Alternative protein R&D priorities

Towards taste and price parity

People from all walks of life want our food system to be sustainable, secure and just, but most people's day-to-day food choices are based on taste, price and convenience.

Global demand for meat is growing, and industrial animal agriculture is already driving climate change and public health risks, so we need to transform how meat is made. Plant-based, cultivated meat and fermented products can deliver the meat people want in a more sustainable way.

However, there are still key R&D and infrastructure bottlenecks that need addressing to ensure alternative proteins can deliver the same experience as meat and dairy at a price point that is accessible to as many consumers as possible.

European and global research investment landscape

Europe is the world's biggest market for plant-based meat and the birthplace of cultivated meat. With ambitious climate targets, many of the world's top universities, and several of the world's leading economies, Europe can be a global leader in alternative proteins but must significantly increase public investment in R&D.

Notable public investments to date include:

In 2024, the European Commission committed €50 million to an accelerator challenge on food made using precision fermentation and algae, topping off the historical investment of more than €100 million invested through Horizon Europe.

In 2023, Denmark published the world's first national action plan for plant-based foods following on from the 1.25 billion kroner (€168 million) in funding announced in 2021 to advance these foods as part of a climate agreement for food and agriculture.

In 2022, the Dutch government announced €60 million of public funding to support the formation of an ecosystem around cellular agriculture – the world's largest-ever public investment in the cellular agriculture field.

In 2023, Germany announced over €30 million in funding for the protein transition, including an expansion of research funding for alternative proteins, transformation support for farmers and the establishment of a Proteins-of-the-Future centre.

In Spain, the Catalan regional government has invested a combined €19 million since 2023 in alternative protein R&D, including the establishment of a €7 million research hub hosted by IRTA and a €12 million investment for the construction of an alternative protein scale-up plant.

2023 was a record-breaking year for UK research funding in alternative proteins with a total of £15.6 million committed, including £12 million to establish the Cellular Agriculture Manufacturing Hub (CARMA) led by the University of Bath.

There are also examples outside Europe. In 2021 the US invested $10 million in a cultivated meat centre of excellence, Singapore has dedicated USD $104 million to the Singapore Food Story R&D programme, and Israel has invested over USD $173 million since 2018 and has a national policy plan to accelerate the sector.

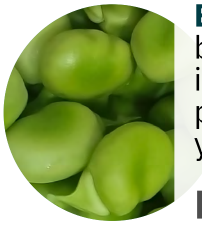
Overview: Research priorities in plant-based

Plant-based meat, eggs, and dairy are made directly from plants. Like animal products, they are composed of protein, fat, vitamins, minerals, and water. Next-gen plant-based options look, taste, and cook like conventional meat, and offer complex carbohydrates and fibre.

Plant-based meat formulation is focused on getting plant proteins to replicate the texture and experience of animal-based ones. Much of this relies on the production method, but advancements can also be made in the source raw materials and ingredients themselves.

Image: Juicy Marbles

Key research priorities for plant-based:



Better raw materials through breeding of crops and increased use of underutilised protein crops for higher protein yields and functionality.

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Improved protein fractionation and functionalisation to achieve higher quality ingredients, better energy-efficiency, and a lower degree of processing.

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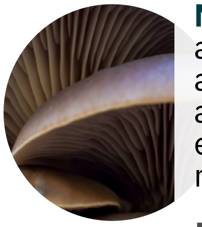

Novel ingredients to mimic animal fat properties, augment nutritional profiles, and enhance the sensory experience of plant-based meat.

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Novel texturization methods in addition to extrusion, electrospinning, 3D printing, enzymatic processing to match the texture of animal protein.

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Deep dive: research priorities in plant-based

Better raw materials

Optimising crops for improved protein content, quality and functionality can help to avoid costly and time-consuming downstream processing and improve the sensory and nutritional profiles of plant-based meat products. Very little crop development has focused on optimising plant protein sources and the vast majority of crops have not yet been explored for their suitability in plant-based meat applications. Crop breeders should focus efforts on developing new crop varieties and exploring the potential of other organisms that have increased protein content and quality. Simultaneously breeding for reduced off-flavours and improved sensory characteristics can increase consumer acceptance of plant-based meat.

Another way to add diversity and scale to plant-based meat raw materials is to valorize existing agricultural side streams. Bottlenecks associated with upcycling of side streams include driving down costs of drying, transportation, and processing agricultural and food side streams, while aiming for improved functionality. Availability of appropriate raw materials and bulk ingredients would be improved if widely adopted standards were established and comprehensive methods for plant protein characterization were available. Process optimisation for maximised recovery of high-value ingredients from sources such as plant biomass and food byproducts, alongside evaluations of their safety for use in food production, are critical.

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Improved protein fractionation and functionalisation

Fractionation and reconstitution are effective processes for creating ingredients for a wide variety of applications but create challenges due to trade-offs between purity and yield. Underutilised crops like pulses and other novel plant protein sources often require unique methods of fractionation which limits the number of cost-effective protein sources available. Moving towards the use of functional fractions such as flours and slurries instead of highly purified isolates can reduce the degree of processing required and make the manufacture of plant-based meat more efficient, economical, and sustainable. It can also improve the sensory profiles of the products themselves.

Protein conditioning can enhance the desirable traits of the protein. Biological processing techniques include using enzymes to fine-tune functional properties like solubility, gelling capacity, and fat- and water-binding capacity, or using microbial fermentation to convert plant protein feedstocks into more functional forms. Gentler and more efficient processing technologies such as pulsed electric fields and sonication should be optimised and scaled to help to improve texture and functionality and retain desirable nutritional and sensory properties. Sourcing optimised crops should also allow for a less intensive fractionation process, making the creation of functional fractions even easier and more efficient.

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Deep dive: research priorities in plant-based

Novel ingredients

Art and science come together in the formulation of plant-based meat end products. Turning plants into meat requires understanding each ingredient, how these ingredients interact, how manufacturing conditions create meat-like texture, and a vision for how to deliver on the appearance, aroma, and taste consumers want. Manufacturers are increasingly exploring the possibilities to achieve taste and texture parity in end product formulation presented by hybrid products which incorporate elements of plant-based, fermentation-made and cultivated proteins. Functional ingredients which can deliver improved end product performance at a price that is attractive to consumers are a major research priority.

Sourcing and incorporating alternatives to animal fats is an example of how this hybrid approach can bridge the taste gap and novel sources of plant and microbial-derived fats are needed. Plant-based proteins are often prone to bitter or "beany" off-flavours which could be addressed by creating new bitter-blocking agents, particularly those derived from natural sources and specifically designed to address the challenges presented by plant-based proteins. There is a need to develop colour indicators for plant-based meat which deliver the red-to-brown visual cue during cooking. Clean label binders and gelling agents alternatives will also be required to deliver the nutritional profiles consumers expect.

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Novel texturization methods

Extrusion is currently the most popular texturization method used to produce a fibrous, meat-like texture for plant-based meat. However, extrusion has limitations including difficulties with fat incorporation, differential breakdown of amino acids resulting in a loss of nutritional quality, operational variation, limited capacity, and high capital costs. Moreover, novel manufacturing techniques may be required to process the appropriate plant-based ingredients required to replicate a specific kind of meat. Researchers should strive for texturization methods which are less energy intensive and can retain the nutritional properties of end products while increasing application flexibility and reducing variability.

New mechanical texturisation methods such as shear cell method, 3D printing or fibre spinning must be optimised and scaled to reduce capital costs and energy use, and enable gentler protein structuring. Non-extrusion methods such as chemical or biological processes to gently denature and crosslink proteins into fibrous structures without the need for high temperature, high pressure, and prohibitively expensive equipment should be explored. Software development is also needed to model plant-based production to allow for systems analysis and predictive capability and life cycle assessments and techno-economic analyses will be required for novel processes.

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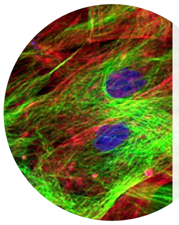
Overview: Research priorities in cultivated

Cultivated meat and fish is produced directly from animal cells. Meat cultivation replicates the processes that happen inside an animal by providing cells with warmth and nutrients to build muscle and fat.

At current production scales, cultivated meat is still more expensive to make than conventional meat. While the literature suggests that economically viable production could be achieved even without breakthrough advancements from current methods, significant chemical and biological engineering challenges remain to further reduce costs and increase yields.

Image: Ivy Farm

Key research priorities for cultivated:



Cell line development to achieve faster cell growth, greater stability and stress tolerance, and higher cell density in terrestrial and aquatic cell lines.

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Reduced cell culture media costs by bringing down the cost of growth factors and sourcing amino acids from cheap plant hydrolysates and other sources.

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Increased bioprocessing efficiency via innovations in bioreactor design and media utilisation strategies to achieve greater scale and bring down costs.

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Improved scaffolding biomaterials that support cell adherence and differentiation which allows the replication of complex animal meat structures.

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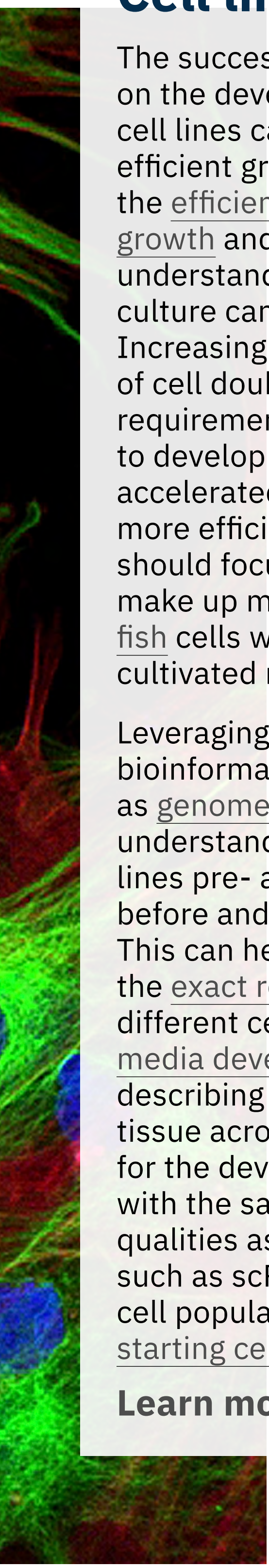
Deep dive: research priorities in cultivated meat and fish

Cell line development



The success of cultivated meat depends on the development of species-relevant cell lines capable of continuous and efficient growth in suspension. Improving the efficiency of adaptation to suspension growth and increasing the mechanistic understanding of non-adherent cell culture can help to unlock this possibility. Increasing the mechanistic understanding of cell doubling time and growth requirements can allow researchers to develop open-access cell lines with accelerated doubling times which grow more efficiently in culture. These efforts should focus on myoblast cell lines, which make up muscle tissue, especially for fish cells which are underrepresented in cultivated meat research at present.

Leveraging technologies such as bioinformatics and omics techniques such as genome and secretome analyses to understand the metabolic profiles of cell lines pre- and post-immortalisation, or before and after suspension adaptation. This can help researchers understand the exact requirements for the growth of different cell lines in culture and guide media development strategies. Equally, describing the genomics of muscle cells in tissue across different species is important for the development of cultivated products with the same composition and sensory qualities as conventional meat. Techniques such as scRNA-seq can distinguish different cell populations to expand the range of starting cell types.

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Reduced cell culture media costs

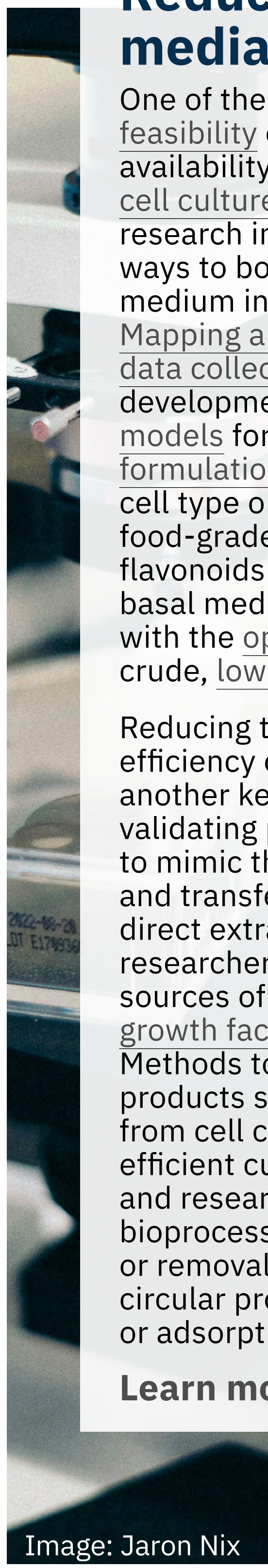

Image: Jaron Nix

One of the key drivers of the economic feasibility of cultivated meat will be the availability of affordable and sustainable cell culture media. This will require research into the most cost-effective ways to both produce and use cell culture medium in cultivated meat production. Mapping animal cell metabolism involves data collection and curation to inform the development of genome-scale metabolic models for the tailoring of media formulation and feed conversion to each cell type or bioprocess design. Testing of food-grade hydrolysates, extracts, and flavonoids for serum replacement and basal media supplementation can help with the optimisation of cell growth on crude, lower-cost media components.

Reducing the cost and increasing the efficiency of use of growth factors is another key challenge. Identifying and validating plant sources of proteins to mimic the roles of serum albumin and transferrin to allow scalability via direct extraction from crops can help researchers uncover economically viable sources of animal-free, non-recombinant growth factors for cultivated meat. Methods to reduce or remove waste products such as lactate and ammonia from cell cultures are also critical for efficient cultivated meat production and researchers should aim to develop bioprocessing strategies for the utilisation or removal of these metabolites via circular processing, co-culture systems, or adsorption.

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Deep dive: research priorities in cultivated meat and fish

Increased bioprocessing efficiency

Improving bioreactor performance while reducing capital expenditure is critical to producing cultivated meat at scale. Researchers should aim to develop bioreactor technologies which are more affordable and scalable than those currently available with lower construction costs. Improved control over and efficiency of bioprocessing conditions can be achieved using novel sensors or biosensors to assess biomass, growth factor, and metabolite concentrations, or other aspects of end-product quality. Exploring the potential of antimicrobial peptides or other cost effective sterilants or sterilisation methods can also be highly effective ways of reducing operating costs and avoiding risks associated with batch spoilage.

Bioreactors that incorporate scaffolds for whole-cut end products may in future be capable of making products that have meat-like structure and texture via the use of scaffolding biomaterials. More advanced methods of semi-continuous bioprocess design using simultaneous perfusion and stretch can go even further in achieving whole cut products with the desired alignment and maturation of muscle fibres. Finally, it is important to consider how post-harvest processes will affect end product characteristics and safety. Researchers should aim to develop a comprehensive understanding of how these processes can deliver quality products with high consumer acceptance.

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Improved scaffolding biomaterials

Scaffolding provides structural support for cells to adhere, differentiate, and mature, making it crucial for the creation of structured meat products like steak. More research is needed to uncover the best food-grade scaffolding materials and methods for constructing different types of cultivated meat products that have meat-like structure and texture and enhance cultivated meat nutrition. Recent demonstrations of stem cell expansion in 3D microenvironments such as encapsulated spheres or tubules can generate cell densities far higher than industry-leading stirred tank bioreactors with minimal loss of cell viability or stemness, but further research is required to make these technologies a scalable solution.

Scaffolds also offer the possibility of more efficient resource use while achieving more complex product design. Incorporating growth factors into scaffold materials can also help to reduce costs and introduce spatial heterogeneity to cultivated products. Likewise, scaffolds can help to optimise fat distribution and content in cultivated meat, and incorporate omega-3s into cultivated seafood to make it nutritionally equivalent to conventional seafood. To achieve this, we must better understand the interactions of materials within these scaffolds. Researchers can address these challenges by developing computational models to describe fluid flow through scaffolds to better understand mass transfer and shear forces.

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Overview: Research priorities in fermentation

Fermentation allows the production of proteins, fats and functional ingredients using microorganisms.

Biomass fermentation grows and uses the whole organism as a source of protein, while precision fermentation uses microbes to produce specific functional ingredients for many foods including alternative proteins. These ingredients can address key functional and sensory challenges faced by plant-based or cultivated meat. Although fermentation is a relatively mature platform, using it in the context of alternative proteins presents new challenges.

Image: Formo

Key research priorities for fermentation:

Target identification and validation to broaden the scope of food ingredients produced by precision fermentation and unlock new experiences for consumers.

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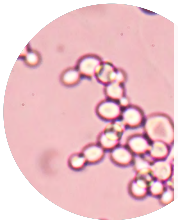

Screening and optimisation of novel strains to identify the most efficient pathways for producing targets and introduce greater robustness to manufacturing processes.

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Unlocking alternative feedstocks by leveraging existing agricultural and food processing waste streams to cut costs, reduce waste, and improve sustainability.

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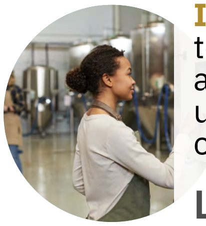

Improved bioprocess design to increase titers and yields, achieve more efficient scale-up, and drive down operating costs across the sector.

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Deep dive: research priorities in fermentation

Target identification

Fermentation is a key enabling technology for optimising the nutrition, taste, cost, and sustainability of alternative protein products. Success in target selection depends on target functionality, food applications and regulatory oversight. Methods for producing and encapsulating fats and oils similar to animal fats hold the key to bridging the taste gap between plant-based and animal-based meats and can provide a source of nutritionally important omega-3 fatty acids, particularly for seafood alternatives. Traditionally these targets require downstream processing technologies for efficient extraction of shelf-stable lipids, but encapsulation within the microbes themselves is a promising emerging solution.

Other areas which merit further attention include recombinant proteins like heme to improve the taste and "meatiness" of plant-based proteins or volatile compounds that improve aroma. Developing trends include developing neutral colour and mild flavour protein ingredients, the manufacture of affordable growth factors for use in cultivated meat production, and adding bioavailable nutrients to foods that would otherwise be lacking. Researchers can accelerate the design of new targets by using AI-backed machine learning to predict protein structure and function. Research on allergenicity and food formulation to inform safety assessment will also be valuable in evaluating precision fermentation-made products.

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Screening and optimisation of novel strains

Microbes offer immense biological diversity which can be leveraged to identify or create strains with enhanced growth potential, nutritional characteristics, flavour profiles, or feedstock preferences. Strain development focuses on bringing out the best features of a particular microbial strain, maximising productivity and minimising undesirable qualities. In precision fermentation, biosynthetic pathway discovery can elucidate the pathways responsible for producing desired molecules and inform strategies for designing microbial strains that produce targets at scale. To broaden the spectrum of available microorganisms, systematic investigation into the physiology of novel microbial strains is needed.

Strain development also has an important role to play in biomass fermentation. Suppressing hyper-branching of filamentous fungi is a key challenge in achieving efficient continuous cultivation which could greatly increase bioprocessing efficiency and reduce costs. Single-cell protein products are widely produced as animal-feed products but often lack the functionality and organoleptic characteristics required for human consumption. Research should focus on approaches to improve the quality of these products. A better understanding of available food-safe selection markers as well as efforts to develop new selection markers to encourage strain development will be important.

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Deep dive: research priorities in fermentation

Feedstock optimisation

In fermentation, feedstocks refer to the predominant raw materials used as a source of energy for microorganisms to grow and produce a range of bioproducts. Sourcing alternative feedstocks can cut costs, reclaim or repurpose food waste, and improve the sustainability of alternative protein production. Most fermentation bioprocesses rely either on glucose derived from hydrolysis of starch or sucrose extracted from crops like sugarcane. Alternative feedstocks remain highly inconsistent and poorly characterised. There is therefore a major requirement for research and development efforts which focus on optimising, valorizing and diversifying feedstock sources, in combination with strain development.

A shift toward more diverse feedstocks will require widely-adopted ingredient standards and comprehensive methods for feedstock characterization. Optimisation of processing conditions for maximised recovery of high-value ingredients from sources such as plant biomass and food byproducts, alongside improvements in drying and stabilisation and evaluation of their safety for use in food production, are critical. Diversification beyond sugar feedstock by using novel microorganisms that grow on other carbon sources like waste gases is another important trend. For all of these processes, life cycle assessments and techno-economic analyses will be required.

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Improved bioprocess design

Innovations in bioprocess design can unlock new opportunities for cost reduction, scale-up, and environmental sustainability. For upstream bioprocessing, research priorities include improvements to monitoring and control, continuous processes, and co-cultivation systems. Bioreactor designs that accommodate more viscous cultures, facilitate nutrient and air exchange at larger volumes, or enable longer periods of continuous production, are needed. Solid-state fermentation platforms also open the door to scale-out rather than scale-up approaches by increasing capacity through parallel small-scale units and mitigate some of the technical risks and capital costs associated with scaling.

Downstream processing can add significantly to operating costs so methods to reduce the cost of steps such as spray drying should be investigated. Improved biomass downstream processing can also unlock better taste, texture, and formulation options. Fats and oils have unique processing requirements which can be a bottleneck for commercialization so advances in lipid extraction are needed. The road to manufacturing readiness requires processes to be technologically mature and ready for deployment at scale and will require iterations of the design, build, test, learn cycle across the lab, pilot, and demonstration scales, as well as efficient knowledge sharing within the research and innovation community.

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