FEASTS
Fostering European Cellular Agriculture for Sustainable Transition Solutions

Title: CM/CSF food formulation matrix - Description of components used for CM/CSF food formulation and their implications to product quality and organoleptic properties

Deliverable 3.6: CM/CSF food formulation matrix

Work Package 3 *Sustainability by design*

Task no: 3.5

Funded by the European Union

Author(s) / Organization

Martin Krøyer Rasmussen	AU, Denmark
Rebekka Rinder Thøgersen	AU, Denmark
Jette Feveile Young	AU, Denmark
Margrethe Therkildsen	AU, Denmark

Reviewed by / Organization

Mona Pederson	Nofima
Remy Kusters	Gourmey
Justin Kolbeck	WildType
Megumi Yoshitomi	JACA
Dwayne Holmes	New Harvest

Project no. 101136749

Project acronym: FEASTS

Project title: Fostering European Cellular Agriculture for Sustainable Transition Solutions

Call: HORIZON-CL6-2023-FARM2FORK-01

Start date of project: 01.12.2023

Duration: 36 months

Deliverable title: Description of the components used for CM/CSF food formulation and their implications to product quality and organoleptic properties (M27)

Due date of deliverable: 28/02/2026

Date of Deliverable: 25/02/2026

Deliverable Lead Partner: Department of Food Science, Aarhus University, Denmark

Dissemination level: Public

Funded by the European Union's research and innovation program under Grant Agreement no. 101136749.
Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or European Research Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

Executive summary

Deliverable 3.6 explores the quality attributes of cultured meat in comparison to conventional meat, aiming to bridge scientific understanding and industrial application. The term “meat” will in this document be used to cover “meat and seafood”, but has been used as this document has been published as a chapter in a book on cultivated meat

It covers:

- Conventional meat quality fundamentals (texture, water-holding capacity, color, flavor, nutritional value).
- Expected and observed quality traits of cultured meat.
- Industry perspectives from five cultured meat companies.
- Future directions for improving cultured meat quality.

Methodology

- Literature Review: Synthesizes existing research on conventional meat quality and emerging studies on cultured meat.
- Comparative Analysis: Evaluates parallels and differences between conventional and cultured meat in terms of sensory and nutritional attributes.
- Industry Input: Incorporates qualitative insights from five companies producing cultured meat or hybrid products.

Key Findings

Texture

  - Conventional meat texture depends on organized muscle fibers and connective tissue; cultivated meat can lack this structure, making scaffolds critical for mouthfeel.
  - Postharvest proteolysis occurs in cultured meat but it is expected to be faster than in conventional meat.

Water-Holding Capacity (WHC)

- WHC in cultured meat is influenced by protein structure and pH changes postharvest; current data show variability and need for advanced evaluation methods.

Color

- Cultured meat generally appears paler due to low myoglobin; strategies like adding pigments or genetic engineering can improve coloration.

Flavor

- Fat content strongly correlates with palatability; cultured meat often lacks sufficient fat, but co-culturing muscle and adipose cells or adding cultured fat improves flavor.
- Maillard reaction precursors and amino acids increase with short aging periods in cultured meat and it will add to the flavor of cultured meat.

Nutritional Quality

- Protein content and amino acid profiles can match conventional meat under optimized conditions (e.g., scaffold composition, cell differentiation).
- Fat content and fatty acid composition in cultured meat can be modulated via co-culture and media adjustments.
- Micronutrient levels (e.g., iron, vitamins) depend on culture media or scaffold composition, and require further research on bioavailability.

Industry Priorities

- Taste and flavor are top priorities, followed by texture and appearance.
- Nutritional optimization is seen as a future focus rather than a current priority.

Future Perspectives

- Emphasis on hybrid products, scaffold innovation, and postharvest handling.
- Opportunities for tailored nutritional profiles.

This deliverable provides a description of the components used for CM/CSF food formulation and their implications to product quality and organoleptic properties. Note that industry evolved on the last years in this sector. Currently, most companies present business models having cell biomass as a food ingredient. Therefore, hybrid products are yet not available to be catalogued. Still, there is a considerable academic and private research and development on these hybrid products and therefore based on papers and patents, it is possible to make a description of components for CM/CSF food formulations.

Table of Contents

From Muscle Fibers to functional foods: bridging conventional and cultivated approaches

Martin Krøyer Rasmussen, Rebekka Rinder Thøgersen, Jette Feveile Young and Margrethe Therkildsen
Department of Food Science, Aarhus University

Graphical Abstract

Abstract

This chapter explores the quality attributes of cultivated meat, drawing parallels and distinctions with conventional meat to support future product development. It examines key technical, sensory and nutritional parameters, like texture, water-holding capacity, color, flavor, and nutritional composition. The chapter highlights how cultivated meat's quality is shaped by cellular composition, scaffold materials, and postharvest processes, and how these factors influence consumer-relevant traits such as tenderness, juiciness, and taste. It also discusses the potential of cultivated meat to match or surpass conventional meat in nutritional value, including protein content, amino acid profile, and micronutrient composition. Contributions from five cultivated meat companies provide an industrial context.

Keywords: Meat quality, Muscle cell, Protein, Flavor, Texture, DIAAS, Amino acids

Abbreviations: DIAAS: Digestible Indispensable Amino Acid Score; FAA: Free amino acids; NMR: Nuclear magnetic resonance; PUFA: Polyunsaturated fatty acids; TPA: Texture profile analysis; WHC: Water holding capacity

Introduction

The quality of conventional meat has been a focus for numerous studies. These studies have identified parameters like tenderness, juiciness, flavor, visual appearance, and nutritional value as key quality attributes for meat. Today, the underlying mechanism behind these quality attributes is to some extent understood and has added to the high quality of several meat products. For example, we have a good understanding of the significance of postmortem maturation of meat to improve quality. We know that during maturation pH changes are significant for not only water-holding capacity (WHC) but also proteolytic activity adding to increased tenderness and flavor development. The events are essential for securing high quality products for the consumer. Thus, quality is paramount and is what makes the consumer willing to buy the product and justifies why much research has been directed into controlling and improving these aspects of conventional meat.
Although the aforementioned quality attributes are often singularly described, it

must be acknowledged that they are often interrelated. For example, for the consumer juicier meat is typically also deemed more tender.
With the prospering transformation of the meat production industry to also encompassing cultivated meat products, more effort must be directed into understanding the fundamental mechanism shaping the quality of cultivated meat. In this chapter we explore, with an offset in knowledge obtained from conventional meat, the quality of cultivated meat as a food product (figure 1). Although research into this aspect is still at an infant stage, some parallels and differences between conventional meat and cultivated meat can be identified. It must be acknowledged that conventional meat consists of well-organized muscle fibers (including different fiber-types), fat (adipocytes and inter- and intramuscular fat) and connective tissue, which each contributes to the quality of the final product. This mixture of cells and organization is not a given for cultivated meat products, where it is often simpler. However, standing on the edge of a new food era also provides the opportunity to reinvent meat into a more functional food and create new quality standards.

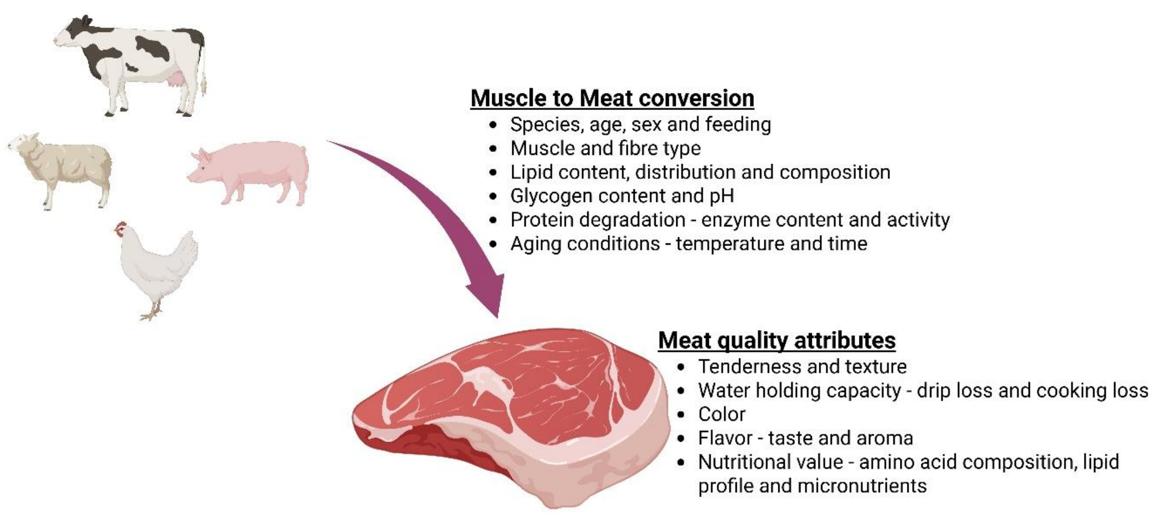

Figure 1: Overview of physiological and biochemical attributes shaping the conversion of muscle into conventional meat and its final quality.

To bridge the gap between the theoretical understanding of cultivated meat quality and its practical relevance to industry, five companies were asked to provide insights into their business-level priorities. These companies represent a diverse range of cultivated product types, including minced beef, hybrid beef products (minced and whole cuts combined with plant proteins), chicken-based ingredients, fat-based ingredients, and integrated beef products containing both muscle and fat components.

Throughout this chapter, we incorporate both collective and individual perspectives on key quality attributes. These include aspects that the companies are currently addressing, anticipated focal points for their own product development, and broader views on which quality parameters will be critical for the cultivated meat sector moving forward.

While the quotes and examples are specific to each company, many of the insights reflect shared priorities across the industry. These contributions help contextualize theoretical quality frameworks within real-world commercial strategies and product development goals.

Industry Perspectives on Consumer Acceptance

All participating companies emphasized that consumer acceptance is the central focus in the development of cultivated meat products.

- *"Our primary quality focus is on delivering an organoleptic experience for consumers." (*Aleph Farms – Neta Lavon)
- *"Consumers make their buying decisions mainly on taste, price, and convenience."* (Re:Meat – Jacob Schaldemose Peterson)

Basic knowledge of meat quality from conventional meat

The quality of conventional meat is basically defined as attributes related to the muscle per se, as well as attributes defined by the conversion of muscle to meat (aging). Some aspects of meat and sensory quality are settled during the production of conventional meat, where species, breed, feeding and growth rate, age and specific muscle will impact the amount of fat, the proteolytic enzyme activity in the tissue, the glycogen content, fibre type distribution and the amount and solubility of collagen. Other traits are dependent on the handling during the slaughter process, like stress prior to slaughter, temperature during the slaughter and rigor process and the stretch of the carcass as an effect of hanging method, and some traits are further affected by the final aging period and environmental conditions. All together these factors will have an impact on the final quality of the meat, that is the texture, water-holding capacity, juiciness, color, flavor and nutritional value.

Quality of cultivated meat

With an offset in conventional meat, this section will highlight knowledge as well as expected quality attributes of cultivated meat and cultivated meat containing products. For more information on meat quality in conventional meat see e.g. Pogorzelski et al. [1].

Texture

Texture of conventional meat is determined by the myofibrillar structure in the muscle fibres, the connective tissue surrounding the fibres and the fascicles (endomysium and perimysium, respectively) and the amount of fat in the tissue, which acts as a diluter of the other components as well as a lubricant during chewing. But the texture is not just given by these factors. The contribution from the myofibrils and the connective tissue depends on the activity of proteolytic enzymes in the tissue. Proteolytic activity is dependent on the postmortem pH profile in the tissue, which is mainly related to the glycogen level prior to slaughter, and the slaughter and rigor process. In addition, texture is dependent on the degree of contraction of myofibrils, which is both regulated physically and biochemically. Proteolytical enzymes are involved in the degradation of myofibrillar and cytoskeletal proteins postmortem, and this degradation opens the myofibrillar structure and releases protein fragments, peptides and amino acids, important for the texture and flavor development. The proteolytic enzymes are indigenous enzymes involved in the protein turnover in the living muscle, and thus the amount and activity are dependent on in vivo factors like growth rate, age and muscle [2], which settles the potential for, proteolysis postmortem. High growth rate at the time of slaughter is usually aligned with a larger protein turnover, and thus also a larger protein degradation and proteolytic activity of enzymes [3-5]. The protein turnover decreases with age [5, 6] and there seems to be an effect of the fibre type in muscles in relation to protein turnover [7-9]. Whereas myofibrillar and cytoskeletal proteins are degraded postmortem, there are only minor changes in the proteins that constitute the perimysium and the endomysium postmortem, thus the connective tissue plays a major role in the experienced texture of conventional meat after cooking [10]. In cultivated meat, there is no contribution from perimysium and endomysium to the texture of the product. For products where the cultivated cells are used as ingredients or a minor part of the product the texture will be largely dependent on the used scaffolds or formulations of the final product, whereas the postharvest processes in the myotubes will play a larger role for products of almost entirely cultivated nature. However, whether these processes can be manipulated as in live animals through the origin of the cells, the growth of the myotubes and the glycogen level at harvest are not established at this time. There is research indicating the same mechanisms in cultured meat as in conventional meat. First of all the key proteolytic enzyme: the calpains (Calpain 1-, 2, 3 and Calpastatin) are expressed during proliferation and differentiation [11-13], and the mRNA expression increase during differentiation [11] (and Skrivergaard et al, unpublished data). Likewise, the expression of the caspase family increase during myogenesis [12], and some of these are known to be part of the apoptotic cell death which, in conventional meat, is related to the postmortem changes [14, 15]. Mehmood et al [16] have further demonstrated active calpains at time of harvest of differentiated bovine myotubes, and expression of both calpain-1 and 2 s in the myotubes postharvest where they autolyze with time as seen in conventional meat, upon activation. Thus, a similar proteolysis as in conventional meat is expected in cultivated cells postharvest, supported by research demonstrating degradation of the cytoskeletal proteins (e.g. desmin) which increases with time [16]. What is still to be evaluated is the optimal postharvest conditions, like the established knowledge about the optimal temperature conditions during the rigor process for conventional meat [17] and the optimal time for the maturation process of the myotube biomass. In Mehmood et al. [16] it seems that the processes occur faster i.e. within the first 24 hours, as opposed to conventional meat where the aging period can be one to 21 days or more [18].

In conventional meat, the myofibrillar and muscle fibre structure is highly organized, which impacts the sensorial experience of texture [19]. However, in cultivated meat we cannot expect the same alignment of myotubes, which seem to depend on the scaffold used [20]. This can have an impact on the texture experience, despite proteolytic processes as in conventional meat. In a study using texture profile analysis (TPA) on cultivated rabbit skeletal muscle proliferated in a gelatin scaffold, compared with conventional rabbit meat and grounded beef, the level of hardness was similar. However, the hardness of the cultivated meat product resembled mostly ground beef when the change in texture from fresh product to cooked product were compared [20], suggesting that the matrix in which the myofibres are embedded, is important for the final texture. Likewise, Wang et al. [21] used the TPA method to quantify hardness of cultivated meat in a combined scaffold of collagen and yeast proteins and compared the texture with beef. The hardness of the products depended on the scaffold and the developmental stage of the cells (proliferation vs. differentiation), but in this comparison the conventional beef was evaluated to be much harder compared with the cultivated meat. Unfortunately, both studies lack information about conventional meat, like the age of the animal and aging process, which makes it difficult to compare the texture of the different products. Importantly, the studies show that similar methods can be used for both products and that the measured texture traits are within the same scale [22, 23]. The research demonstrates that in most cases [21-23], cultivated meat does not have the same hardness and chewiness as conventional meat, which might be a drawback for the experience of mouthfeel, so from a texture perspective postharvest maturation might not be important. On the other hand, postharvest proteolysis is desired in order to release peptides and amino acids for flavor development. The efforts regarding texture of products with high content of cultivated product should therefore be allocated to development of scaffolds that can resemble the cytoskeletal structure of meat and support an alignment of the myofibres to reflect conventional meat as much as possible. For products where the cultivated element is only used as ingredient or as a minor component the post processing strategy is determining the structure and composition as modified by processing technologies [24] and enzymes [25].

Industry Perspectives on Texture

Texture is a key sensory attribute of meat, and several companies highlighted its importance—particularly mouthfeel, melting behavior, and product homogeneity.

- *"The tactile experience while cutting—ensuring the product remains intact—is important, but most critical are the taste, flavor, and texture during consumption."*
  (*Aleph Farms - Neta Lavon)*

Water-holding capacity

Water-holding capacity is an important quality parameter in conventional meat, which not only affects the weight of the product, but also adds to the sensory evaluation of the meat. Basically, most water can be found associated with the protein structure of actin and myosin inside the muscle fiber. Hence, changes to these protein structures and their interrelated architecture, caused by e.g. proteolysis, sarcomere shortening and basic chemical properties caused by pH changes, would impact the water holding capacity of cultivated meat. In conventional meat, water holding properties have been evaluated using methods like drip loss over time or nuclear magnetic resonance spectroscopy. Unfortunately, none of these methods have been applied in order to evaluate water holding capacity in cultivated meat. However, simple methods, like evaluating gross water content in the product, have been applied. In a study by Yen et al. [26] using bovine mesenchymal stem cells, it was demonstrated that the moisture content in two different prototypes (layer-by-layer or burger-like) of cultivated meat was similar to or reduced compared to beef patty. The moisture content was quantified by weighing the products before and after freeze-drying. To provide a more consumer-related estimate of the water holding capacity, cooking loss was assessed, demonstrating comparable losses between the cultivated meat prototypes and beef patty. Likewise, it was demonstrated that scaffold-free cell sheets made of bovine myoblasts stacked to produce a < 3 mm thick structure had water content of approx. 88 % compared to 60 % in beef [27]. However, given the above-mentioned information it is still difficult to predict the water holding capacity of cultivated meat and more focused investigations using methods like nuclear magnetic resonance (NMR) spectroscopy [28] are needed.

From the detailed knowledge obtained from conventional meat, some predictions can be made for the water holding capacity of cultivated meat. As the myofibrillar structure is important for water holding capacity it can be speculated that the content of myosin and actin is highly correlated with the capacity of the myocytes to hold water. It has been demonstrated that when satellite cells undergo myogenesis *in vitro*, the differentiated cells have significantly greater expression of myosin compared to cells in the proliferative stage [29]. This implies that the basic proteins for creating myofibrils are larger in differentiated cells compared to proliferating cells and therefore better water holding capacity could be expected in differentiated cells.

Although some features improving water holding inside the myofiber can be suggested, others compromise this. One major event is the very rapid increase in lactate postharvest in cultures of differentiated bovine satellite cells [16]. This increase suggests a corresponding decline in pH, which could affect the net charge of the proteins, causing lower WHC if the ultimate pH is approaching pH 5.1-5.3 (Figure 2A). Likewise, rapid degradation of myofibrillar proteins has been observed postharvest [16], causing changes in water-holding. Together, this will potentially affect the water holding capacity negatively. Moreover, it could be speculated that the sarcomere length is greatly shortened postharvest, as the cells are detached from their growth surface and thereby have the potential to reshape and round up, resulting in shorter sarcomeres and less water holding capacity because of reduced space (Figure 2B).

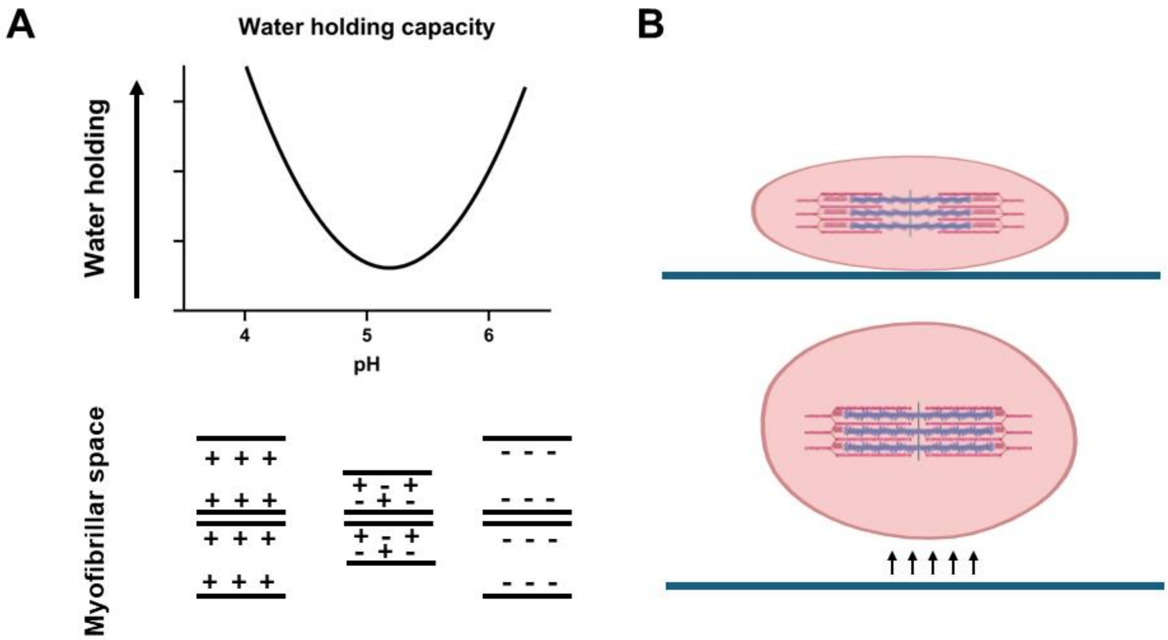

Figure 2: Water holding capacity is dependent on basic muscle structures. A) pH of the meat dictates the electrostatic charge of the contractile proteins, myosin and actin, which make up the myofilaments. At the isoelectric point, the net charge is zero, resulting in less myofibrillar space, causing lower water holding capacity. B) When satellite cells are in suspension, they round up, possibly causing the sarcomere structure to shorten. This will potentially result in lowering the water-holding capacity.

Industry Perspectives on Water Holding Capacity
Although water-holding capacity was not explicitly highlighted by the companies, related attributes such as mouthfeel, cooking behavior, and humidity were mentioned as important indicators of product quality.

- *"Our blended product, which includes undifferentiated bovine adipogenic precursors, offers added value in terms of taste, mouthfeel, and cooking behavior compared to conventional plant-based alternatives." (*Mosa Meat – Mark Post)

- *"At Vital Meat, we have a business to business approach, so making sure the format of our product suits our clients is a continuous focus. Currently, our cultivated chicken is used by industrial partners in combination with plant-based ingredients. Its water content is well-suited to existing dry ingredient formulations and processing methods, which supports seamless integration into current manufacturing workflows" (*Vital Meat – Claude Rescan)

Color

The color of meat is an important quality trait and is probably the most important single factor for the average consumer to evaluate the quality of the meat in the buying situation. The color of conventional meat ranges from pale red (chicken) to deep red (beef). Thus, the color of a cultivated meat product must meet the expected color based on species origin. The color of meat is generally determined by the presence and state of color pigments, mainly myoglobin. The color of conventional meat is mainly dictated by the content of myoglobin and the state of the iron atom bound within. In its ferrous (Fe^{2+}) state the meat will have a purple color, when no oxygen is present. However, upon exposure to oxygen the color of the meat will change to red, while if the iron atom is oxidized to ferric (Fe^{3+}) the color will become brown. Thus, this implies that manipulation of the intracellular antioxidant capacity of the myofibers could foster color optimization. Likewise, the amount of myoglobin could also foster coloration of cultivated meat. Interestingly,

the increased expression of myoglobin has been observed with differentiation of bovine satellite cells [29].
The state can be manipulated by e.g. packaging strategies because it is linked to oxygen availability. For beef, the deep red color is often associated with a high-quality product. However, the color of bovine satellite cells in culture is very pale (figure 3).

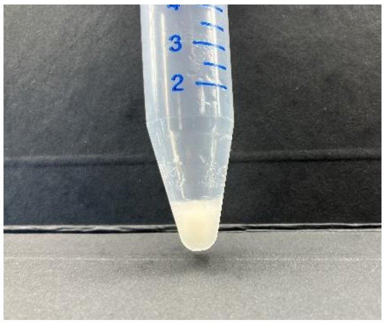

Figure 3: Representative pictures of bovine satellite cells. Cultures of bovine satellite cells were cultured until clear myotube formation, trypsinised and washed with PBS before pelleted by centrifugation.

In prototypes of cultivated meat, darker color was observed both before and after cooking compared to conventional beef patty [26]. For pure bovine satellite cells, however, more pale colors can be seen. Consequently, in a study comparing bovine satellite cells grown in fibrin hydrogels with conventional beef, not only were lower pigment levels observed but also large ΔE (differences) values (based on the CIE76 formula) [30]. If the cells were cultured with the addition of hemoglobin or myoglobin (both 3mg/ml) for 9 days the pigment content increased slightly and the ΔE values were reduced, but still far from that of conventional beef. However, cooking the sample diminished the differences.
Genetic engineering of cells offers the possibility to improve the coloration of the final product. In an attempt to increase nutritional quality, Stout et al. [31] produced transgenic bovine satellite cells containing various enzymes boosting the carotenoid biosynthesis pathway. This resulted in production of cell pellets with a more orange appearance compared to control samples. While orange color is not associated with high-quality meat products, this approach highlights the possibility of using genetic engineering to optimize coloration of satellite cells cultures to resemble that of conventional meat

Another interesting aspect of cultivated meat is the prospect of using colorants like beet juice or supporting structures like scaffolds to optimize coloration of the final product. In a study by Wang et al. [32] it was demonstrated that scaffolds based on proanthocyanidins and dialdehyde chitosan as crosslinkers of collagen could produce products with coloration comparable to beef.

Industry Perspectives on Visual Appearance: Color and Homogeneity
Appearance, including attributes such as color and visual uniformity, was mentioned by only a few companies. This is likely because some of the companies focus on producing ingredients or cultivated cells intended for use in hybrid products, where the final appearance is shaped by the complete formulation rather than the cultivated component alone.

- *"Delivering an organoleptic experience for consumers encompasses various sensory attributes, including the product's appearance—such as color and homogeneity."* (Aleph Farms – Neta Lavon)

- *"Appearance similar to regular meat."* (Mosa Meat – Mark Post)

Flavor

Several compounds add to the sensory perception of flavor of conventional meat. These compounds range from well-defined single compounds, like Inosine 5'-monophosphate, to groups of compounds like fatty acids [33, 34]. While the flavor of raw meat is important, more important are the flavor precursors and compounds produced during maturation and cooking. During heating of the meat, reducing sugars will react with the amino group of amino acids to create a mixture of flavor-rich compounds, a process known as the Maillard reaction. Hence, to make a true and applicable evaluation of the flavor attributes of cultivated meat, heating must be considered.

With Mark Post's presentation of the first burger made from cultivated meat in 2013, it became obvious that the taste rating of cultivated meat was low. Especially, it was identified that the taste, although meaty, missed some fatty taste. This is not surprising, given that the burger patty was made from pure muscle fibers. From conventional meat it is known that, within the 3% to 7% fat percentage area in the uncooked meat, the content of fat is greatly correlated with palatability [35]. Hence, it could be expected that increasing the fat content of the cultivated meat product would increase the flavor and consumer acceptance. Research from our lab has shown that cultures of both bovine and porcine satellite cells take up fatty acids and store them inside the muscle fiber for several days (Anupam, et al. unpublished data). However, this is not straight forward, as the fatty acids when added to the cell culture medium can introduce cytotoxic effects. Thus, the concentration of the fatty acids added to the media is vital, as well as the type of fatty acids (saturated is more toxic compared to unsaturated). Moreover, the composition of the media before adding fatty acids also determines the cellular lipid uptake and accumulation. Satellite cells grown in no or low serum (2%) media have significantly higher lipid accumulation compared to cells grown in high serum (≥ 10%). Attempts to mimic the fatty acid composition of conventional meat demonstrated that cocktails of fatty acids matching the *in vivo* lipid distribution in beef did not introduce cytotoxicity of bovine satellite cells (Mehmood et al, unpublished data).

In the conversion of muscle to meat, time of maturation is paramount. This is especially true for beef. To what extent this is crucial for cultivated meat has only recently started to be elucidated. In a study from Mehmood et al. [16] it was demonstrated that differentiated bovine satellite cells expressed active forms of the proteases calpain, which are heavily involved in maturation of beef. Moreover, the same study also demonstrated proteolytic degradation of structural proteins like Desmin. Thus, the degradation of proteins, as well as the presence of sugars originating from glycogen, could potentially cause more substrate for Maillard reactions, and by that improve taste. In an unpublished study from our lab, it was demonstrated that porcine myotubes aged for up to 24 hours, had increased concentrations of several amino acids (Anupam, et al. unpublished data). Interestingly, some of these amino acids, like glutamine and glutamate, have been ascribed to umami taste [36].

Although, the improvement of the flavor score of myocyte-based cell mass *per se*, is an appealing approach, the option of mixing in flavor-adding compounds in the final stage of the production is relevant, and here the option of adding cultivated fat to the product could be advantageous. In an evaluation of the flavor of porcine cultivated fat, where GC-MS was coupled to descriptive sensory analysis and compared to conventional pork fat [37], only minor differences were observed between cultivated fat and fat samples obtained from pork. Furthermore, the flavor profile (obtained using Gas Chromatography-Mass Spectrometry) of conventional meat and cultivated meat assembled of 2D structures of muscle tissue and adipose tissue have been demonstrated to be similar [22].

Along this line, there is also the possibility of using scaffold materials that contribute to the flavor of the final product. Using a mixture of gelatin and agar to coat a scaffold of textured vegetable protein, similar sensory scores (using an electronic tongue) were observed, between cultivated and conventional meat [23].

With the *in vitro* production of cell-mass to create the final meat product, also comes the opportunity to avoid off-flavors as well. One example is the off-flavor phenomenon known as boar taint caused by the microbial metabolism of tryptophan producing the odorous compound skatole, and the testicular production of androsterone [38]. The production of both compounds is bypassed in cultivated meat production. Likewise, off-flavor caused by specific feeding ingredients are eliminated [39], but whether media components used for cultivated meat can impact flavor is not known.

Industry Perspectives on Taste and Flavor: The Top Priority Across the Industry

All participating companies identified taste and flavor as the most critical quality parameters—both in their current development efforts and in their long-term product strategies. These sensory attributes are consistently viewed as the primary drivers of consumer acceptance and market success for cultivated meat.

- *"Taste will always be N°1 in food! This is particularly relevant for cultivated meat: rather than imitating conventional chicken, our cultivated chicken inherently replicates its authentic taste."* (Vital Meat – Claude Rescan)

- *"CultiFat acts as a flavouring agent and improves taste and extends aroma to increase the meaty and piggy flavour in plant-based meat formulations."* (Cultimate Foods – Jordi Morales-Dalmau)

Nutritional quality of cultivated meat products

Conventional meat is rich in nutrients and has likely played an important role in human evolution. As part of a human diet, meat can contribute to important macro- and micronutrients including highly digestible proteins, iron, vitamin B12, zinc and selenium. The nutritional content of meat depends on various factors such as species, cutting, and feeding [40]. Given the high nutritional value of conventional meat, the nutritional quality of cultivated meat is an important parameter to take into consideration. A previous study indicated that the perception of cultivated meat as healthy and nutritious was positively associated with willingness to consume cultivated meat [41]. If the consumption of cultivated meat is to substitute or partially substitute conventional meat consumption, matching the nutritional value of conventional meat is important. The production of cultivated meat might offer the potential of modifying the nutritional value of the final product, producing healthier products that meet the nutritional requirements of the consumer. As an example, Stout et al. [31] engineered the production of antioxidant phytonutrients (carotenoids) into immortalized mouse myoblasts and primary bovine muscle stem cells. It was shown that the resulting endogenous production of carotenoids was able to reduce lipid oxidation, thereby potentially enhancing nutrition and quality of cultivated meat products [31].

Protein content and amino acid composition

Protein is an important nutritional component of meat. Protein from conventional meat is characterized by high digestibility and contains all essential amino acids with no limiting amino acids [42]. The Digestible Indispensable Amino Acid Score (DIAAS) is used as a measure of protein digestibility. Proteins with DIAAS values ≥ 100 are classified as excellent-quality protein [43]. Pork, beef and chicken have been reported to have DIAAS scores above 100 [44-46]. The protein content of meat is 22 % on average but it has been reported to vary from 12.3 % up to 34.5 % depending on species and production strategy [40]. Since protein is considered an important nutritional compound of conventional meat, the protein content and quality of cultivated meat is crucial.

Very few studies have reported the protein content of cultivated meat products. In addition, comparison of nutritional values between products is difficult due to the diversity of products in relation to cell type, cell density, scaffold material etc. Kim et al. (2025) investigated the amino acid composition of cultivated meat which was based on pig muscle stem cells cultured on cross-linked gelatin hydrogel scaffolds [47]. The cultivated meat had a higher moisture content compared to pork but lower compared to the scaffold alone, thus the composition of the scaffold will affect the protein content of the final product. Differences in total amino acid composition were found for most of the investigated amino acids, where the content of most amino acids was lower in cultivated porcine cells compared to pork. The total amino acid content did not differ significantly between pork and cultivated porcine cells but was significantly lower in the scaffold alone. When amino acids were expressed as g/kg protein, the concentration of most of the amino acids were equal or higher in cultivated pork compared to pork, although some still had lower values [47]. It should be noted that the values reported are related to total amino acid composition, not bioaccessible amino acids, reflecting digestion of the proteins by gastric and intestinal enzymes. Recently, Wang et al (2024) were able to produce a cultivated meat product matching the total protein content of beef via a co-culture of bovine myocytes and adipocytes [32]. By regulating the bovine myoblast to adipocyte ratio, the authors were able to control the protein and fat content of the final product. Hence, when using a bovine myoblast to adipocyte ratio of 10:0, 9:1 and 8:2 the cultivated meat could match the protein content of beef. In addition, it was found that the cultivated meat had higher digestibility compared to beef [32]. For cultivated chicken made from cultured chicken fat and high moisture extruded soy protein it has also been possible to match the protein content of conventional chicken breast [48].

Various factors in the production process of cultivated meat are likely to affect the protein content of the final product. One factor affecting protein content of the final product is the degree of differentiation of the muscle cells. The differentiation of muscle satellite cells ultimately resulting in the formation of mature muscle fibers has been deemed necessary for consumer acceptance in order to produce cultivated meat products resembling conventional meat with regard to functionality, taste and texture [49]. Furuhashi and Takeuchi (2025) investigated the effects of cell differentiation and aging on intracellular free amino acids (FAA) in bovine muscle cells [50]. They found that differentiation decreased FAAs, whereas aging increased

FAAs. The total content of protein per gram of dry cell weight was higher in myotubes compared to myoblasts but decreased with aging. In addition, it was found that cultured cells had a higher content of FAAs per dry weight compared to beef [50]. The degree of differentiation can be affected by the scaffold material used. Wang et al. 2024 determined the protein content of cultivated meat from bovine myoblasts using scaffolds with varying proportions of yeast and collagen protein for bovine myoblasts. A significantly lower protein content was found in the cultivated meat compared to beef, except for the cultivated meat grown on scaffolds with a yeast protein/collagen ratio of 3:7. Together with fusion index (a measure of myotube formation) determination, the results indicated that the addition of yeast protein in the scaffold promoted myogenic differentiation and muscle tissue formation [21]. It has also been shown that the stiffness of a scaffold can affect myogenesis and adipogenesis. Hence, Lee et al. 2024 regulated cell differentiation by controlling the stiffness of gelatin scaffolds by varying degrees of alginate crosslinking [22]. Using these scaffolds, primary bovine myoblasts and bovine adipose-derived mesenchymal stem cells were cultured to produce 2D blocks of muscle and fat, respectively. These blocks were combined to produce an assembled cultivated meat product. A lower protein content was found in the assembled cultivated meat product compared to beef, however, the results indicated that the nutritional value of the final product was affected by the degree of differentiation [22]. Together these studies indicate that scaffold material can promote cell differentiation and thereby protein content, but the scaffold material itself can also provide valuable protein and amino acids. Liu et al. 2022 produced engineered porcine muscle satellite cell meatballs and analyzed nutritional value. Compared to a commercial product (Shizitou), dried porcine muscle satellite cell meatballs had 5 times higher protein content, which was likely due to high cell density and a gelatin scaffold rich in proteins [51]. Hence, the scaffold material has the potential to improve the protein content and amino acid composition of the cultivated meat product [52].

Lipid content

The fat content and fatty acid profile of conventional meat varies and is dependent on species, feeding and breeding style, and the specific cuts. Cooking can also affect fat content with considerable fat loss depending on cooking method [40, 53].

Conventional meat can contain a relatively large proportion of saturated fatty acids but does also contain monounsaturated and polyunsaturated fatty acids (PUFA) [42, 53]. The relatively high content of saturated fatty acids in conventional meat has received attention due to a possible association with cardiovascular disease and diabetes, however, this association is being increasingly questioned [54]. Different approaches to incorporate fat into cultivated meat products have been investigated, including assembly of 2D fat and muscle blocks and co-culturing of myocytes and adipocytes [22, 32]. Few studies report the fat content of cultivated meat products containing both muscle and fat. For cultured chicken, it has been possible to match the fat content of conventional chicken. The fat content of chicken strips made from cultured chicken fat and high moisture extruded soy protein exceeded the fat content of chicken breast. At the same time, the cultured chicken product had a lower amount of saturated fat and cholesterol compared to chicken breast [48]. An assessment of cultured chicken meat based on data submitted to the US Food and Drug Administration on a cultured chicken meat product found higher fat content in cell cultured chicken meat compared to conventional chicken [55]. Matching the fat content of cultivated meat to conventional beef and pork has been challenging. Two studies using bovine myoblasts found lower fat in cultivated meat compared to beef [21, 22] and a third of fat in porcine muscle satellite cell meatballs was found compared to a commercial product (Shizitou) [51]. Using a co-culturing approach combining myocytes and adipocytes, Wang et al 2024 was able to produce a cultured meat product reaching the fat levels of conventional beef. Hence, when using a bovine myoblast to adipocyte ratio of 8:2 and 5:5 the fat content in the cultivated meat was significantly higher than the conventional beef and statistically similar to a ratio of 0:10. The results indicated that the fat content of cultivated meat products can be controlled by the ratio of myoblasts to adipocytes [32]. Being able to modify the nutritional content is a possible advantage of cultivated meat production, and other studies have investigated the possibility of regulating the fatty acid composition of cultivated meat. Thus, it has been shown that it is possible to control the fatty acid composition of cultivated fat by adjusting the culture media composition during *in vitro* culture. As an example, murine and porcine adipocytes were grown in 2D cultures, and after *in vitro* adipogenesis the cells were aggregated into 3D tissues.

Treatment with a lipid emulsion based on soybean oil during *in vitro* culture affected the intracellular adipocyte triacyl-glycerides in the adipocytes including an increase in PUFA levels. For the murine cells, the lipid addition resulted in the fatty acids more closely resembling native mouse fat [56]. In addition, Louis et al. (2023) cultured bovine adipose-derived stem cells and found that the fatty acid composition of the culture medium during adipogenesis could be used to control the fatty acid composition of the final product [57]. It has also been found that the phospholipid, phosphatidylcholine, can not only promote adipogenic differentiation and lipid accumulation in a sodium alginate-gelatin 3D culture system, but also increase the content of PUFA and lower total cholesterol of cultivated fat [58].
The scaffold material may further affect the final fat content of cultivated meat products. As previously mentioned, the stiffness of the scaffold can affect myogenesis and adipogenesis. Hence, Lee et al. 2024 demonstrated that they were able to regulate and optimize the degree of adipogenic differentiation of bovine adipose tissue-derived mesenchymal stem cells to produce 2D fat blocks. Combining these blocks with 2D blocks of cultivated muscle cells resulted in an assembled cultivated meat product. Despite the optimized cultivated fat blocks, the assembled product had lower total fat content compared to raw beef, but the study demonstrates the possibility of controlling the amount of lipids in the product via the scaffold [22]. Wang et al. 2024 investigated bovine myoblasts cultured on scaffolds with varying proportions of yeast protein and found a lower amount of fat in cultivated meat compared to conventional beef. The content of fat was reported to be markedly lower in the cultured meat product compared to beef. The fat content in the cultivated meat varied between the products made with different yeast protein and collagen content [21].

Vitamins and minerals

Meat is a rich source of vitamins and minerals, including bioavailable vitamin B12, vitamin B6, riboflavin and niacin in addition to zinc, selenium and iron [53]. Red meat in particular can provide over two-thirds of the daily requirement of vitamin B12 in a 100 g serving [42]. A large part of the iron found in meat is heme-bound iron, which is more bioavailable than non-heme iron which is the form present in vegetables. Therefore, meat is an important source of iron with beef having the highest heme-iron content followed by pork and chicken [53]. Cultivated meat prototypes have shown high mineral content values compared to conventional meat which might be due to the elements being present in the culture media [52]. As an example, cultivated engineered pork meatballs contained relatively high levels of essential minerals including zinc, calcium and iron [51]. In the assessment of cultivated chicken meat, using data submitted to the US Food and Drug Administration, it was reported to have a superior mineral content compared to conventional chicken, likely due to the presence of these elements in the culture media. The study also pointed out the importance of investigating bioavailability in future analyses [55]. Since most heme-iron in meat is present in myoglobin and to a lesser extend hemoglobin, increasing the amount of myoglobin in cultivated meat would probably be beneficial from a nutritional point of view [59]. Among the compounds found in meat, not all of them are directly produced in the muscle. Some of them might derive from digested animal feed and reach the muscle after modification by non-muscle organs [59]. As an example, a nutrient such as B12 will not be produced by myoblasts nor adipocytes and therefore, it is likely that it needs to be added to the culture media and taken up by the cells [60]. However, whether vitamin uptake from the culture media will result in vitamin levels in the cultured meat corresponding to the levels in conventional meat still needs to be explored. Adding vitamins after culturing might be an alternative approach if addition via culture media is insufficient [59].

Industry Perspectives on Nutritional Value

While nutritional value is not yet the central focus in the current stage of cultivated meat product development, companies recognize its importance. Many view it as both a future area for innovation and a key indicator of overall product quality.

Some early-stage efforts have already incorporated nutritional targets:

- *"Nutritional value is a key consideration in Aleph Farms' product development. Our first product, Aleph Cut, contains at least 15% protein and less than 5% fat."* (Aleph Farms – Neta Lavon)

Looking ahead, others emphasize the role nutrition will play in shaping the next generation of products:

- *"Nutritional composition and uptake will be important for future products."* (Re:Meat – Jacob Schaldemose Peterson)

Future Perspectives on Cultivated Meat Quality

As the cultivated meat sector evolves, future developments will increasingly focus on refining product quality beyond basic functionality. A key distinction will be made between cultivated meat as a standalone ingredient versus its role in hybrid products, where it is combined with plant-based or other components. This opens opportunities to optimize individual elements—such as flavor and nutrition—while designing them to work synergistically in final formulations.

Scaffold materials will play a more active role in quality enhancement, potentially serving as carriers for micronutrients like vitamin E or functional fats, contributing both to nutritional value and oxidative stability. Meanwhile, texture development will benefit from hybrid approaches, where plant-based matrices or novel structuring techniques can complement the mouthfeel and bite of cultivated muscle tissue.

A critical area of innovation lies in balancing production-stage optimization with postharvest processing. Minimizing downstream processing—while still achieving desired sensory and nutritional profiles—will be essential for both sustainability, cost-efficiency and possibly consumer acceptance. This will require detailed characterization of postharvest processes and a clear understanding of their time and resource implications.

Product diversification will also expand, with differentiation based on muscle types, animal species, and developmental stages (e.g., calf vs. adult cattle), enabling tailored products for specific markets or consumer groups. This includes the potential to design targeted nutrition profiles for patient populations or other specialized dietary needs.

Another aim is understanding how cultivated cells interact with other food components—from fats and binders to flavor carriers - to form a cohesive, appealing final product. Achieving a balance between homogeneity and heterogeneity will be key: while uniformity ensures consistency, controlled heterogeneity may better mimic the complexity of conventional meat.

Finally, nutritional evaluation will become increasingly important, not only to meet regulatory standards but also to substantiate health claims and guide product development. As the industry scales, robust upscaling strategies and postharvest quality control will be vital to ensure that cultivated meat delivers on its promise of being a sustainable, nutritious, and affordable food of the future.

Acknowledgment

The authors would like to express their sincere gratitude to the companies Vital Meat, Mosa Meat, Aleph Farms, Re:Meat, and Cultimate Foods for generously sharing valuable insights into the commercial perspectives on cultivated meat quality.

References

1. Pogorzelski, G., et al., *Towards an integration of pre- and post-slaughter factors affecting the eating quality of beef.* Livestock Science, 2022. **255**: p. 104795.
2. Koohmaraie, M., *Biochemical factors regulating the toughening and tenderization processes of meat.* Meat Sci, 1996. **43S1**: p. 193-201.
3. Kristensen, L., et al., *Dietary-induced changes of muscle growth rate in pigs: effects on in vivo and postmortem muscle proteolysis and meat quality.* J Anim Sci, 2002. **80**(11): p. 2862-71.
4. Therkildsen, M., et al., *Compensatory growth in slaughter pigs—in vitro muscle protein turnover at slaughter, circulating IGF-I, performance and carcass quality.* Livestock Production Science, 2004. **88**(1): p. 63-75.

5. Maharjan, P., et al., *Effects of dietary energy levels on Pectoralis major mixed muscle protein turnover and body composition in two broiler lines housed in different grow-out environments.* J Anim Physiol Anim Nutr (Berl), 2021. **105**(3): p. 535-548.
6. Lobley, G.E., et al., *The effects of breed and level of nutrition on whole-body and muscle protein metabolism in pure-bred Aberdeen angus and Charolais beef steers.* Br J Nutr, 2000. **84**(3): p. 275-84.
7. Garlick, P.J., et al., *Fiber-type composition of nine rat muscles. II. Relationship to protein turnover.* Am J Physiol, 1989. **257**(6 Pt 1): p. E828-32.
8. Therkildsen, M., et al., *Compensatory growth response in pigs, muscle protein turn-over and meat texture: effects of restriction/realimentation period.* Animal Science, 2002. **75**(3): p. 367-377.
9. Chang, Y.-M. and H.-W. Wei, *The Effects of Dietary Lysine Deficiency on Muscle Protein Turnover in Postweanling Pigs.* Asian-Australasian Journal of Animal Sciences, 2005. **18**(9): p. 1326-1335.
10. Purslow, P.P., *Intramuscular connective tissue and its role in meat quality.* Meat Sci, 2005. **70**(3): p. 435-47.
11. Theil, P.K., et al., *Changes in proteolytic enzyme mRNAs relevant for meat quality during myogenesis of primary porcine satellite cells.* Meat Science, 2006. **73**(2): p. 335-343.
12. Yang, Y.B., M. Pandurangan, and I. Hwang, *Changes in proteolytic enzymes mRNAs and proteins relevant for meat quality during myogenesis and hypoxia of primary bovine satellite cells.* In Vitro Cell Dev Biol Anim, 2012. **48**(6): p. 359-68.
13. Wang, W., et al., *Changes in calpain and caspase gene expression at the mRNA level during bovine muscle satellite cell myogenesis and the correlation between the cell model and the muscle tissue.* Russian Journal of Bioorganic Chemistry, 2017. **43**(3): p. 270-277.
14. Laville, E., et al., *Proteome changes during meat aging in tough and tender beef suggest the importance of apoptosis and protein solubility for beef aging and tenderization.* J Agric Food Chem, 2009. **57**(22): p. 10755-64.
15. Kemp, C.M. and T.L. Wheeler, *Effects of manipulation of the caspase system on myofibrillar protein degradation in vitro.* J Anim Sci, 2011. **89**(10): p. 3262-71.

16. Mehmood, W., et al., *Postharvest changes in bovine satellite cells in vitro resemble postmortem conversion of muscle to meat.* Food Chemistry, 2025: p. 144292.
17. Rosenvold, K., U. Borup, and M. Therkildsen, *Stepwise chilling: tender pork without compromising water-holding capacity.* J Anim Sci, 2010. **88**(5): p. 1830-41.
18. Joo, S.T., et al., *Aging mechanism for improving the tenderness and taste characteristics of meat.* J Anim Sci Technol, 2023. **65**(6): p. 1151-1168.
19. Listrat, A., et al., *How Muscle Structure and Composition Influence Meat and Flesh Quality.* ScientificWorldJournal, 2016. **2016**(1): p. 3182746.
20. MacQueen, L.A., et al., *Muscle tissue engineering in fibrous gelatin: implications for meat analogs.* NPJ Sci Food, 2019. **3**(1): p. 20.
21. Wang, Y., et al., *3D edible scaffolds with yeast protein: A novel alternative protein scaffold for the production of high-quality cell-cultured meat.* Int J Biol Macromol, 2024. **259**(Pt 1): p. 129134.
22. Lee, M., et al., *Cultured meat with enriched organoleptic properties by regulating cell differentiation.* Nat Commun, 2024. **15**(1): p. 77.
23. Lee, M., et al., *Tailoring a Gelatin/Agar Matrix for the Synergistic Effect with Cells to Produce High-Quality Cultured Meat.* ACS Appl Mater Interfaces, 2022. **14**(33): p. 38235-38245.
24. Lambert, E.G., et al., *Enhancing the palatability of cultivated meat.* Trends Biotechnol, 2024. **42**(9): p. 1112-1127.
25. Karp, S.G., et al., *Enzymes in the production of cultivated meat products.* Systems Microbiology and Biomanufacturing, 2024. **5**(1): p. 57-68.
26. Yen, F.C., et al., *Cultured meat platform developed through the structuring of edible microcarrier-derived microtissues with oleogel-based fat substitute.* Nat Commun, 2023. **14**(1): p. 2942.
27. Tanaka, R.I., et al., *Production of scaffold-free cell-based meat using cell sheet technology.* NPJ Sci Food, 2022. **6**(1): p. 41.
28. Bertram, H.C., P.P. Purslow, and H.J. Andersen, *Relationship between meat structure, water mobility, and distribution: a low-field nuclear magnetic resonance study.* J Agric Food Chem, 2002. **50**(4): p. 824-9.

29. Skrivergaard, S., et al., *Bovine Satellite Cells Isolated after 2 and 5 Days of Tissue Storage Maintain the Proliferative and Myogenic Capacity Needed for Cultured Meat Production.* Int J Mol Sci, 2021. **22**(16): p. 8376.
30. Simsa, R., et al., *Extracellular Heme Proteins Influence Bovine Myosatellite Cell Proliferation and the Color of Cell-Based Meat.* Foods, 2019. **8**(10): p. 521.
31. Stout, A.J., et al., *Engineering carotenoid production in mammalian cells for nutritionally enhanced cell-cultured foods.* Metab Eng, 2020. **62**: p. 126-137.
32. Wang, Y., et al., *A rich-nutritious cultured meat via bovine myocytes and adipocytes co-culture: Novel Prospect for cultured meat production techniques.* Food Chem, 2024. **460**(Pt 3): p. 140696.
33. Calkins, C.R. and J.M. Hodgen, *A fresh look at meat flavor.* Meat Sci, 2007. **77**(1): p. 63-80.
34. To, K.V., et al., *Inosine 5'- monophosphate derived umami taste intensity of beef determination by electrochemistry and chromatography.* Meat Sci, 2023. **206**: p. 109343.
35. Miller, R.K., *CHEMICAL AND PHYSICAL CHARACTERISTICS OF MEAT I Palatability*, in *Encyclopedia of Meat Sciences*, W.K. Jensen, Editor. 2004, Elsevier: Oxford. p. 256-266.
36. Diepeveen, J., T.C.W. Moerdijk-Poortvliet, and F.R. van der Leij, *Molecular insights into human taste perception and umami tastants: A review.* J Food Sci, 2022. **87**(4): p. 1449-1465.
37. Lew, E.T., et al., *Chemical and sensory analyses of cultivated pork fat tissue as a flavor enhancer for meat alternatives.* Sci Rep, 2024. **14**(1): p. 17643.
38. Rasmussen, M.K. and G. Zamaratskaia, *Regulation of porcine hepatic cytochrome p450 - implication for boar taint.* Comput Struct Biotechnol J, 2014. **11**(19): p. 106-12.
39. Melton, S.L., *Effects of feeds on flavor of red meat: a review.* J Anim Sci, 1990. **68**(12): p. 4421-35.
40. Pereira, P.M. and A.F. Vicente, *Meat nutritional composition and nutritive role in the human diet.* Meat Sci, 2013. **93**(3): p. 586-92.
41. Leung, A.K., et al., *Higher well-being individuals are more receptive to cultivated meat: An investigation of their reasoning for consuming cultivated meat.* Appetite, 2023. **184**: p. 106496.

42. Williams, P., *Nutritional composition of red meat.* Nutrition & Dietetics, 2007. **64**(s4): p. S113-S119.
43. *Dietary protein quality evaluation in human nutrition. Report of an FAQ Expert Consultation.* FAO Food Nutr Pap, 2013. **92**: p. 1-66.
44. Herreman, L., et al., *Comprehensive overview of the quality of plant- And animal-sourced proteins based on the digestible indispensable amino acid score.* Food Sci Nutr, 2020. **8**(10): p. 5379-5391.
45. Ertl, P., W. Knaus, and W. Zollitsch, *An approach to including protein quality when assessing the net contribution of livestock to human food supply.* Animal, 2016. **10**(11): p. 1883-1889.
46. Marinangeli, C.P.F. and J.D. House, *Potential impact of the digestible indispensable amino acid score as a measure of protein quality on dietary regulations and health.* Nutr Rev, 2017. **75**(8): p. 658-667.
47. Kim, M., H.Y. Jung, and C. Jo, *Fundamental study on structural formation, amino acids and nucleotide-related compounds of cultivated meat from 3D-cultured pig muscle stem cells.* Food Sci Biotechnol, 2025. **34**(2): p. 457-469.
48. Pasitka, L., et al., *Spontaneous immortalization of chicken fibroblasts generates stable, high-yield cell lines for serum-free production of cultured meat.* Nat Food, 2023. **4**(1): p. 35-50.
49. Martins, B., et al., *Advances and Challenges in Cell Biology for Cultured Meat.* Annu Rev Anim Biosci, 2024. **12**(Volume 12, 2024): p. 345-368.
50. Furuhashi, M. and S. Takeuchi, *The effects of differentiation and aging on free amino acid profiles in cultured bovine muscle tissue.* Food Chem, 2025. **488**: p. 144753.
51. Liu, Y., et al., *Engineered meatballs via scalable skeletal muscle cell expansion and modular micro-tissue assembly using porous gelatin micro-carriers.* Biomaterials, 2022. **287**: p. 121615.
52. Lim, P.Y., R. Suntornnond, and D. Choudhury, *The nutritional paradigm of cultivated meat: Bridging science and sustainability.* Trends in Food Science & Technology, 2025. **156**: p. 104838.
53. Pereira, P.C. and F. Vicente, *Meat nutritive value and human health*, in *New Aspects of Meat Quality*, P. Purslow, Editor. 2022, Woodhead Publishing. p. 561-577.

54. Geiker, N.R.W., et al., *Meat and Human Health-Current Knowledge and Research Gaps.* Foods, 2021. **10**(7): p. 1556.
55. Sikora, D. and P. Rzymski, *Assessment of the potential nutritional value of cell-cultured chicken meat in light of European dietary recommendations.* Journal of Food Composition and Analysis, 2024. **135**: p. 106663.
56. Yuen, J.S.K., Jr., et al., *Aggregating in vitro-grown adipocytes to produce macroscale cell-cultured fat tissue with tunable lipid compositions for food applications.* Elife, 2023. **12**: p. e82120.
57. Louis, F., et al., *Mimicking Wagyu beef fat in cultured meat: Progress in edible bovine adipose tissue production with controllable fatty acid composition.* Mater Today Bio, 2023. **21**: p. 100720.
58. Liu, S.Q., et al., *Production of sodium alginate-gelatin composite hydrogel-based 3D cultured fat with low cholesterol and high polyunsaturated fatty acids.* Food Hydrocolloids, 2024. **154**: p. 110156.
59. Fraeye, I., et al., *Sensorial and Nutritional Aspects of Cultured Meat in Comparison to Traditional Meat: Much to Be Inferred.* Front Nutr, 2020. **7**: p. 35.
60. Zidarič, T., et al., *Cultured Meat: Meat Industry Hand in Hand with Biomedical Production Methods.* Food Engineering Reviews, 2020. **12**(4): p. 498-519.

FEASTS
Fostering European Cellular Agriculture
for Sustainable Transition Solutions

Final notes.

Deliverable 3.6 will be published with open access as a chapter of a book:

Rasmussen, M.K., Thøgersen, R.R., Young, J.F., Therkildsen, M. (2025). From Muscle Fibers to Functional Foods: Bridging Conventional and Cultivated Approaches. In: Advances in Biochemical Engineering/Biotechnology. Springer, Berlin, Heidelberg. https://doi.org/10.1007/10_2025_290

Funded by
the European Union