring different advantages and disadvantages to the non-discriminatory justices. There are three different concepts through which CA can be analyzed: food system reforms, food justice, and food sovereignty (Broad 2019). The idea of *food system reforms* tends to emerge within the corporate system and have a strong connection to neoliberalism and technological innovations to solve food-related problems without considering historical injustices or intercultural differences (Broad 2019). CA advocates may be more progressive in their approach to *food justice* when they look for solutions that achieve environmental benefits without marginalizing certain social groups (Broad 2019; Ellis et al. 2022). To comply with non-discriminatory factors, *food sovereignty* could be a focus for CA. Food sovereignty, or the right of all people despite their gender, age, or culture, to have the decision power in their food system is thus the most radical and most considered perspective of the three.

CA advocates would have to proactively try and shut down the dominant food system structures and put the focus on small-scale stakeholders around the world, such as in a decentralized model (Soice and Johnston 2021). A decentralized food system model therefore eliminates central operating power and puts the responsibility on individual stakeholders and their needs that all stem from different backgrounds. However, CA is a market-driven production sector. Even more than that the publicly subsidized conventional livestock production. When food sovereignty is not considered, CA would be missing aspects of recognition justice and therefore also fail to have a significant impact on the planet (Broad 2019). To go beyond the market-driven approach, CA development would need to follow a path that appreciates pluralism and non-discriminative practices along the value chain (Ellis et al. 2022; Soice and Johnston 2021; Broad and Chiles 2022; Chiles et al. 2021).

Capacities and Justice

Capacity building is the only principle in this dimension and refers to the necessity for all actors to be equipped through individual skills and collective action to formulate an

informed opinion about CA and perceive themselves as a part of food system transitions. To form an opinion and take part in food system transitions, stakeholder groups need to have the capacity to understand what CA is and to anticipate how it could be related to food system transitions.

Consumers' and citizens' perceptions of cultured meat have been studied most. Consumers' and citizens' capabilities to evaluate the progression of CA tend to be limited and speculatively visible in studies analyzing news and online news comments: whereas the media publicity about CA tends to be overly positive (Painter et al. 2020), online commenters are rather negative and present several doubts related to CA's naturalness, health, ethical aspects, and so on. (Ryynänen and Toivanen 2022).

Politicians' and experts' perceptions of cultured meat have also been studied. A recent study about German politicians' perceptions concluded that none of the leading parties had an official and clear stance toward CA (Moritz et al. 2022). The same seems to apply to Finnish politicians (Moritz et al. 2023). The politicians emphasized that they were commenting as individuals and trusted the present food system regulations. Although a consensus within German politicians could be found regarding the urgent need for developing the sustainability of current food systems, the potential role of CA was ambiguous. Studies analyzing primary producers' or farmers' capabilities to adapt to food system transitions originating from CA remain scarce. Although farmers tend to perceive novel technologies such as CA as the next step in a long continuum of technological advancements in agriculture, they are worried about the development of rural areas and the potential roles of livestock farmers and farmed animals in the future (Newton and Blaustein-Rejto 2021; Räty et al. 2023).

The reviewed studies show that stakeholders' capabilities for assessing CA and forming informed opinions about novel food technologies such as CA and particularly their role in a changing food system remain unclear. This lack of knowledge and capabilities to assess the potential impacts of CA are fruitful grounds for speculation and for raising ungrounded doubts. One study analyzed debates and social movements about Genetically Modified Organisms (GMOs) that led to banning these technologies in the EU and drew analogies to CA development (Mohorčich and Reese 2019). The study concluded that CA could encounter similar opposition in the future if not addressed early on and if the key stakeholder groups' concerns were not considered. In this case, stakeholders used their capacity to fight GMO and succeeded in their demands to prohibiting GMO products (Mohorčich and Reese 2019).

Discussion

The aim of this review was to evaluate how CA may contribute to a just food system transition and to outline the prospects of such foods for the planet and for people. The results (Table 3) show that CA is often portrayed as a solution for future food systems, solving major environmental problems that traditional agricultural practices have caused. While prospective LCA studies have anticipated that CA has the potential to lower GHG emissions, decrease agricultural land use, and generally contribute to SDGs, the results also reveal several caveats. These include issues such as the inequity that CA could cause if the current development excludes stakeholders, perpetuates power imbalances, disregards the rights of all individuals and non-human beings within the food system, and fails to respect food traditions and cultural differences.

Next, the results are discussed in the context of how CA is positioned in terms of justice dimensions and the prospects of these foods to overcome the barriers of power inequities and sociocultural norms in food systems transformation.

A Justice System of Cellular Agriculture

CA may have the ability to shift the current food system if all the necessary parameters, such as inclusion, technical barriers, and justice dimensions are considered. However, the current literature on CA is rather limited when it comes to discussing justice in the prerequisite food system transition. Most of the reviewed literature focuses on CA improving the environmental outcomes of food production and animal welfare conditions or asserting possible contributions to more healthy food to feed the world. Moreover, the papers that discuss CA and its ability to transform the current food systems (Moritz et al. 2022; 2023; Klerkx and Rose 2020; Newman et al. 2023a), fail to include the historical contexts of just transformations that are required by multiple authors who have developed just transition frameworks (Whitfield et al. 2021, Heffron 2021; Tribaldos and Kortetmäki 2022; Kaljonen et al. 2021). If the current food system is to shift toward a just CA food system, the process needs to be inclusionary, tracing history, understanding the interconnectedness, and including both human and non-human stakeholders (Whitfield et al. 2021; Heffron 2021; Tribaldos and Kortetmäki 2022; Kaljonen et al. 2021). Table 1 describes the potential justice system for cellular agriculture that covers all the reviewed justice dimensions and principles.

The reviewed articles address the complexity of a just transition and tend to anticipate challenges if consumers, farmers, and retailers are excluded (Broad and Chiles 2022; Chiles et al. 2021; Howard 2022). The literature about transitions of socio-technical systems is focused mainly on landscape pressures such as climate change; this literature presents radical niche innovations as being able to shift the current regimes that are often portrayed as somehow problematic or unsustainable (Geels and Schot 2007). However, such literature has analyzed the non-linear nature of system transitions and the necessity for actors in complex systems to consider the different dimensions of justice (Geels and Turnheim 2022). Economic incentives are necessary to reach sustainability goals and these incentives are included in most transition theories; however, justice dimensions should also be emphasized (Broad and Chiles 2022; Chiles et al. 2021).

Technological advancements have historically neglected the inclusion of populations in developing regions. Whitfield et al. (2021) draw attention to the deep-rooted inequalities that overlooked groups experience in different parts of the global food system. They further argue that agricultural transformations based on technological solutions, as discussed in extant studies, hold the risk of more power asymmetries and injustice (Whitfield et al. 2021). Howard (2022) adds that in the context of CA, new technology is not made to feed people where food is needed, at least not in the immediate future. Instead, new technology only serves to provide new products to already captive market audiences. Mahoney (2022) and Ellis et al. (2022) add the concern that CA would widen disparities between the developed and developing regions and hence would not seek to end poverty, which is the first SDG. The reviewed literature thus adds to the concern that global justice (Heffron 2021) will not be met by the development of CA by, for example, the current distribution of CA startups.

CA could be a prospect for meeting cultural desires in diets for animal-derived food options with lower impacts, but concurrent transitions are needed. If green energy transition

is achieved in parity with CA technological developments, CA could make more significant progress toward sustainable food systems (Tuomisto et al. 2022). Additionally, green energy transitions are required to produce CA products sustainably with renewable energy sources (Sillman et al. 2020).

Most of the promises of CA in current literature center on the environmental aspects, with some consideration of nutrition in relation to the SDGs. Though current global guidelines for sustainable diets focus on the implications for lower environmental impacts, the SDGs encompass other justice principles, which are missing in the current CA literature. The EAT Lancet Commission emphasizes the nutritional and environmental aspects of food transition and therefore focuses on SDGs that are more connected to the human and to the planetary health diet (Willett et al. 2019). However, other SDGs have focused on people and profit or prosperity in a more targeted aim for equity. SDGs are interconnected and often even co-dependent. The omission of equity in CA technological development neglects the justice implications of CA production in the larger food system. Most of the literature reviewed here seems to have the same concern that CA could eventually lead to more inequalities and work against the 10th SDG, which promotes the reduction of inequalities (Ellis et al. 2022; Howard 2022; Mahoney 2022; Newman et al. 2023a).

The results of two papers show that CA is a nascent technology that will not disrupt the current food systems soon and they even conclude that CA products may end up as merely "niche innovations," namely expensive additions to elite markets (Moritz et al. 2022; Stephens et al. 2018). These results suggest the presence of the limited narrative of CA in that the literature almost exclusively discusses CA in terms of benefits for the environment and animal welfare outcomes. While the narrative of reducing livestock suffering is present in most of the narratives, the potential negative impacts on the development of CA is overlooked. Developing livestock-derived cultured products may strengthen the meat intake rather than shifting away from animal-sourced foods (Heidemann et al. 2020). While one of the initial aims of CA is reducing harm to farmed animals by replacing mass produced conventional meat, it is uncertain if cultured products will replace factory farming or alternative forms of livestock production (Cole and Morgan 2013).

While some articles contributed to the justice discussion by showing the contribution of CA to the SDGs (Newman et al. 2023a; Tuomisto 2022), the historical and intercultural injustices relevant to CA development were much less discussed in the literature.

Rather than analyzing the root causes of injustices in food systems, the reviewed literature only mentioned the necessity to consider injustices in the CA production process (Ellis et al. 2022; Soice and Johnston 2021; Broad and Chiles 2022; Chiles et al. 2021). Specifically, regarding the recognition justice dimension, our findings suggest that the development of CA does not reveal a prospect for critical questioning or a recognition of the values of present food ways and values of eating well. Moreover, the early stage of the current development of CA might also be the cause for missing literature on how to restore jobs in the CA transition. While Helliwell and Burton (2021), Newton and Blaustein-Rejto (2021), and Räty et al. (2023) mention the future roles of farmers, constructive programs to restore precisely those jobs with respect to justice are largely absent.

The resources invested in CA technologies with uncertainties should be spent where such efforts can work in an abiding way to solve current food system challenges (Broad and Chiles 2022; Chiles et al. 2021). These voices call for investments to instead be directed toward more promising technologies, such as controlled environmental agriculture (Glaros et al. 2022). In this way, the opportunities that CA could bring are reasons why CA is worth investing in if equity, transformation, and diet transitions are considered (Newman et al. 2023a). While Newman et al. (2023a) emphasize how CA could contribute to reaching the SDGs by 2050, Broad

and Chiles (2022) acknowledge that if CA follows the thin justice path it could be accepted by its critics as well. In the end, the commitments made by current cellular agriculture developers continue to adhere to a simplistic, binary narrative and an impractical timeline, which often results in reduced transparency. This lack of transparency can contribute to growing injustices during the transformation process, contrary to the intended goal of improving the sustainability of food production systems.

Lastly, throughout the review it became apparent that the justice framework we used is missing a dimension that also includes the prospect of technical equity. As innovation and digital solutions for sustainability are more present than ever, we suggest that future research should include a dimension to consider technical developments that are not readily available yet as well as the ethical and cultural implications of technocratic solutions. We therefore propose a seventh dimension, *technological justice*, along with the principles of *access to open data* and *funding opportunities* as these are crucial to each technical innovation that aims to enhance justice (Table 1).

Considerations and Limitations

As the literature on CA and justice is scarce, the methodology used in this paper also has its limitations. Analyzing a limited number of papers through a framework with six dimensions showed gaps in the extant research on CA from justice perspectives. While reviewing the literature, it also became apparent that most of the findings portray CA as a development that does not consider justice, rather than analyzing what its actual contribution to justice so far is. Therefore, our results reflect the state of CA research, which tends to concentrate on narratives debating on anticipated environmental impacts, farmed animal welfare, and consumer acceptance issues.

One consideration when doing research in a field that aims to tackle a larger, systemic problem is the need to move away from the Eurocentric or 'Western' world-centric perspective. As is the case in CA development, there is little research from developing countries, which currently are the most affected by several major food systems challenges, such as the climate crisis and the increasing hunger epidemic. While technological solutions such as CA aim to address these problems, the potential regional gaps between producers dependents) need to be avoided.

Moreover, investments in technological developments, which reify the power imbalances in the current food system, should be prevented in the pursuit of justice in future transitions. In the case of CA, giving intellectual property rights and investments to large companies for the development of sustainable products could be problematic. It could lead to the disproportionate extraction of natural resources and the development of more expensive processed foods for a narrow group of wealthy consumers, while at the same time excluding farmers, communities, and non-human stakeholders. Forthcoming research on CA should address power dynamics, consider situated knowledge and values in context, and reflect on path dependencies in the development of technologies for future food systems.

Conclusion

The need for sustainability is urgent considering the current food system challenges, such as the climate crisis. CA products aim to contribute to a more sustainable future food system and are thus part of the solution. In comparison to animal source proteins, CA has a lower environmental footprint if the production technologies are developed in concert with a

renewable energy transition. Crucially innovative technologies and food production methods must adhere to a comprehensive justice framework encompassing various dimensions: distributional, cosmopolitan, ecological, considerations for non-human beings, procedural justice, recognition, and capacities. In addition, a justice dimension that addresses technological principles is needed as emerging cellular agriculture production relies on complex technical systems and innovations in engineering and science. This approach ensures that power imbalances are mitigated, preventing the re-concentration of knowledge, technology, and wealth.

CA developers could benefit from taking concrete steps to ensure that their approach to sustainable food production is rooted in all justice dimensions, aiming not only to innovate but also to genuinely contribute to a more equitable world. Recognizing food security, sovereignty, and sufficiency as intrinsic human rights enshrined within the SDGs would create a solid basis for the development of CA products. Consequently, those at the forefront of CA technologies will benefit from being aware of the sensitivity inherent in this subject and should commit themselves to inclusivity, transparency, and a resolute dedication to fulfilling their promises.

Appendices

Table 2 Examples of cellular and acellular products, their origins and cellular agricultural components

CELLULAR AGRICULTURE PRODUCTS		
Consumer product category	Origin	Cellular agriculture component
Cellular		(Cells as main product)
Meat	A	Cultured meat cells
Fish	A	Cultured fish cells
Coffee	P	Cultured coffee cells
Chocolate	P	Cultured cacao cells
Fat	A	Cultured fat cells
Microbial protein	M	Microbial cells
Acellular		(Ingredients produced by the cultivated cells)
Milk	M	Precision fermented microbes producing milk protein casein
Milk	A	Cell cultured mammalian gland cells for milk production
Baby formula	A	Cell cultured mammalian gland cells for human milk production
Egg white	M	Precision fermented microbes producing protein ovalbumin
Fat	M	Precision fermented microbes producing fats that mimic animal or plant fats
Heme	M	Precision fermented microbes producing heme protein [Gives the blood a taste for plant-based foods]

Origin: *A* Animal, *M* Microorganism, *P* Plant

Table 3 Reviewed articles and summary of the results. Note: **CA** = cellular agriculture, **CM** = cultured meat, **LCA** = life cycle assessment, **SDG** = sustainable development goals

#	Study	Key Findings	Justice dimensions fit
1	Broad and Chiles (2022)	If CA were able to go beyond the narrative of reducing animal harm, there would be space for CA in the thin food justice approach. The thick food justice approach seems to be out	Procedural justice Recognition justice
2	Broad (2019)	There are three different concepts through which CA can be analyzed: food system reforms, food justice, and food sovereignty. Animal product alternatives are most likely to be incorporated as reforms within the corporate food regime and are generally incompatible with food sovereignty perspectives	Recognition justice
3	Chiles et al. (2021)	CA has the potential to democratize ownership and thus create environmental benefits through more stakeholder participation. It is worth investing more in technologies that could advance the 4th Industrial Revolution if that means a more just transition is possible	Procedural justice Recognition justice
4	Howard (2022)	The development of CA is predominantly controlled by big companies that already produce animal source proteins. Therefore, CA runs the risk that it could create more power asymmetries	Distributive justice Cosmopolitan justice
5	Mahoney (2022)	CA has the potential to create inequity in four different ways. It could become a niche in the luxury sector; it could further limit the access to food in certain regions and thus increase the disparity between the North and South; and lastly CA would further support big developers who currently keep their patents under disclosure	Distributive justice Cosmopolitan justice
6	Ellis et al. (2022)	The triple bottom line (TBL) is defined as the benchmark that measures people, the planet, and profit. Cultured meat needs to be affordable and profitable and the line between real corporate social responsibility and mere greenwashing is thin. CA developers are encouraged to include all those stakeholders who in the past have been deliberately overlooked and disenfranchised in these discussions and thus create equity for people affected by CA development	Procedural justice Recognition justice

Table 3 (continued)

#	Study	Key Findings	Justice dimensions fit
7	Klerkx and Rose (2020)	Novel technologies with a sustainability goal need to be discussed more carefully than other technologies. Agriculture 4.0 technologies need to take on the responsibility of going down sustainable pathways rather than compromising and taking the profit-driven pathway, even though these two pathways are not exclusive to each other. CA producers need to realize that they ought to coexist with other solutions and create diverse transition pathways that have explicit inclusion and exclusion criteria	Distributive justice Cosmopolitan justice
8	Newman wt al. (2023a)	The 17 SDGs can be categorized into focus areas on people, the planet, prosperity, and the protection of animals. CA is portrayed as an opportunity to partly reach the SDGs by cles can be overcome	Cosmopolitan justice Ecological and non/human beings
9	Moritz et al. (2022)	CA from the perspective of German stakeholders is seen as an addition to the market rather than transforming food systems. Even though environmental benefits are acknowledged, disadvantages of power asymmetries are also present	Distributive justice Capacities and justice
10	Helliwell and Burton (2021)	The promissory narratives of CA are that it is a technology that is able to reduce or even replace all the negative outcomes of traditional agriculture without addressing the possible consequences of this development. However, CA has creative destructive silences with the ability to reproduce new monocultures and new environmental problems	Distributive justice
11	Soice and Johnston (2021)	CA is analyzed in the light of centralized, decentralized, and distributed supply systems. CA in a centralized model would lead to the highest economic outcome. In the decentralized model, small-scale stakeholders could be included, and the supply chain would be shorter. The distributed model follows the idea of every household having its own bioreactor, therefore eliminating the value-chain and reducing, for instance, contamination hazards. The latter model would improve food security but is highly unlikely to be accessible and available to everyone and therefore it is not a fair solution	Distributive Justice Cosmopolitan justice Recognition justice
12	Glaros at al. (2022)	CA is one of the five novel food frontiers that has the potential to contribute to a more sustainable food system. CA producers show a high confidence in their products and CA could have a positive impact on the global food system by 2050, even though CA has a very low feasibility. The highest ecological and dietary benefits will come from controlled environmental agriculture (e.g., vertical farming)	Cosmopolitan justice Ecological and non/human beings

Table 3 (continued)

#	Study	Key Findings	Justice dimensions fit
13	Tuomisto (2022)	LCA studies of CA are based on modelling and assumptions, and thus the results have high uncertainties. As CA still requires major development before the production can be scaled up, it is unlikely that CA would make a major contribution to reaching the SDGs. Regarding cultured meat production, the accuracy of LCA studies can be improved when data from large-scale production facilities become available	Cosmopolitan justice Ecological and non/human beings
14	Rijssenbeek et al. (2022)	Conceptual normative uncertainty concerning the interpretation of sustainability is questioned. Therefore, it seems that companies might follow a different notion of sustainability (environmental impacts) than what would be required to achieve societal change. CA is part of the problem by causing with its practices a new norm of understanding sustainability. Thicker versions of sustainability are needed	Cosmopolitan justice
15	Stephens et al. (2018)	The development of CA faces various opportunities and challenges. To have an impact on the planet, a multi-faceted approach should be promoted, and CA should not be seen as the only solution. The public perceptions of CA development can quickly change and should not be taken for granted by current developers	Ecological and non/human beings Recognition justice
16	Lee (2018)	Technological solutions, such as CA, to fix complex systematic problems, should recognize the need to include social and gender transformations as proposed from the ecofeminism point of view. The feminist ecological view further emphasizes the importance that the development of CA should not be used as a tool for more dominance but should consider an inclusive and ethical perspective meaning that acknowledges that where benefits are concerned non-human beings should be valued the same as humans	Recognition justice
17	Moyano-Fernández (2023)	Cultured meat seems to have positive short-term consequences such as food security. From a utilitarian point of view, the long-term consequences need to be considered. Even if the benefits outweigh the costs compared to traditional agriculture, one moral pitfall is the missing sovereignty. Producers of cultured meat thus far fail to recognize and communicate the power dynamics that come along with this new development. Further, the integrity of non-human beings should be recognized when humans decide which animals to produce in vitro and which not	Procedural justice
18	Abrell (2023)	The development of CA is purposely miscommunicated by its producers to attract funding. It is not fast enough to have a positive impact on the climate. Current investments should have been directed toward alternative protein projects	Procedural justice

Table 3 (continued)

#	Study	Key Findings	Justice dimensions fit
19	Morais-da-Silva (2022)	The jobs that are affected by the development of CA differ along the value chain. The most affected are farmers in traditional agricultural industry. However, farmers seem optimistic that novel food technologies can create new jobs if policy measures and new strategies are supportive enough. Brazilian farmers seem more optimistic than European farmers, who seem to be the most pessimistic	Distributive justice
20	Mazac et al. (2022)	CA products such as precision fermented milk and microbial proteins can contribute to the reduction of negative environmental impacts of diets	Distributive justice Ecological and non-human beings' justice
21	Tuomisto (2019)	Novel food technologies such as cultured meat production is developed to improve global food security, but they are as yet too underdeveloped to have an impact on current problems. Due to the high production costs, it is unlikely that cultured meat will be available in low-income countries, where the highest food security issues exist. In the short term, the focus should be on advancing the sustainability of existing agricultural practices	Cosmopolitan justice
22	Parodi et al. (2018)	CA is an environmentally efficient way of producing food but only if done with renewable energy sources	Ecological and non-human beings' justice
23	Newman et al. (2023b)	There is an approach to agricultural beyond the traditional vs. alternative systems. It is a combination of many different practices including novel food technologies such as CA. A high yield, local agricultural approach would lead to shorter supply chains and more decentralization. When discussing these new ways of doing agriculture, the plurality of practices needs to be acknowledged	Distributive justice
24	Mok et al. (2020)	From a global point of view, the development of CA needs to be analyzed at according to each countries' resources. The reason why Singapore is well adapted to novel food technologies is due to its lack of agricultural space and its dependency on food technologies	Cosmopolitan justice
25	Smith et al. (2022)	To address the problems of a premature technology, such as CA production, a multidisciplinary approach is necessary to generate food for the future that is also affordable for everyone	Cosmopolitan justice
26	Smetana et al. (2015)	The LCA of meat substitutes shows that CA (cultured meat and mycoprotein-based analogues) of all the alternatives has the worst environmental impact, whereas insects and soy have the lowest impact	Ecological and non-human beings' justice
		Additional data	Part of

Table 3 (continued)

#	Study	Key Findings	Justice dimensions fit
27	Räty (2023)	A study on how farmers can be included in the CA transition. Farmers seem open to it although they consider technology to be too nascent	Distributive justice
28	Sinke et al. (2023)	Ex-ante LCA for cultured meat production, which is considered more efficient than animal-based proteins from traditional food systems, although the energy use is still high	Ecological and non-human beings' justice
29	Tumisto et al. (2022)	In the cultured meat production process, the medium has the highest environmental impact. It can be lowered through renewable energy sources	Ecological and non-human beings' justice
30	CE Delft (2021)	A techno-economic assessment (TEA) analysis of cultured meat and future scenarios	Ecological and non-human beings' justice
31	Spiller et al. (2020)	Microbial protein is assessed as a more sustainable solution for proteins. Energy consumption needs to be lowered by means of renewable sources	Ecological and non-human beings' justice
32	Sillman et al. (2020)	A LCA study of microbial proteins through power to food applications. Power to food applications shows a lower environmental impact	Ecological and non-human beings' justice
33	Kobayashi et al. (2022)	The LCA of plant cell cultures shows that energy consumption is quite high	Ecological and non-human beings' justice
34	Järviö et al. (2021)	The impact of microbial proteins compared to other proteins. Compared to animal-based proteins the environmental impact is significantly lower	Ecological and non-human beings' justice
35	Ryynänen and Toivanen (2022)	The emerging meanings of cultured meat based on online news comments. How naturalness or risks are perceived and discussed by people on the internet	Capacities and justice
36	Glaros et al. (2023)	Stakeholder interviews to assess the dimensions of how CA will enter the market. Centralized versus decentralized, open versus closed and replacement versus complementary	Procedural justice

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Declarations

Ethical The authors declare no ethical conflicts.

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