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Critical review of cultivated meat from a Nordic perspective

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ABSTRACT

Background: Cultivated meat is a novel technology with the potential to partly substitute conventional meat in the future. Production of cultivated meat is based on biotechnology for tissue engineering, up-scaling of cell cultures and stem-cell differentiation, providing the basis for large-scale proliferation of the parent cell and subsequent differentiation into primitive skeletal muscle structures known from conventional meat. Development of cultivated meat is considered a socio-technological challenge including a variety of technical, sustainability, ethical, and consumer acceptance issues.
Scope and approach: As the Nordic countries share common history and roots of food culture, cultivated meat will be introduced into a socio-cultural context with established food traditions. This review summarizes the current knowledge and activities on the development of cultivated meat in the Nordic countries and considers this novel food product in a specific socio-cultural context.
Key findings and conclusions: The production of cultivated meat in the Nordic countries, must encompass solutions that are accepted by the typical Nordic consumer. In general, this favors solutions for cell culturing based on non-GMO cells and locally accessible raw material for cell medias and scaffolding. From the perspective of the Nordic countries, this will improve the environmental, societal, and ethical context of cultivated meat.

1. Introduction

Cellular agriculture is an emerging food production sector that involves cultivation of animal, plant, fungal or microbial cells in bioreactors. The products of cellular agriculture consist of the cultivated cells such as cultivated meat (i.e., cellular products) or substances synthesized by the cells such as proteins or fats (i.e., acellular products). Cultures of animal cells in bioreactors have been suggested as a valuable source of proteins for the future. A recent report from IPCC highlights that cellular agriculture, including cultivated meat, has potential in mitigating climate change (Rama et al., 2022). The Nordic countries (Denmark, Norway, Sweden, Iceland and Finland) have strong traditions within agriculture and food production and, cultivated meat has attracted attention among consumers, producers, politicians, and researchers in these countries.

Although an early international scientific Symposium on cultivated

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meat[1] in 2008 in Norway and a workshop[2] in 2011 in Sweden have put cultivated meat on the agenda, it has been slow in gaining momentum in the Nordic countries. Generally, there has been a lack of support among public funding agencies in the Nordic countries to establish research and development of cultivated meat, although funding programs embracing cultivated meat have appeared recently (e.g. "GrowPro" funded by the Norwegian Research Council, "CleanPro" funded by the Danish Ministry for Food and Agriculture, and a minor part of the "Catch the Carbon" research program funded by the Ministry of Agriculture and Forestry of Finland).

Within the past 5–7 years, the number of start-up companies in cultivated meat and seafood internationally has increased exponentially. In the Nordic countries >5 startup companies have recently been established and large 4–5 year publicly funded R&D and platform programs have been recently funded in Denmark[3] and Norway.[4] The Nordic countries have recently prioritized the research field and the development of cultivated meat requiring multi-actor participation.

Historically, the necessity for alternative meat production or alternative proteins in the Nordic countries has not been high on the agenda. The Nordic countries have a relatively low population density ranging from 14 (Norway) to 136 (Denmark) people/km^2.[5]A wealth of agricultural land is available and allows outdoor farming of grazing cattle, sheep, goats or reindeer, or in-door farming of chicken and pigs. Moreover, hunting of wild moose, deer and boars has strong cultural traditions in the Nordic countries. Hence, limitations on the production of and access to meat is not experienced in the Nordic countries. This is in strong contrast to countries with high population densities, such as Singapore, Holland, and Israel, where cultivated meat acceptance, production, and consumption (at least for Singapore) is already in place.

The Nordic countries have, to a certain extent, a common history and worldview, which has fostered a high level of cohesion. Therefore, cultivated meat research has to encompass the cultural, ethical and societal setting of these countries. Moreover, Sweden, Finland and Denmark are all members of EU, while Norway has access to the market of the EU member states through its membership in the European Economic Area. This arrangement allows the free movement of food products within the Nordic countries and the EU market. Hence, a European perspective frames cultivated meat development within the Nordic countries. In addition, the emerging field of cultivated meat development together with alternative plant-based protein sources are anticipated as essential in the future sustainable food production systems. Therefore, the production of cultivated meat should be aligned with the concept of circular bio economy working together with the conventional meat, vegetable, and grain production industries in the Nordic region, based on local production using local raw materials.

The Nordic Joint Committee for Agricultural and Food Research funded a novel network, joining researchers from the Nordic countries working within the space of cultivated meat in 2020. The network consisted of researchers from many fields, covering the technical, environmental, ethical and consumer perspectives of cultivated meat. This review is the outcome of the network activities and aims to collate the current knowledge and activities on cultivated meat in the Nordic countries and provide the cultural context as a common ground for the discussion of the future of cultivated meat within the Nordic countries. The paper provides a perspective to discuss the future of cultivated meat in the Nordic region. Thus, we have taken a holistic, yet critical, approach to describe the technical, societal, and ethical settings in which cultivated meat will be operating and identify current challenges for consumer acceptance in the region (Fig. 1).

2. The technical aspects of cultivated meat

Bypassing livestock production cultivated meat is a complex food product that consists of animal muscle cells grown in a bioreactor. The basic technology for cultivated meat includes the following four steps: 1) harvesting of the muscle stem cells, 2) multiplying the number of cells, 3) differentiation of the muscle cells into primitive muscle fibers, 4) and assembly and maturation into a final meat product.

2.1. *Cell sourcing and culturing*

The starting point for cultivated meat production is the in vitro cultivation of animal cells with a high proliferative capacity, which subsequently can differentiate into primitive muscle fibers. Several stem cell types can theoretically be utilised for this purpose, e.g. embryonic stem cells (ESCs) (Bogliotti et al., 2018; Yuan, 2018), mesenchymal stem cells (MSCs) (Du et al., 2010; Okamura et al., 2018; Ramírez-Espinosa et al., 2016) and induced pluripotent stem cells (iPSCs) (Specht et al., 2018). However the currently most used and well-studied cell source is the satellite cells (SCs) (Ben-Arye & Levenberg, 2019).

2.1.1. *Satellite cells*

Satellite cells (SC) are adult skeletal muscle stem cells located between the sarcolemma and the basal lamina of skeletal muscle fibers (Mauro, 1961). The ability of the activated SC, to undergo proliferation, differentiation, and fusion into new multinucleated muscle fibers, makes them relevant candidates for creating cultivated meat products. These animal stem cells can be obtained from a muscle biopsy from live animals or tissue sampled at the slaughterhouse. The isolation of SCs is relatively straight-forward; consisting of mechanical disruption of the muscle tissue followed by an enzymatic digestion, which collectively releases the SCs along with other cell types (Veiseth-Kent et al., 2019). The SCs can be further purified by several strategies such as pre-plating techniques (Shahini et al., 2018; Yoshioka et al., 2020), cold treatment (Benedetti et al., 2021), density gradient centrifugation (Matsuyoshi et al., 2019), fluorescence-activated cell sorting (Maesner et al., 2016) and magnetic-activated cell sorting (Agley et al., 2015). Nevertheless, SCs can still be used without any purification (Baquero-Perez et al., 2012), and even after prolonged cold storage of muscle tissue, SCs retained their viability and myogenic capacity (Skrivergaard et al., 2021). Interactions between SCs and fibroblasts are important for SC expansion, myogenesis and muscle regeneration (Murphy et al., 2011), which suggests advantages of an impure cell population. However, the heterogeneity of these cultures might negatively affect long-term expansion and subsequent myogenic differentiation in large-scale bioreactors, as a fibroblastic sub-population could potentially overtake the culture. Hence, cell population characteristics is important for predicting and controlling upscaling.

The innate ability of satellite cells to easily differentiate into mature muscle-fibers, due to their committed stem cell type (Asakura et al., 2001), also limits their ability to proliferate. Thus, after a certain amount of cell doublings (known as the Hayflick limit) they will eventually undergo cell senescence (Khorraminejad-Shirazi et al., 2019). This provides the SC with a major disadvantage to produce cultivated meat and necessitate a continuous source of starting cell material, although the availability is not an issue with the current production of farmed animals. This limitation could however be overcome by genetic

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[1] The first In vitro Meat Symposium, April 2008, hosted by Nofima (previous Matforsk) and Norwegian University of Life Sciences, Ås, Norway. http://web.archive.org/web/20150216061850/http://invitromeat.org/content/view/14/1/.

[2] European Science Foundation Exploratory Workshop on In vitro Meat: Possibilities and realities for an alternative future meat source, Julie Gold & Stellan Wellin, Aug 31-Sept 2, 2011, Chalmers University of Technology, Gothenburg, Sweden.

[3] Flagship project on Cellular food for sustainable production and innovative food concepts (CellFood), Jette Feveile Young, Aarhus University, June 2022.

[4] ARRIVAL of cellular agriculture- Enabling biotechnology for future food production, Coordinated by Nofima/funded by Norwegian Research Council, June 2023–2027.

[5] Wikipedia, population data from 2020.

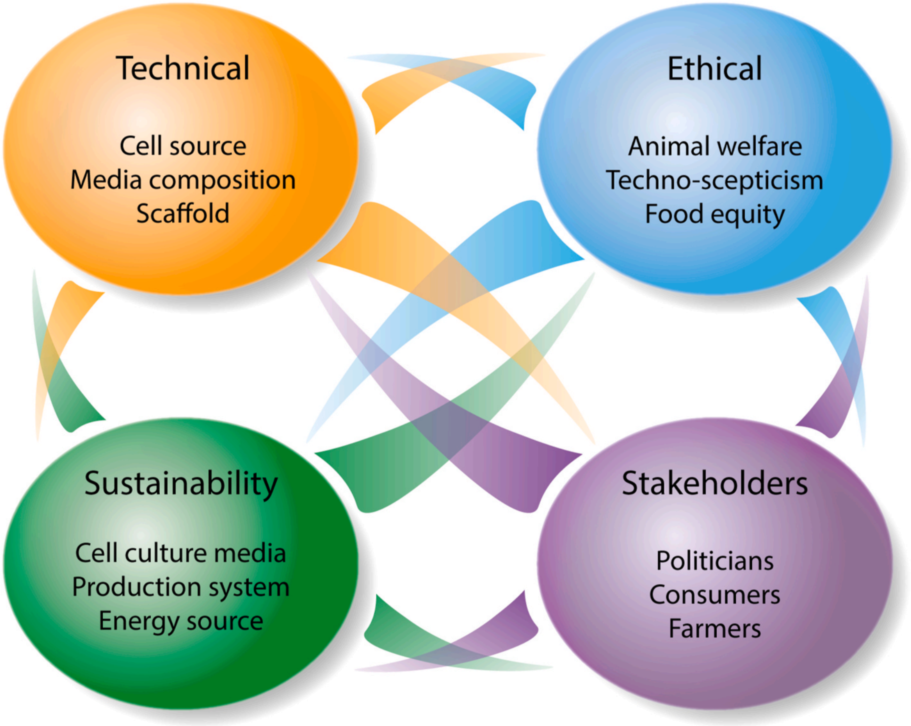

Fig. 1. The future frame of cultivated meat is defined by the interplay between technical, ethical, sustainability and stakeholder aspects.

engineering (Lundberg et al., 2002) or environmental cues (Ding et al., 2018) fostering immortalization. The limitation of SC expansion might be more easily circumvented by cell immortalization. Some established methods exist for the creation of an immortalized cell line, e.g. discovering spontaneous immortalization or genetically engineering the cells to express telomerase and/or to inactivate cell cycle regulators (Soice & Johnston, 2021a). Examples of these in the cultivated meat industry already exist, as the company Future Meat (Israel) uses a patented spontaneously immortalized chick embryo fibroblast, while Upside Foods (USA) uses a patented engineered chicken skeletal muscle cell line with both overexpression of telomerase and gene knock-out (the cell cycle regulators p15 and p16 (Soice & Johnston, 2021b)).

2.2. *Cell culture media*

Although the first proof-of-concept burger, produced using bovine SCs, were presented in 2013, only ground meats and patties (usually in the mm thickness range) are produced today for several reasons. Large-scale bio-production of animal proteins needs to become more efficient than the 2D standard technique used for culturing the first hamburger (Post, 2014). It is difficult to grow enough viable muscle cells, since the muscle cells are adherent and efficient growth depends on optimal growth conditions including sufficient nutrients and an appropriate microenvironment. Thus, the cell culture media to sustain the production of cultivated meat is among the biggest challenges to solve. The optimal growth media must be low-cost, sustainable, food-grade, available in large quantities, and most importantly effective in maintaining cell proliferation and promote differentiation (O'Neill et al., 2021). Basic cell culture media contains glucose, amino acids, minerals, vitamins and buffers; ingredients generated by bacterial fermentation and from plant sources. In addition, cell culture media is traditionally supplemented with large quantities of blood serum, containing growth factors, enzymes, carbohydrates, and proteins vital for growth and differentiation of cells. Normally, blood serum is harvested from bovine fetuses at the slaughterhouse, which positions serum supplementation as a limiting factor for sustainable large-scale productions in addition to ethical issues.

Internationally, a great deal of research has been conducted to develop serum-free media (SFM) using e.g., recombinant proteins (Venkatesan et al., 2022), and many different SFM formulations have now been developed that supports high cell growth and differentiation capacity. However, commonly these media are seldom based on components compatible with food. Moreover, while commercial SFMs are effective for most immortalized cell-lines, they are not necessarily designed for primary cells, with cost and sustainability in mind. Many of the commercially available serum replacements show lower performance, are only suitable for a limited number of cell lines and may even undesirably alter the cell phenotype (Kolkmann et al., 2020; Post et al., 2020). For example, most SFMs are produced with biomedical research-grade quality compounds, applied in industries where the final product value is exceptionally high (millions of dollars per kg) compared to the food industry market value (O'Neill et al., 2020).

A promising solution, from a Nordic perspective is the use of side-streams from established food-productions. A recent study reports increased cell growth and metabolic rates using SFM based on protein hydrolysates from pig blood plasma, egg white, chicken carcass and yeast extract (Andreassen, Pedersen, Kristoffersen, & Ronning, 2020). By-products from food production are available in large quantities, in fact it is estimated that nearly 40–60% of total mass of farmed fish and animals are classified as residual products with food-grade quality, including carcasses, blood and skin (Aspevik et al., 2017). Biotech industries in the Nordic countries, based on enzymatic hydrolysis of by-products, have already begun exploring the promising potential of the generated peptides from underutilized biomasses. In Norway, there are already industrial enzymatic protein hydrolysis plants built that produce peptides from poultry and marine resources at industrial scale. Apart from the nutritional values, bioactive peptides are released from the by-products via hydrolysis and can exert beneficial effects on physiological functions, including cell growth regulation and promoting cell culture performance. For example, hydrolysates from food sources such as chicken carcass have been shown to have growth-promoting effects and stimulate insulin-associated signaling pathways in mammalian cell culture (Iwasa et al., 2021; Roblet et al., 2016). Bioactive molecules originating from by-products, such as carbohydrates, glycosaminoglycans, eggshell membrane and protein hydrolysates, are examples of promising constituents that can be included in a tailor-made growth media. Also, plant-based hydrolysates are promising constituents in SFM, and preliminary data from Nofima, Norway, show e.g., pea hydrolysates as growth promoting agents (unpublished data). Interestingly, hydrolysates from food by-products are food-grade, low-cost, easy to obtain and contain a wide range of low molecular weight (MW) nutrients found in traditional basic cell culture medium.

Previous research has shown that hydrolysates of by-product rich in small peptides were beneficial to cell growth (Andreassen, Pedersen, Kristoffersen, & Beate Rønning, 2020). The response was dependent on both material and choice of enzyme during hydrolysis. Also, it was demonstrated that supplementation of fibrous proteins (collagen, entactin and laminin) in combination with glycosaminoglycans improved cell growth and early differentiation of primary skeletal bovine muscle cells (Rønning et al., 2013). Others have shown improved muscle protein synthesis using protein hydrolysates from soy, dairy, beef and egg protein (Roeseler et al., 2017). The eggshell membrane (ESM) is another promising fibrous material that contains active components (carbohydrates, proteins, and peptides), growth factors and enzymes supporting cell growth and survival (Ahmed et al., 2017; Vuong et al., 2017) (Fig. 2).

Kolkmann et al., (Kolkmann et al., 2020) demonstrated that SFMs developed for fibroblasts and human pluripotent stem cells could sustain cell expansion of bovine satellite cells, although not as efficiently as media containing FBS. Adding various myogenic-related growth factors (GFs) to the medium improve myogenesis progression and may be sufficient as serum replacement (Ben-Arye et al., 2020; McAleer et al., 2015). However, like FBS, these essential signaling molecules are expensive, and the cost can be over 95% of the total SFM composition. Recently, Stout et al., (Stout et al., 2021) also demonstrated that bovine satellite cells could maintain robust cell growth for several passages when adding recombinant albumin to SFM. Although this research clearly shows promising results for development of a SFM, further optimization of cell culture efficiency and cost reductions are required to produce a scalable cultivated meat SFM.

2.3. *The production of cultivated meat as a food*

2.3.1. *Scaffolds*

The ability of the muscle cells in up-scaled production to produce structured proteins, fats, and connective tissues is a challenge for cultivated meat production. Scaffolds offers support for cell attachment, provide guidance for cell proliferation, differentiation, and organization (Chan & Leong, 2008; Engler et al., 2004; O'Brien, 2011). Thus, the scaffold should provide the cells with biochemical and biophysical cues, so to control the shape and cell type of the growing tissues, and at the same time facilitate oxygen and nutrient delivery and removal of toxic products produced by the cells (Chan & Leong, 2008; Chen et al., 2012; Schuster et al., 2016). Scaffold development for cultivated meat has many aspects in common with the research area of tissue engineering, with the additional challenges of scalability, edibility, sensory properties and affordability required for food production. Hence, while several materials are suitable for biomedicine, here we only include those that

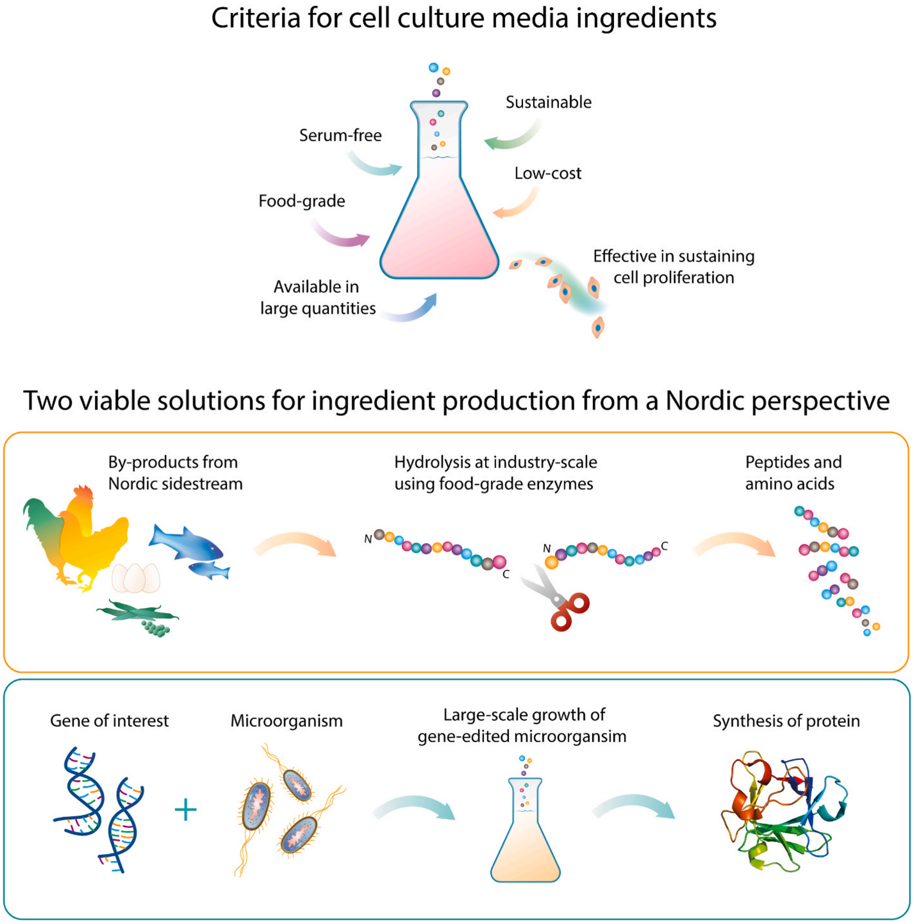

Fig. 2. There are several important criteria for an optimal growth medium: Low-cost, sustainable, serum-free, food-grade, available in large quantities, and most importantly effective in maintaining cell proliferation. Two viable solutions from a Nordic perspective are using by-products from Nordic side streams (upper part of figure), and by recombinant protein production (lower part of figure).

could be edible and relevant to the Nordic countries e.g., originating from side-streams of food or ligocellulosic production in the Nordic countries (Fig. 3).

Scaffolds can be used as support only; e.g. microcarriers used during an expansion phase in bioreactors which are removed from the final product or incorporated within the cultivated cells for consumption. The last option will probably be the most appealing for large scale production. The mentioned options require different scaffold material, and it follows that if the scaffold will be consumed as food, it needs to be food grade, and add desirable nutritional and sensorial attributes to the cultivated meat. This reduces the choices of material and cross-linkers.

Apart from gel-based scaffolds, cells can grow on micro-particles or micro-carriers. There are several micro-carriers developed for the biomedical area, with potential in cellular agriculture (McKee & Chaudhry, 2017). These are micro-carriers based on cellulose, gelatin, starch and microcarriers based on food side-streams. (Norris et al., 2022; Wallin, Hoglund, et al., 2012). Starch is a non-animal derived carbohydrate, abundantly available across the globe and in the Nordic countries. Starch microspheres can be used for differentiation of muscle cells in suspension culture but needs to be cross-linked to form the micro-spheres and surface functionalized to support cell attachment and growth. C2C12 myocytes were shown to attach and differentiate into myofibers on positively charged starch microspheres, but not to negative or neutral spheres (Wallin, Hoglund, et al., 2012). Micro-carriers will not structure the cells, so the cells needs either to be separated from the carriers, the carrier degrade over time or be edible. Nutritional value of the C2C12 cells growing on positively charged starch microspheres had total protein content of cultivated cell or starch biomass within the range measured for hamburger, sausage and steak, while myoglobin levels were 10 fold lower (Wallin, Hoglund, et al., 2012). Moreover, microcarriers based on by-products from the food industry, including eggshell membrane powder and collagen from turkey, have bioactive surfaces allowing interactions with the satellite cells (Andreassen et al., 2022).

Porous scaffolds have sponge like structure with pore size ranging from 10 to 100s of μm, showing advantages compared to hydrogels, in having larger pore size allowing for flow of nutrients through the scaffold-cell construct. Porous scaffolds can be obtained through different techniques. Texturized soy, i.e., extruded defatted soy flour, has been shown to act as support for growth of skeletal muscle cells (Ben-Arye et al., 2020). Texturized soy provides a support with interconnected pores in the micrometer range when wet. Seeding cells on top of wet texturized soy, enable cells to grow and penetrate up to 1 cm into the scaffold (Ben-Arye et al., 2020). Soy protein is not a Nordic grown ingredient, but extrusion of the Nordic-relevant pea protein has been suggested as scaffold (Krona, Klose, Gold, Kádár, & Stading, 2017), in a similar way as shown for soy.

The mentioned scaffolds are example with little control of material properties (such as mechanical, pore size and elasticity). Porous scaffolds can also be made under more controlled routes and has been used extensively in biomedicine. Generally, pores in the region of μm require a template, such as salt, ice, or sugar. The network is formed around the template, which, when removed, are dissolved, or melted, leaving a network with large pores, resembling a sponge like material (Lozinsky et al., 2003; Ström et al., 2015). Examples are cryo-gels that can be made with edible polysaccharides and proteins such as; chitosan-gelatin, crosslinked with glutaraldehyde (Miranda et al., 2011), as well as chitosan-collagen and fish gelatin (Tylingo et al., 2016), collagen (Chen et al., 2024) or freeze drying of ethanol suspended glutenin, which supported proliferation and differentiation of C2C12 cells without the

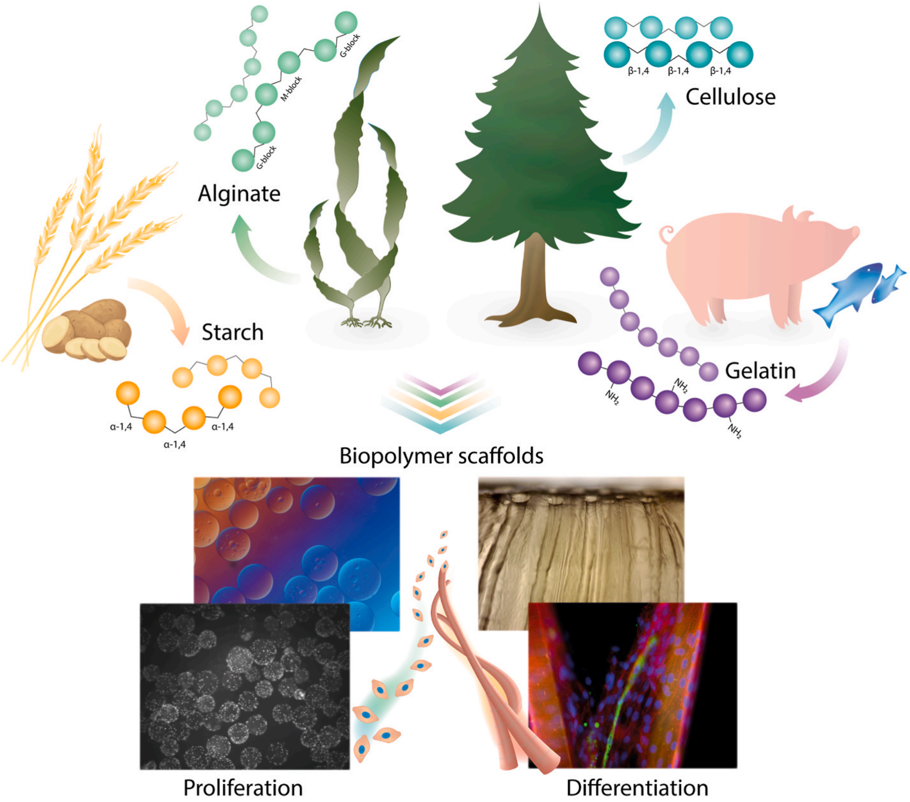

Fig. 3. Sources and biopolymers for microspheres and scaffolds. Cellulose derived from wood, alginate from macroalgae, gelatin from animal or fish side-streams and starch from cereals or potatoes are examples of polymers that can be made into microcarrier beads and other forms of scaffolds for cultured meat production (upper part of figure). Images of microcarrier beads based on modified starch (images on the left) with proliferating cells, and porous scaffolds exemplified through calcium alginate gels interspersed with capillaries or polymeric fibers (images on the right) with differentiation of cells to muscle fibers (green, myosin heavy chain) (lower part of figure). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

addition of ECM proteins (Xiang et al., 2022). Porous scaffolds have also been prepared from eggshell membrane containing bioactive ingredients (Rønning et al., 2020).

Hydrogels are crosslinked hydrophilic polymers with large water holding capacity. It is common that gels contain up to 99% water and 1% polymer. Hydrogels have been extensively used in the biomedical area due to its high-water content mimicking biological tissues. Gels are also used widely in the food industry. The gels have pore-sizes in the range of nm. Examples of polysaccharide hydrogels are calcium induced alginate (Draget et al., 1997; Schuster et al., 2014) and pectin gels (Strom et al., 2007), agarose (Martinez-Sanz et al., 2020; Normand et al., 2000), ion induced gellan (Rodriguez-Hernández et al., 2003), chitosan (Montembault et al., 2005) and carrageenan (Rochas & Rinaudo, 1984). Such gels can be made in a variety of shapes and with controlled mechanical properties. They are based on food-grade materials of low cost but lack the tripeptide sequence arg-gly-asp (RGD), necessary for cell adhesion. Alginate synthetized with RGD is commercially available, but the mentioned polysaccharides can also make gels in the presence of gelatin (Goudoulas & Germann, 2017; Panouillé & Larreta-Garde, 2009), collagen (Baniasadi & Minary-Jolandan, 2015; Moxon et al., 2019) or fibrin (Vorwald et al., 2020), which inherently provide RGD motifs. Alginate forms gels readily when in contact with calcium ions (Draget et al., 1997; Schuster et al., 2014). Schuster and co-workers showed how skeletal muscle cells could be grown in capillaries through an alginate gel. The capillaries served to align the muscle cells as well as ensuring constant nutrient delivery (Schuster et al., 2017).

Addition of proteins to polysaccharide-based gels can also be done for nutritional reasons. The gelation properties of the polysaccharides can in these cases be altered. Agarose and pea protein ($<2.5\%$), as well as gellan and pea protein ($\leq 1\%$) gels can be formed, and the proteins are non-toxic for C2C12 cells. However, it is not yet known whether the added protein influence cellular growth, morphology and differentiation (Wollschlaeger et al., 2022). Collagen is often mixed with polysaccharides or require crosslinking as collagen by itself forms mechanically weak materials. Crosslinking with edible, non-toxic riboflavin-derivate lumichrome offers a viable alternative to other cross-linkers (Grønlien, Pedersen, Sb, Solberg, & Tønnesen, 2022).

Achiving adequate vascularization and or alignment of the muscle cells, are often mentioned challenges for the scaffolds formed from hydrogels (Schuster et al., 2016). Solutions could be to grow the cells on porous sheets, and then stack these together to form 3D-scaffold (Papenburg et al., 2009) and to develop channel networks in 3D printed sacrificial molds (Mohanty et al., 2015), or creating micropatterned gels promoting alignment of cells (Orellana et al., 2020). Creating micropattern of such gels are simple and flexible: a mold is made from for example acrylic material, upon which the micro-patterned gels are cold-casted (Andersson et al., 2018; Orellana et al., 2020).

The possibilities of creating scaffolds with controlled mechanical properties, in different shapes and patterned structures from different materials are considerable. However, limitations of their use in terms of scaling (Post, 2012), as edible ingredients, their taste and texture if consumed with the cultivated cells, and their nutritional value is not yet explored.

2.4. *Sensory and nutritional characteristics*

Apart from the technical challenges of producing a muscle-based biomass suitable for cultivated meat, the final transformation into food should also be considered. Cultivated meat consisting of muscle fibers and adipocytes, or lipids added as supplement, needs to be transformed from a cell culture into a food product. In terms of taste and nutrition of a cultivated meat product, the addition of cultivated animal fat is essential (Fraeye et al., 2020). Therefore, cell sources that can contribute to this might be equally important as the muscle component. Due to several differentiation pathways of SCs (Aguiari et al., 2008; Song & Tuan, 2004) and the adipogenic potential of SCs (Asakura et al., 2001; Sanna et al., 2009), it would be possible to transdifferentiate SCs in such a way that both muscle-fiber and fat cells are co-cultured for a better tasting cultivated meat product. SCs with co-cultured adipocytes is also a possibility (Kuppusamy et al., 2020). However, the added complexity might be problematic, and the addition of cell cultured fat after muscle-fiber formation might be the solution.

The use of iPSCs, immortalization and genetic engineering would also apply for the many possible adipogenic cell types and lipid producing systems herein. Nevertheless, the importance of fat in cultivated meat should not be neglected (Fish et al., 2020). We have recently described the importance of fat from the perspective of conventional meat science extrapolating to possible similar processes in cultivated meat (Young et al., 2023). To the best of our knowledge, the scientific literature does not yet offer sensory comparisons between conventional meat and cultivated meat. Nutrients and oxygen are withdrawn from the cells when harvesting cells for cultivated meat. In this process, it is foreseen that the individual muscle fibers change their metabolism leading to a maturation process where the structural proteins in the myofibrils, are degraded. This process both changes the structure and generates peptides and amino acids contributing to the taste, or as precursors reacting with reducing sugars upon cooking (Maillard reactions) where a range of aroma components are formed (Jousse et al., 2002).

In addition, lipids also significantly contribute to flavor both per se and through oxidation processes. Fat in the final product further contributes to the unique mouthfeel and juiciness of cultivated meat. Moreover, juiciness is also closely linked to water holding capacity of the meat. Water is held within the myofibrillar structure, being dependent of the pH change derived from the anaerobic post-harvest metabolism. This emphasizes the importance of ensuring the development of myofibrils in the cell culture, ensure embedding of a lipid source into the product and secure an optimal post-harvest pH profile which all contributes to taste and juiciness of the final product.

Apart from taste and functionality, nutritional value is important for the consumer. Protein and lipid are the major nutritional components of meat. The biological value (BV) related to amino acid composition and digestibility of the protein (Protein Digestibility Corrected Amino Acid Score, PDCAAS) and the profile of fatty acids are central. For proteins, it is desirable to obtain as high BV and PDCAAS (Pereira & Vicente, 2013) as possible whereas a health beneficial fatty acids profile with high amounts of unsaturated fatty acids should be aimed for from a purely nutritional perspective. Moreover, it may also be critical to ensure the content of minor components like vitamin B12 and highly bioavailable iron (heme iron) as these components are primarily obtained from the animal derived products (Bohrer, 2017). The officially recommended diet in the Nordic countries (Blomhoff et al., 2023), recommends reduced overall meat intake. Thus, it is expected to demand a cultivated meat product delivering similar or better nutritional value compared with conventional meat for consumer acceptance.

3. The sustainability of cultivated meat

One of the overarching arguments for establishing the technology to produce cultivated meat is the perspective of producing meat in a more sustainable way than today. A few studies have estimated the environmental impacts of cultivated meat using prospective life cycle assessment (LCA) methods (Mattick et al., 2015; Sinke et al., 2023; Smetana et al., 2015; Tuomisto, Allan, & Ellis, 2022; Tuomisto & Teixeira de Mattos, 2011). These studies have high uncertainties as they rely on modelling of large-scale cultivated meat production facilities, for which no data are currently available. The studies estimated the environmental impacts of cultivated meat along the life cycle of the production process from resource extraction up to the factory gate, including processes such as input production (medium ingredients, energy, scaffolds and bioreactors and infrastructure in some of the studies), cell culturing processes, wastewater treatment and cleaning of the bioreactors. All of the studies used 100-year time frame for estimating the climate impact (i.e. global warming potential within 100 years, GWP100). The studies included food grade medium ingredients, such as amino acids and glucose. When comparisons were made with conventionally produced meat, the livestock systems had similar system boundaries from resource extraction up to the farm gate. The carbon sequestration of pasture lands is not included in the calculations. However, as ruminant meat production requires more land area than cultivated meat production, the replacement of livestock meat with cultivated meat would free the current permanent pastureland areas for other uses. In some areas that would enable growing more trees on the old pasture lands, which would fix more carbon into the vegetation and soils (Hayek et al., 2020). The soil carbon stock changes are usually not included in LCA studies due to high uncertainties regarding the carbon flows. Even the soils at ruminant livestock farms are not always net carbon sinks in the Nordics (Henryson et al., 2022). The results show that the production of cell culture medium and energy requirements of the bioreactors have the highest contribution to the environmental impacts. Therefore, the sources of medium ingredients and the bioprocess design are the most important factors determining the environmental impacts. In addition, the quantities and composition of medium are highly uncertain and have high influence on the environmental outcomes. Thus, also improving the efficiency of nutrient use and recycling of used medium can reduce the environmental impacts. Due to the differences in the process design included in the LCA studies, the results for carbon footprint of cultivated meat have a wide variation between the studies (Fig. 4).

Importantly, the environmental impacts of cultivated meat also depend on the production location. For instance, the energy sources for electricity and the associated environmental impacts vary highly between different countries and regions. Similarly, water scarcity impact depends on location, as the weighting factors used to describe the impact of using a unit of water ranges between 1 and 100 depending on the availability in the region (Boulay et al., 2019). Biodiversity impacts are dependent on the species richness of the natural state of the land, which is significantly higher, for instance, in the Amazon area compared to Nordic countries. The environmental impacts of conventional meat production further vary highly in different countries and production systems. Even the production systems in Nordic countries are versatile ranging from extensively grazed beef production systems in the highlands of Norway to intensive pork production in Denmark.

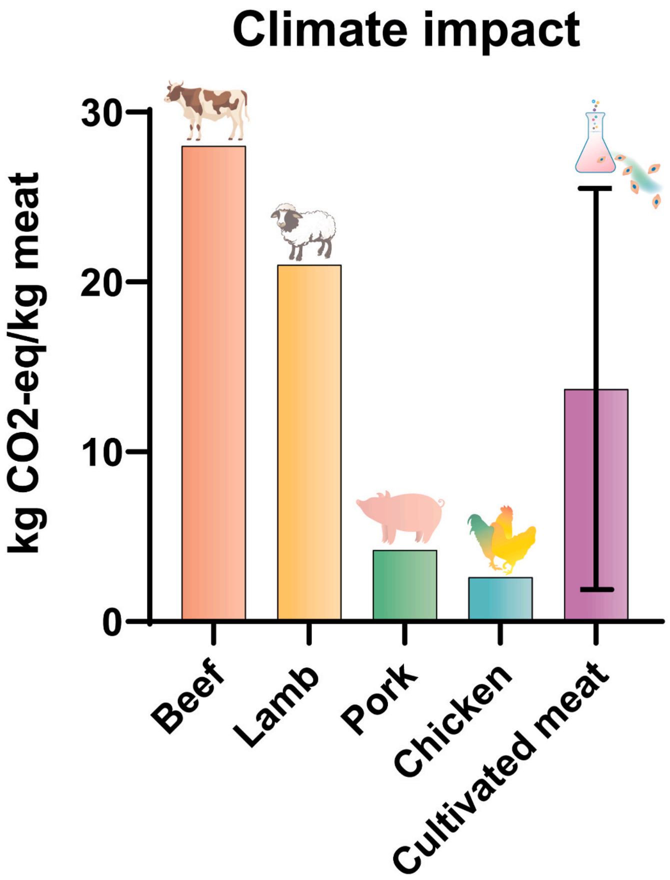

Fig. 4. Climate impact of conventionally produced meat produced in Sweden (source: RISE Food climate database, 2021) and cultivated meat production (error bar shows the range from the minimum and maximum values found in published LCA studies of cultivated meat, and the bar shows the mid-point value: Mattick et al., 2015; Sinke et al., 2023; Tuomisto and Teixeira de Mattos, 2011; Tuomisto et al., 2022a).

3.1. *Cell culture medium*

The main challenges regarding the development of culture medium include the replacement of FBS and lowering the overall cost. In terms of environmental impacts, the production of synthetic amino acids have high impact contributing over 50% to most environmental footprints of the whole cultured medium production (Tuomisto et al., 2022). Serum-free medium can reduce the environmental impacts of culture medium production by 30–50%, but the net benefits depend on how the serum-free medium support the cell growth (Tuomisto et al., 2022). FBS contain factors that affect cell adhesion, such as fibronectin, laminin and albumin. Also, FBS has a high level of specific growth factors and cytokines, which specifically affect the cell growth and proliferation. Also, specific sugars and amino acids supports the cell growth. Finally, hormone factors and transport proteins are necessary components that ensure cell viability. Animal-based ingredients naturally contain many of these ingredients (Lee et al., 2022). Therefore, the use of animal-based by-products from slaughterhouses and food industry could provide culture medium ingredients supporting a circular bio economy. Preliminary results of the environmental impacts of protein hydrolysates, however, show that plant-based sources have lower impacts compared to animal-based sources (Karinen, Beate Rønning, & Tuomisto, 2023). Hence, plant-based protein hydrolysates could be used as source of amino acids further reducing the environmental impact of culture medium production (Sinke et al., 2023).

The contribution of glucose on the environmental impacts of culture medium production vary between 10 and 30% depending on the impact category (Tuomisto et al., 2022). Typically, glucose is obtained from maize or sugar cane that are not commonly grown in large parts of the Nordic countries. Potatoes, grain crops and sugar beet as well as side-streams of food and forest industries could provide potential sustainable sources for glucose in the Nordic countries (Karinen et al., 2023; Upcraft et al., 2021). Preliminary findings show that especially potatoes and lignocellulosic production of sawdust could have lower environmental impacts compared to glucose production from maize (Karinen et al., 2023).

3.2. *Energy sources*

As cultivated meat production is highly energy intensive, the source of electricity has a major impact on the environmental footprint of the products. For example, the use of solar or wind energy instead of the average electricity grid energy for cultivated meat production processes and production of amino acids and glucose, would reduce the climate impacts of cultivated meat production by 30% the United Kingdom (UK) (Tuomisto et al., 2022). Further reductions in the climate impacts would require the use of low emission energy sources also in other input production processes. In the UK, the CO_2 emission intensity of electricity grid in 2021 was 254 g/KWh (O'Sullivan, 2022) whereas in Sweden it was only 9 g/KWh, Norway 27 g/KWh, Finland 77 g/KWh and Denmark 130 g/KWh (EEA, 2022; Nowtricity, 2022). As cultivated meat production has higher electricity requirements compared to conventional produced meat the expansion of cultivated meat production would increase the demand for energy. The provision of low emission energy sources or optimized energy utilization is a requirement for achieving a low carbon footprint for cultivated meat (Lynch & Pierrehumbert, 2019). Therefore, capacity of expanding low emission electricity supply in Nordic countries is a key for sustainable cultivated meat production. As cultivated meat production requires less agricultural land compared to conventional meat, the land area released from agriculture could potentially be used for sustainable energy production.

3.3. Integration with sustainable farming

The sustainability of cultivated meat production could be further improved by integrating the production with sustainable farming systems and renewable energy generation (Koppelmäki et al., 2019). Cultivated meat production facilities at farms or near farms would provide possibilities for efficient recycling of nutrients and reduce the transportation of inputs. The cultured medium ingredients, such as amino acids from legumes and glucose from potatoes, could be produced at farms using sustainable agricultural practices. Grass leys could also be potential source for both amino acids and glucose. Side-streams of crop production and other locally sourced side-streams from forestry or food industry could be processed for culture medium ingredients. The farm would also produce sustainable energy, such as biogas, solar energy or wind for the farm operations and bioreactors. Especially, biogas production from grass-clover lays would also help to improve the nutrient self-sufficiency and improve soil properties. The residual nutrients from the biogas and cultivated meat production could be used as fertilizers at the fields.

The issue with high hygiene standards and food safety may limit the possibilities of cultivated meat production at farms. However, similar environmental benefits and efficient recycling of nutrients could also be achieved when the cultivated meat production facilities are placed near the farms even if they were not part of the same enterprise. The optimal location for the cultivated meat production would depend also on the proximity to the consumers. In many Nordic countries, the agricultural production locates relatively far from most of the consumers. In these cases, the cultivated meat production facilities may be more efficiently located closer to the consumption as transportation of the inputs may be more cost effective than that of the final products. In urban environments, vertical farming or urban farming systems could potentially provide opportunities for nutrient recycling.

4. The ethical aspects and value-choices of cultivated meat

Although technological potentials and environmental impacts associated with cultivated meat form the starting points for the development, the final products will be introduced to extant Nordic food cultures. In addition values and ethical issues are arguably among the major drivers of the development of cultivated meat and other food-technological developments (Kaiser & Algers, 2016). Given that innovation and development of industrial products is highly cost-intensive, investments are a function of expected market-returns. These are dependent on consumers' willingness to pay for it and eat cultivated meat. Nevertheless, investments are made now, and the returns are a good way into the future. What follows from this is a relatively high degree of uncertainty: even if we know something about consumers' (and producers') attitudes to cultivated meat at present, we cannot easily extrapolate from these data into the future. Attitudes may change. What we do know, however, is that the future attitude will be a reflection of underlying value-commitments, which in turn have a relatively long permanence and life (Kaiser, 2022). We can frequently change a specific attitude to certain aspects of life or goods on the market, while we cannot with the same frequency change our underlying values, which inform these attitudes without threatening our personal and social identity.

The values are an element of our food identities. Here a historical and socio-cultural observation needs to be made. One may reasonably assume that roughly half a century ago our food identities were mainly a function of three to four parameters, most probably: tradition, locality, availability and price. These parameters were basically, not much affected by individual choices and were typically shared within larger groups of similar socio-cultural and regional background. This has changed dramatically as food identities reflect the fragmentation in our Nordic socio-cultural surroundings; they often define niche consumption patterns and are highly influenced by value-based ethical convictions of the individual (Herdoiza et al., 2022).

It is for this reason that a closer look at ethical issues can provide us with some guidance on framing conditions for developing cultivated meat. We shall examine some of them. They are: (1) animal welfare, (2) sustainability and greenhouse gas (GHG) emission, (3) food equity and food sovereignty, (4) naturalness and techno-skepticism, (5) nutrition and food safety, and (6) issues of global justice.

4.1. Animal welfare

One of the strongest positive drivers for the development of cultivated meat is the animal welfare perspective. During the last decades, animal welfare has become a major political factor in food production and consumption in the industrialized world (Cornish et al., 2016). For example, pictures of battery caged hens in egg production, the confinement of pigs in metal-barred crates, packed transports of sheep across the country or the industrialized mass-killing of cows in slaughterhouses have enraged the public opinion and brought about massive criticism, and to a certain extent regulatory measures (Sødring et al., 2020). Economic and nutritious qualities alone would not account for consumer attitudes to food, but that concern for the quality of life of the animal before slaughtering would count as a driver towards acceptance. This is a marker of what has also been called "political consumerism" (Stolle et al., 2005; Ward & de Vreese, 2011). Ultimately, cultivated meat has a definite market advantage; no (or nearly no) animal suffering or killing for obtaining cells for the production. This does not mean that all existing animal welfare issues as faced in existing and agricultural practices will disappear. It is only focused on those products that will result from in-vitro meat. A consumer of this meat will have the assurance that no animal had to be killed to provide for the hamburger, sausage or chicken in-vitro meat consumed. There might still be a small number of animals which will be supplying the necessary growth medium, possibly from side-streams of conventional food production. However, this is a negligible amount compared to the conventional production of these products. Potentially this could even be an argument for a segment of vegetarians to accept cultivated meat as food, while some vegetarians may still object to the centrality of meat in our diet. However, developing cultivated meat will mainly be targeted at a section of current meat-eaters, namely those who feel uncomfortable about the implications of their dietary preferences for the animals (Bryant & Barnett, 2020). Cultivated meat products will realistically not be a replacement of all other and more conventional ways of meat production, which means that positive animal welfare issues arise only for the market segment that consumes these products.

4.2. Sustainability

One of the current ethical dilemmas is bringing food production into a more sustainable framework. A significant amount of global GHG-emissions is caused by our current livestock production (and to a certain extent its consumption patterns as well) (O'Mara, 2011). Meat consumption is also on the rise globally as many countries experience economic growth, especially China. The global human population is expected to rise to up to 10 billion by the year 2050 and the resulting need to produce and distribute enough food for this number of people. The global Human Trophic Level is steadily on the rise, mainly due to ever increasing meat consumption in China and India, and more or less stagnating levels of meat consumption in the industrialized countries like in the EU and USA (Bonhommeau et al., 2013). In this context, switching to cultivated meat production could potentially reduce the need for agricultural land, freshwater, antibiotics, polluting chemicals (herbicides and pesticides) and resources for feed (Tuomisto, 2019). It should be noticed that antibiotics might still be needed in some production systems and that herbicide and pesticides could still be used in plant-based production of glucose. However, all extrapolation into the future environmental benefits is still uncertain as described in previous section. In particular, one needs to look more specifically at certain products. The feed conversion rate for salmon aquaculture or chicken for instance is rather good, and when this should compare to the currently high energy amount which goes into the production of cultivated meat the net result is certainly not clear. Thus, there are admittedly a number of presuppositions which one needs to make in order for this accounting to go through. Yet, when examining the global GHG emissions from ruminants and when assuming that renewable energy sources can go into the production of cultivated meat then one may assume a sustainability account in favour of cultivated meat.

4.3. Food equity and sovereignty

One of the current problems in our food systems is the inequality of access to food. This has been aggravated recently through the COVID-19 pandemic and the war in Ukraine, which both affected global supply lines. What we witness is an increase in food insecurity, and this insecurity is disproportionately divided among continents and countries. To improve food equity the call for more food sovereignty is increasing (Edelman et al., 2014). Even in affluent countries, like in Northern Europe, voices can now be heard to counter the trend to globalized food webs by more reliance on locally produced food. Given the sustainability and environmental aspects, people seek to increase alternative food production systems as, for instance, organic food production. This combined with a trend towards local production rather than imports would arguably increase food sovereignty (Diehl et al., 2020). One has to add that all such statements are currently nothing but statements of mere belief, but a belief apparently shared by many consumers in the industrialized world. Local food products see a rise in demand in Europe, for instance in local food markets and festivals. How this will position cultivated meat remains an open question. It seems to depend on whether the producing industry would be from the region and therefore positively identifiable by the consumers. However, currently this is assumedly not the most likely path for further developments.

4.4. Naturalness and techno-skepticism

One of the main obstacles to novel foods, like GMO-food, is the perception of “unnatural” or the “natural-is-better-heuristic” (Siegrist et al., 2018; Siegrist & Hartmann, 2020a). This was often associated with an emotional “yuk-factor” that consumers direct at some industrial food products. It may be speculated that it will be difficult to overcome this feeling, as it is impossible to accept for many that very little of our food is actually “natural”. The appeal to cold rationality is of very little help when our food identities are such a complex mixture of tradition and values. From the point of view of ethical theory the argument based on lacking “naturalness” is supposedly weak (Kaiser, 2005), while this does not necessarily its power on a segment of consumers. Clearly, cultivated meat will not be able to absorb any such attribute of naturalness, and for the sake of integrity, it should not attempt it either. Arguably, it is also a matter of trust (Kaiser & Algers, 2017). In short supply-lines we can identify the producer, identify the resources that went into the production, and associate a person (e.g. the farmer) with the food. Then we know who is accountable for the quality of the food.

Nevertheless, this responsibility seems to dissolve in industrial production. Industrial branding, food certifications, and clear labelling are mechanisms to overcome this potential distrust, but they have not managed to replace the felt asymmetry among small-scale and big food producers. Furthermore, many people would prefer a risk-aversive attitude to food since food enters our bodies. Industrial processes are typically very complex, and we always suspect that we humans are not always on top of these processes. Natural processes even though complex too, have served us well for thousands of years, and thus come with a certain safety bonus.

4.5. Nutrition and food safety

One of the pressing issues related to our diet is questions related to our health. It is an obvious fact that malnutrition has negative impacts on health. Likewise, over-nutrition has serious negative health effects like obesity, coronary diseases and diabetes. Unfortunately, nutritional science is beset with countless uncertainties still (Brown et al., 2014; Ioannidis, 2013; Schoenfeld & Ioannidis, 2013). Yet, we do have a pretty good idea that less red meat and more vegetables and fruit would be rather beneficial (Habumugisha et al., 2023; Kaiser, 2021). But what are the “dangerous” substances in this diet? Hopefully science will come up with some answers here. If we learn more about it, then cultivated meat may be produced without these substances. It should be noticed that initial work exploring this has been done in the US.[6]

However, every once and a while there are news about unsafe ingredients in our diet. Food safety is a matter of concern among consumers. This is often the result of unsafe supply lines and sub-standard producers (Unnevehr, 2022). Again, cultivated meat might benefit here due to a more controlled environment during production.

4.6. Issues of global justice

Approximately, 70% of all consumed human food is still produced by small-scale producers, most of this in the developing world (Lowder et al., 2021). Typically, it is these small-scale farms and the small coastal fishery boats that contribute to our regional cultures and landscapes. Thus, they are regarded as important assets maintaining our cultural identity whilst increasingly threatened by big and multi-national companies. The top four corporations’ control over 70% of the seed and agrichemicals industry. When it comes to animal genetics in chickens, the top three companies control almost 100% and with respect to swine they control almost 50% of the business. Fertilizers are also controlled with over 50% by the top five corporations. The top six companies control 52% of the business for farm equipment. New actors are now entering the stage: asset management companies, tech companies, data processing companies, and E-commerce retailers (Mooney et al., 2021). This massive intrusion into the food webs threatens traditional small-scale food production. All of this comes with a twitch: ownership in these global corporations is mostly among shareholders in the rich world, while the earnings are made among the poor. This triggers the notion of a global inequity in the food business.

Producing cultivated meat is both capital-, knowledge- and resource-intensive. The stage seems set for another increase in global inequity in the food business. How to combine the production of cultivated meat with the maintenance of our regional culture-landscapes and the survival of small-scale food producers is still an open question.

5. Cultivated meat perceptions of Nordic consumers, political stakeholders and livestock farmers

Cultivated meat is a rather futuristic food item for most people in the Nordic countries. Some have heard about it, but most do not have a clear conception of cultivated meat (Klöckner et al., 2022). Cultivated meat is

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[6] https://www.food.gov.uk/sites/default/files/media/document/Cultured%20meat%20hazard%20identification%20final_0.pdf.

also a challenging research topic from the social science perspective. Products are not yet available on the Nordic market and people have not tasted them. Cultivated meat tends to carry a technologically advanced image that may summon imaginative and overtly positive expectations but more often negative and unfounded associations or even fears. Although social science research on cultivated meat may appear premature, critical and transparent analyses exploring societal sentiments are needed. Lessons from genetically modified organisms' adoption and resistance show that companies' efforts for producing the common good are not enough, dismissal of consumer activism may lead to unfavourable outcomes and putting the focus on responding to negative perceptions associated with the novel technology may be an adverse strategy (Mohorcich & Reese, 2019).

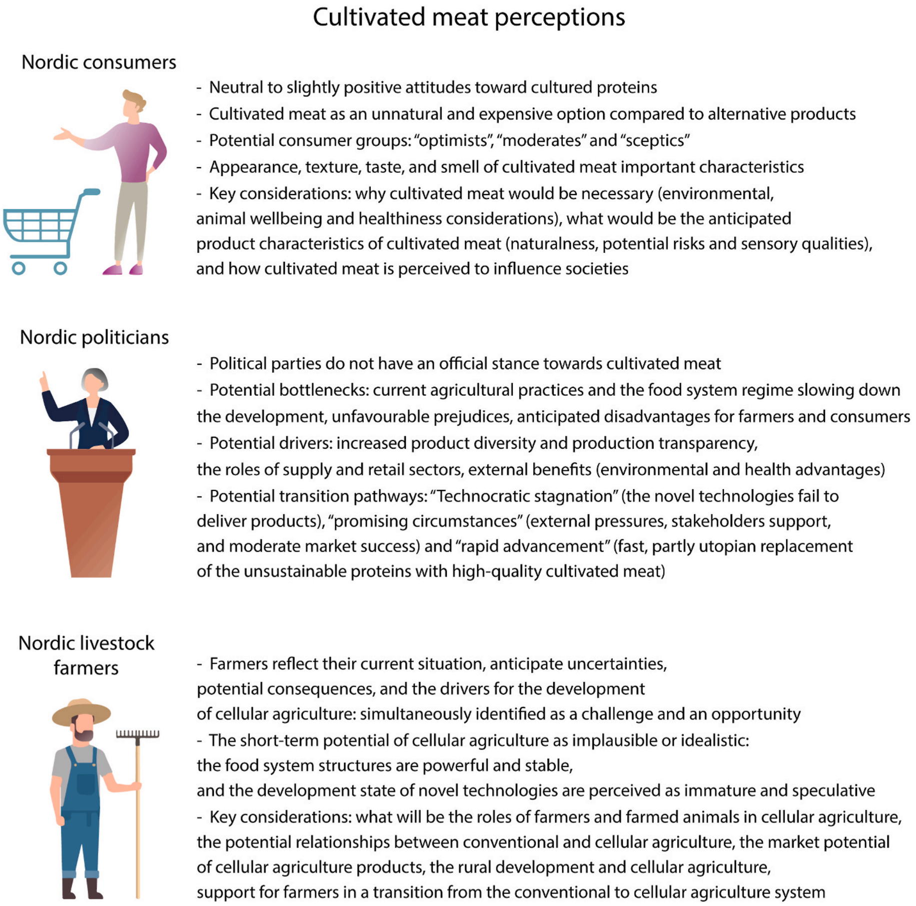
This section reviews the perceptions of three Nordic stakeholder groups: consumers, political actors, and livestock farmers (Fig. 5). These groups have been only scarcely studied in the Nordic context. However, the consumers' role is clear. Their acceptance or willingness to buy, try or eat cultivated meat will determine the success of the novel foods in the long run. The political actors are well advised to meet the consumers' or citizens' demands but they also exert significant power to advance or hinder the development of the novel food products. They reflect the sentiments of their voters as do policy organisations' representatives that emphasise their supporters' views (Chiles, 2013). Political stakeholders set societal agendas, engage in direct and indirect lobbying, steer the usage of public funding, participate to law and regulation drafting on regional, state and European Union levels, and can start or advance development and assessment projects for or against cellular agriculture (Moritz et al., 2022).

In addition, conventional livestock farmers will probably be a stakeholder group impacted most adversely, if cultivated meat production can be scaled and the products reach the mass-market stage. Citizen sentiments tend to favour conventional farmers, especially in rural areas. However, the farmers will potentially be a significant stakeholder group also in terms of producing input materials for cellular agriculture such as glucose and amino acids, or energy from field-cultured crops (Chen & Zhang, 2015). Conventional livestock farmers can also provide stem or SCs for cultivated meat and fat production or engage in local cultivated meat production by setting up small-scale bioreactors on their farms (Newton & Blaustein-Rejto, 2021). It is suggested that small-scale production of cultivated meat on a village-level would be particularly promising from technological but also from societal acceptance perspectives (van der Weele & Tramper, 2014).

5.1. *The Nordic consumers and cultivated meat*

Consumer perceptions and their acceptance of cultivated meat are relatively well studied (Bryant & Barnett, 2018, 2020; Pakseresht et al., 2022). Generally, 40–70% of European and North American respondents would be willing to taste cultivated meat (Bryant & Dillard, 2019; Bryant et al., 2019; Dupont et al., 2022; Franceković et al., 2021; Mancini & Antonioli, 2019; Weinrich et al., 2020; Wilks & Phillips, 2017). Consumers in Finland, Norway and Denmark fall within this range as 57,7% (28,1%) of Danish, 58,2% (28,1%) of Norwegians and 65,3% (37,2%) of Finns would taste (or eat regularly) cultivated meat (Klöckner et al., 2022). The differences between the countries are statistically significant, showing that the Danish respondents were least willing to accept cultured proteins compared to the Finns and the Norwegians.

The evidence for the links between socio-demographic factors and the acceptance of cultivated meat varies. In general, the results from



- Neutral to slightly positive attitudes toward cultured proteins
- Cultivated meat as an unnatural and expensive option compared to alternative products
- Potential consumer groups: "optimists", "moderates" and "sceptics"
- Appearance, texture, taste, and smell of cultivated meat important characteristics
- Key considerations: why cultivated meat would be necessary (environmental, animal wellbeing and healthiness considerations), what would be the anticipated product characteristics of cultivated meat (naturalness, potential risks and sensory qualities), and how cultivated meat is perceived to influence societies

- Political parties do not have an official stance towards cultivated meat
- Potential bottlenecks: current agricultural practices and the food system regime slowing down the development, unfavourable prejudices, anticipated disadvantages for farmers and consumers
- Potential drivers: increased product diversity and production transparency, the roles of supply and retail sectors, external benefits (environmental and health advantages)
- Potential transition pathways: "Technocratic stagnation" (the novel technologies fail to deliver products), "promising circumstances" (external pressures, stakeholders support, and moderate market success) and "rapid advancement" (fast, partly utopian replacement of the unsustainable proteins with high-quality cultivated meat)

- Farmers reflect their current situation, anticipate uncertainties, potential consequences, and the drivers for the development of cellular agriculture: simultaneously identified as a challenge and an opportunity
- The short-term potential of cellular agriculture as implausible or idealistic: the food system structures are powerful and stable, and the development state of novel technologies are perceived as immature and speculative
- Key considerations: what will be the roles of farmers and farmed animals in cellular agriculture, the potential relationships between conventional and cellular agriculture, the market potential of cellular agriculture products, the rural development and cellular agriculture, support for farmers in a transition from the conventional to cellular agriculture system

Fig. 5. Summary of stakeholders' perceptions about cultivated meat in the Nordic context.

several studies imply that younger people, men, and liberal leftists are more receptive to cultivated meat, as are the highly educated and people with higher income (Slade, 2018; Wilks & Phillips, 2017). The demand for cultivated meat tends to rise when the price drops (Carlsson et al., 2022; Mancini & Antonioli, 2019), but almost half of the Swedish respondents would not swap a traditional hamburger patty for cultivated meat even if they would get it for free (Carlsson et al., 2022). A survey study exploring the acceptance, perceived naturalness, and evoked disgust of cultivated meat in ten countries concluded that Swedes' acceptance was relatively low (acceptance was lower in France, Germany, and the US). Moreover, cultivated meat was perceived as reasonably unnatural (only the French perceived cultivated meat as more unnatural) and Sweden ranked in the middle-range in evoked disgust between the US and China (Siegrist & Hartmann, 2020b).

Consumers' future expectations associated with cultivated meat tend to be rather dismal. Vinnari and Tapio (Vinnari & Tapio, 2009) studied future images of meat consumption in 2030 with a Delphi study in 2009 in Finland. They enquired whether "laboratory-grown artificial meat" will have replaced conventional meats in 2030. Both consumers but especially experts expressed that the claim seemed very undesirable or very improbable. However, there was significant variation in the images of meat substitutes, which ranged from the very negative perspectives of the traditional group valuing conventional agriculture to the very positive views held by the vegetarian group (Vinnari & Tapio, 2009).

Similar and quite negative perceptions resulted from a study that examined online news comments in Finland (Ryynänen & Toivanen, 2022). The results show that the Finnish online commenters pondered why cultivated meat would be necessary (environmental, animal wellbeing and healthiness considerations), what would be the anticipated product characteristics of cultivated meat (naturalness, potential risks and sensory qualities), and how cultivated meat is perceived to influence societies (the role of actors, decision-making and potential inequities caused by cultivated meat). The uncertainties surrounding these themes tend to lead to conflicting interpretations, which may prevent the achievement of a shared definition of cultivated meat and complicate the establishment of cultivated meat as an accepted food (Ryynänen & Toivanen, 2022). However, the results show also that these nine themes discussed by the Finnish online commenters describe the emerging meanings of cultivated meat and all meanings were utilised in arguments both for and against culture meat.

A study among omnivore and flexitarian participants from the Netherlands and Finland show that cultivated meat is still perceived as an unnatural and expensive option when compared with plant-based meat substitutes and hybrid meat products (van Dijk et al., 2023). Klöckner et al. (2022) concluded that the people in Finland, Norway and Denmark have neutral to slightly positive attitudes toward cultured protein products such as meat, fish, or dairy. The comparison of these countries indicates that an increased familiarity might improve acceptance, males and younger people tend to be particularly positive whereas vegans and vegetarians evaluate products of cellular agriculture favourably (Klöckner et al., 2022). The anticipated attitude change profiles show that meat-eating identity, social norms, environmental concern, and market structural or cultural differences in the countries resulted in the clearest profile differences whilst health identity, age, innovativeness, income, education, and gender had only minor effects (Klöckner et al., 2022). In addition, the Klöckner et al. (2022) indicated that consumers from three countries would react negatively if product characteristics such as appearance, texture, taste, and smell of cultivated meat would be worse compared to conventionally produced meat.

Preliminary results from ongoing research suggest that there are three major cultivated meat consumer clusters in Finland. These "optimists", "moderates" and "sceptics" differ in their attitude towards the environment, conventional animal farming and cultured proteins. 77% of optimists, 23% of moderates and 18% of sceptics are in favour of cultured proteins. Optimists and moderates share environmental concerns, but moderates and sceptics tend to perceive innovative foods and the impacts of cultured proteins more negatively. Positive attitudes towards cultured proteins are significantly related to social norms and beliefs about the global and national benefits of cultured proteins. Environmental concerns tend not to predict the willingness of the clusters to use cultured proteins, but climate impacts are the most mentioned benefit of cultured proteins. Major concerns identified in the ongoing study were associated with dependency on big companies, negative impacts on Finnish agriculture, sensory properties of cultured proteins, use of genetically modified organisms in production and perceived (un)naturalness.

5.2. *Political and policy stakeholders and cultivated meat*

Research considering perceptions of political and policy stakeholders in the Nordic countries are non-existing and peer-reviewed international studies are scarce. Chiles' (Chiles, 2013) study is an exception. It examines the ideologies of political stakeholders and the potential political consequences of ambiguous goods such as cultivated meat. The studied stakeholders tend to rely upon stable institutional ideologies such as the Techtopian, Green Luddite and Work Machine ideologies that explain potential choices for or against cultured products (Chiles, 2013). The Techtopians perceive technology as the route to societal well-being, assume that consumers are not aware of the cellular agriculture development and become aware once these products are introduced on the market. The Green Luddites are environmentalists supporting the natural order, biodiversity and traditional landscape, and they tend to be against unsustainable conventional meat production whilst preferring local small-scale farming solutions. The Work Machine ideology emphasizes economic growth achieved through productivity and wealth as well as business-*as*-usual methods or conventional meat production.

Moritz et al. (Moritz et al., 2022) studied 13 career politicians' and policy stakeholders' perceptions about cultivated meat in Germany. The study utilised the transformative innovation policy (TIP) approach and identified 22 themes from the interview data. The informants addressed potential bottlenecks for cultivated meat development such as current agricultural practices or the current food system regime hindering the progress, unfavourable prospects or anticipated artificial and pre-decided image for the future and straight threats or disadvantages for farmers and consumers from cultivated meat production. They also considered drivers for cultivated meat development such as increased product diversity and production transparency, the potential roles of supply and retail sectors in advancing the development of cultivated meat and external benefits such as environmental and health benefits provided by cultivated meat.

Moritz et al. (2023) study included additional interviews from 12 political stakeholders from Finland. The study compares the German and Finnish stakeholders' perceptions and utilises the multi-level perspective (MLP) framework in showcasing how the current food system could transform into a more sustainable system. Socio-technological landscape pressures such as the climate change put pressure on the current animal-based food regime from above whereas niche innovations such as cultivated meat offer novel and more sustainable food alternatives that challenge the regime from below.

The results of this study suggest that the perceptions of the informants in Finland vary from opportunistic to sceptical (Moritz et al., 2023). Some of the opportunistic perceptions include that cultivated meat could have the power to solve current challenges of livestock production or that cultivated meat could be eaten without guilt associated with conventional livestock products. Sceptical perceptions include that cultivated meat is perceived as a technocratic solution to a problem that could also be dissolved with increased usage of alternative plant-based proteins. Moreover, the informants tended to agree that cultivated meat is not a threat to current livestock production or local food traditions as the Finnish informants did not believe in the rapid development of cultivated meat nor transformation towards a cellular agricultural system. Moreover, the stakeholders' perceptions were used in constructing potential transition pathways for cultivated meat. “Technocratic stagnation” pathway refers to a development where the novel food technologies fail to deliver products such as cultivated meat timely, “promising circumstances” pathway is characterised by external pressures, support, and moderate success but cultivated meat remaining an additional niche product in the market whereas in “rapid advancement” pathway cultivated meat development would be fast, partly utopian and replace the unsustainable proteins in the market (Moritz et al., 2023).

5.3. Livestock farmers and cultivated meat

Similarly, to political stakeholders’ views, livestock farmers’ perceptions about cellular agriculture are only marginally studied. However, research considering the potential impacts of cellular agriculture on livestock farmers’ practices and livelihoods is needed as the potential market entry of these novel products may radically change the conventional food system (Chiles et al., 2021; Gerhardt et al., 2020; Reis et al., 2020, 2021; Saavoss, 2019).

A recent study examined various stakeholders’ perceptions regarding cultivated meat in the US (Newton & Blaustein-Rejto, 2021). Although the informants in the study indicated that the cultivated meat production could create new employment opportunities, improve food security, and provide health benefits, potentially adverse developments were also discussed. Threats such as the loss of income for livestock producers or the exclusion of farmers by transitioning into the cultivated meat production were raised as only a few large companies were anticipated to overtake cultivated meat development (Newton & Blaustein-Rejto, 2021). Helliwell and Burton (Helliwell & Burton, 2021) identified similar threats and called them narrative silences. These are currently missing discussions of what happens to rural communities and the development of the countryside in a situation where cultivated meat replaces conventional livestock farming. Agricultural employment and consolidation of food production (Bryant, 2020) are pressing questions when the impacts of cellular agriculture are evaluated from the rural perspective.

Livestock farmers may need to find replacement production in a situation where products from cellular agriculture are adopted widely and start replacing foods from livestock in the future. According to Newton and Blaustein-Rejto (Newton & Blaustein-Rejto, 2021), there are several options for farmers to choose from: producing ingredients or input materials for cellular agriculture, raising animals for cell sources for cultivated meat or producing cell-cultured foods at the farm. In addition, farmers could provide ecosystem services, transition from farming to forestry, use their land for regenerative pasture-based high nature value animal production or produce renewable energy at the farm (Newton & Blaustein-Rejto, 2021).

A qualitative study based on 22 semi-structured livestock farmer interviews in Finland explore farmers’ perceptions of cellular agriculture and their potential roles in the novel food system (Räty et al., 2023). The results indicate that the farmers address various themes. They try to position themselves and farmers in general in cellular agriculture, they ponder the roles of farmed animals in cellular agriculture and try to picture the potential relationships between conventional and cellular agriculture. The informants also discussed the market potential of cellular agriculture, needs from the rural development perspective and how to support farmers in a potential transition from the conventional to cellular agriculture system (Räty et al., 2023).

The themes reflect the interviewed farmers’ current situation, anticipated uncertainties, potential consequences, and the drivers for the development of cellular agriculture. Cultivated meat and other cellular agriculture products, along with their production technologies were identified as being simultaneously a challenge and an opportunity for conventional livestock farmers and rural areas. However, the interviewed Finnish farmers evaluated the short-term potential of cellular agriculture as implausible or idealistic. Against the researchers’ expectations, the interviewed farmers were neutral or slightly positive about the novel developments in the agricultural sector. Many of them emphasised that agriculture is a sector under constant development and novel technologies have been introduced regularly (Räty et al., 2023). The interviewed farmers perceived cellular agriculture yet another link in the continuous chain of novel agrotechnologies such as tractors, robots, computer-assisted farm management tools and smart farming solutions. However, they also emphasised that the current food system structures are rather powerful and stable. In addition, the development state of cellular agriculture technologies was perceived as immature and speculative: the solutions of cellular agriculture were perceived as powerless and currently unable to match conventional livestock production volumes and compete with the subsidised prices anytime soon (Räty et al., 2023).

6. Conclusion

There is an overarching likelihood that cultivated meat will be commercially available to the Nordic consumers in the future. However, before that will happen there are several issues that needs to be solved within the context of the Nordic countries, as outlined in this review. In general, this includes, solutions for cell culturing that includes the willingness of Nordic consumers to accept e.g. GMO. Moreover, the specific additives for cell culturing should utilize the availability of materials from the Nordic countries e.g. for growth promoting factors and scaffolds. Together this approach will also improve the environmental, societal and ethical side of cultivated meat in the Nordic countries. Hence, there is a need for a discussion on several technical aspects, such as the acceptance of cell source, scaffold material and media composition. All with the aspect of an up-scaled production. Likewise, it should also be kept in mind that the final product with respect to sensory properties and nutritional composition should comply with the needs of the consumer and align with the Nordic nutrition recommendations (Blomhoff et al., 2023). One major factor for the development of cultivated meat is the question of sustainability. If cultivated meat is not produced in a sustainable way, it will not be accepted. Hence, aspects such as energy consumption, land use, raw material source and ethical aspect needs to be fulfilled for the Nordic consumer to accept cultivated meat. In addition, a mission-oriented transition to cellular agriculture and measures guaranteeing that nobody is left behind needs to be designed and implemented in a spirit of the Nordic welfare societies.

CRediT author statement

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Data availability

Data will be made available on request.

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