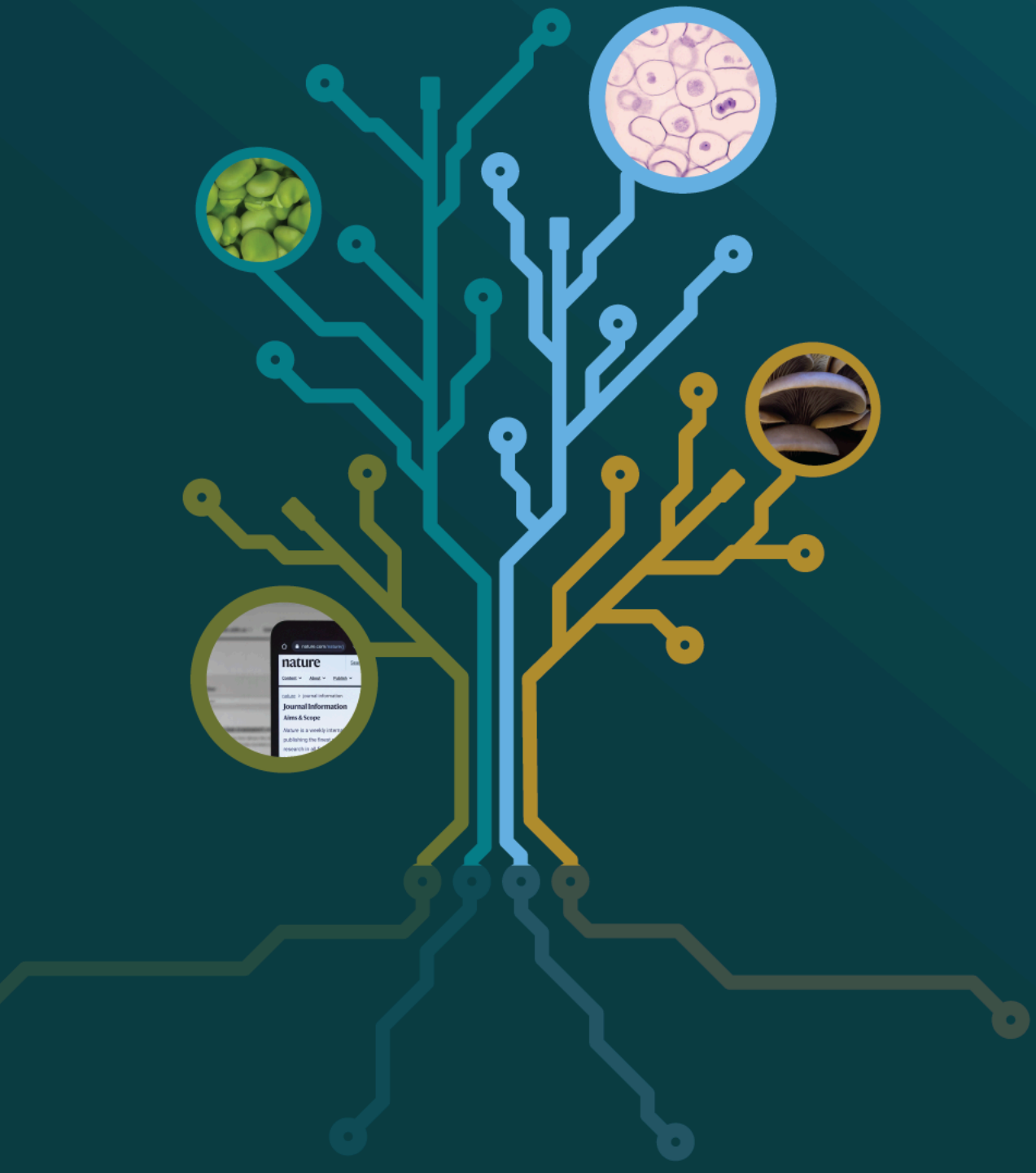
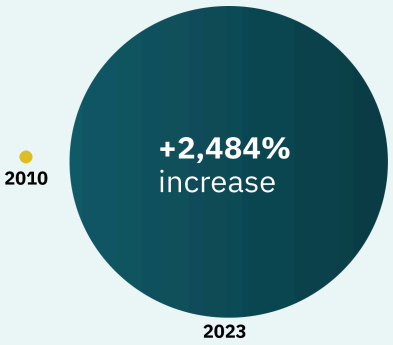
State of the European Alternative Protein Research Ecosystem 2019-2023

Publishing landscape analysis



Headline statistics



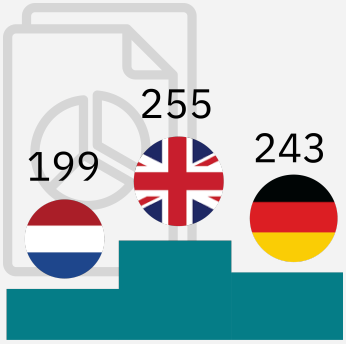
Alternative protein research is undergoing tremendous growth in Europe, with an **average year-on-year growth in publications of 32%.**

Since 2010, when 19 research outputs were published on alternative proteins, the field has seen rapid expansion, with 472 papers published in 2023, a **2,484% increase.**

The **bulk of this output has come in the past five years.** 77% were published between 2019 and 2023, and 26% were published in 2023 alone.

The United Kingdom leads the way in Europe with 255 publications since 2010, followed by Germany (243), and the Netherlands (199).

Considerable **differences in output can be observed between countries**, especially on a per capita basis, with some smaller countries performing strongly while their larger neighbours have the capacity to expand their activity in this field.

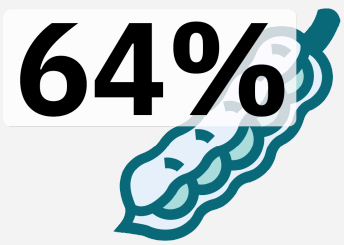


5,800 researchers have contributed to this output, **representing 1,250 organisations from 84 countries**, including 29 of the 30 countries analysed in this report and collaborators from an additional 54 external countries.

Alternative protein researchers show a **lower degree of international collaboration than the European average** and the research ecosystem needs support to become more cohesive and integrated.

Plant-based protein research has been the dominant alternative protein pillar in this timeframe, contributing 64% of total publications.

Large discrepancies are observed in the relative maturity of some technology areas, particularly topics on cultivated meat and precision fermentation, which are highly underdeveloped.



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01 Mapping the European alternative protein research ecosystem

Why alternative proteins

Alternative proteins offer a promising solution to meet the projected growth in the global demand for meat, while building a more sustainable food system. Plant-based and cultivated meat could help satisfy demand for meat with up to 90% less land, and fermentation can help Europe achieve a circular bioeconomy, using crops that would otherwise go to waste.

However, in order to achieve widespread uptake, alternative proteins must compete on taste, healthiness, and price as well as being widespread and available to purchase. European consumers report taste and price as the main barriers to trying and continuing to purchase these products. Yet in order to meet these expectations, key technological hurdles must be overcome.

Why a thriving open-access research ecosystem is important in Europe

In order to address these challenges, publicly funded, open-access research[1] is key. Many of the technical challenges facing the sector are of a fundamental, pre-competitive nature. Rather than each company addressing these challenges in silos, it is much more efficient for scientists to publish their research for the benefit of the wider ecosystem, ultimately de-risking and providing a solid foundation on which to build private sector innovation. This kind of research also reduces duplication of effort, promotes interdisciplinary collaboration, and can tackle the kinds of questions that industry isn't necessarily incentivised or well-placed to address.

Historically, research and development in alternative proteins has been heavily dominated by the private sector, meaning that many of the learnings have not been published for the wider scientific community to learn from. However, with the recent onset of increased public funding into the space, we have seen this balance start to shift. Trends in public R&I funding for alternative proteins are covered in the companion report from GFI Europe *Research and Innovation funding landscape analysis 2020-April 2024* that analyses in which countries, and at what scale, public funding has been directed to the space in recent years.

[1] Unless otherwise specified, GFI Europe uses the term 'open-access research' to refer to all results which are published in an academic journal. We use this term independently of the open-access status of the journal in which the research is published.

As a global research and innovation powerhouse accounting for over 20% of global R&I investment, Europe can be home to a thriving alternative protein research ecosystem. The EU is second only to China in terms of scientific output and is responsible for 18% of global scientific publications, while 49 of the world's top 200 universities are in Europe, more than any other region. However, the full breadth and depth of alternative protein research activity in Europe has never been mapped.

What we hope to achieve with this analysis

This report aims to address this knowledge gap by evaluating the growth and development of the open-access research ecosystem in alternative proteins across Europe on the basis of the published literature. This helps us to understand what research is happening, identify which scientists, institutions, and countries are conducting it, and develop key recommendations to further catalyse this growing research field.

We have collated a comprehensive dataset of publications on research topics related to alternative proteins published by authors working in European organisations (defined here as the 27 EU member states, along with Norway, Switzerland, and the United Kingdom) during the years 2010-2023 inclusive and analysed the key trends and themes. A full description of the methodology used, including caveats and limitations, can be found in the Methodology section.

On the basis of this analysis, this report aims to:

1. Present a thorough overview of the European alternative protein research landscape, including overall growth, key actors (individuals, institutions, and countries), trends in collaboration, and specific fields of research.
2. On the basis of published scientific literature, help current and future scientists understand how they can best contribute to the development of this field and identify future collaborators for their work.
3. Provide recommendations for how other stakeholders, including public research funders, can best support the further development and growth of the space.

What we mean when we talk about alternative proteins

The Good Food Institute defines alternative proteins according to three pillars:

Plant-based meat, seafood, eggs and dairy are produced directly from plants but look, taste, and cook like conventional animal products.

Image: Mosa Meat

Image: Juicy Marbles

Cultivated meat and seafood. Foods like chicken, pork, beef and fish that are produced by cultivating animal cells directly, thus replicating the sensory and nutritional profiles of conventional meat and seafood.

Image: Perfect Day

Fermentation-made protein and ingredients.[2] Fermentation is used in three primary ways. *Traditional fermentation* uses intact live microorganisms to modulate and process plant-derived ingredients. *Biomass fermentation* leverages the fast growth and high protein content of many microorganisms to efficiently produce large quantities of protein. *Precision fermentation* uses microbial hosts to produce specific functional ingredients which are important for the manufacture of alternative protein end products.

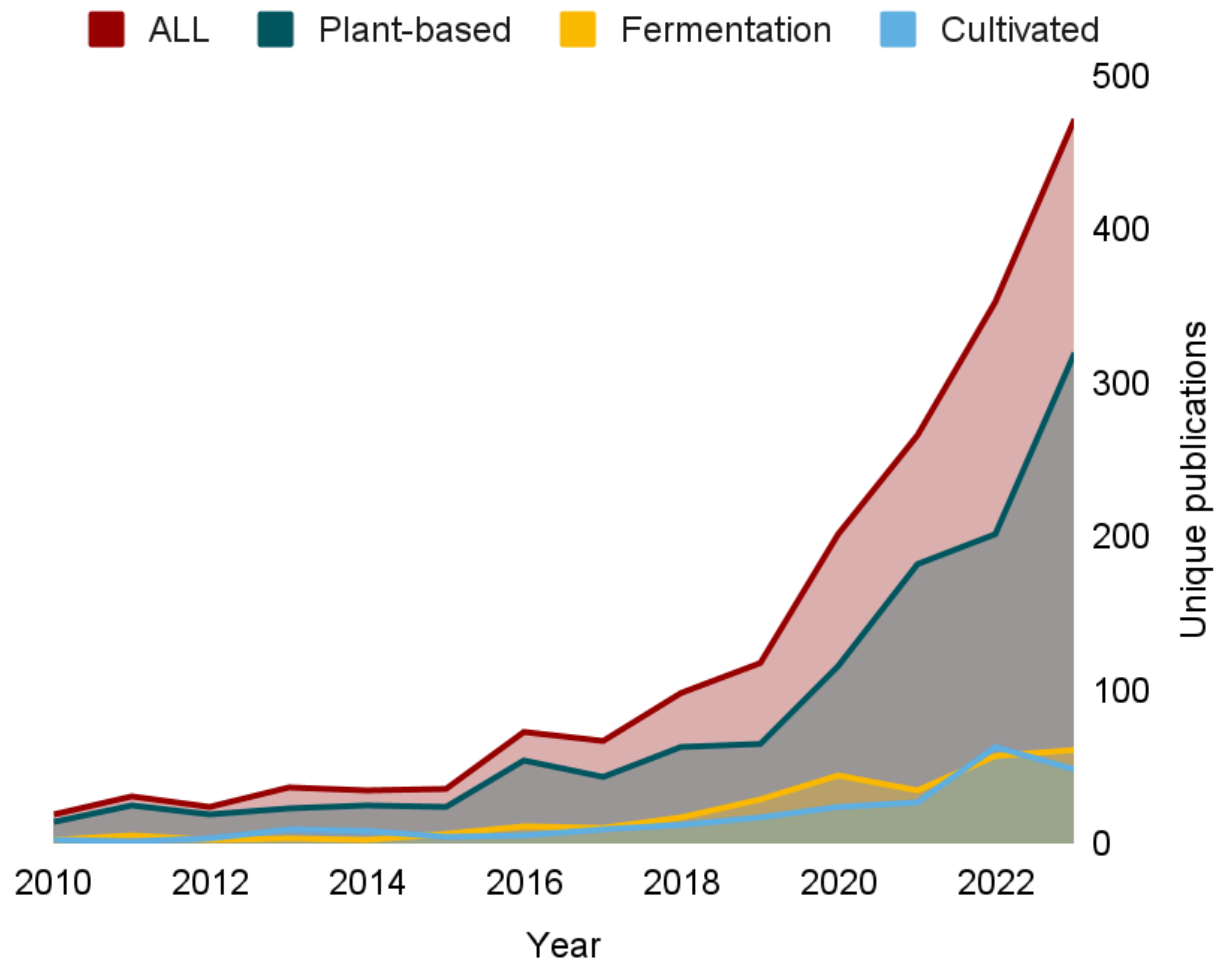
[2] NB: For the purpose of this report, traditional fermentation techniques which are used to modify or enhance the characteristics of plant proteins will be considered within the 'plant-based' analysis

02 Historical context: 2010 to 2023

Overall growth trends

Historically, most of the R&D in alternative proteins has been carried out in the commercial realm by startups and established companies. As a result, progress in this field has not always been fully reflected in the scientific literature. This analysis shows that open-access alternative protein research is undergoing rapid growth in Europe and is quickly catching up with industrial advances to fill fundamental knowledge gaps.

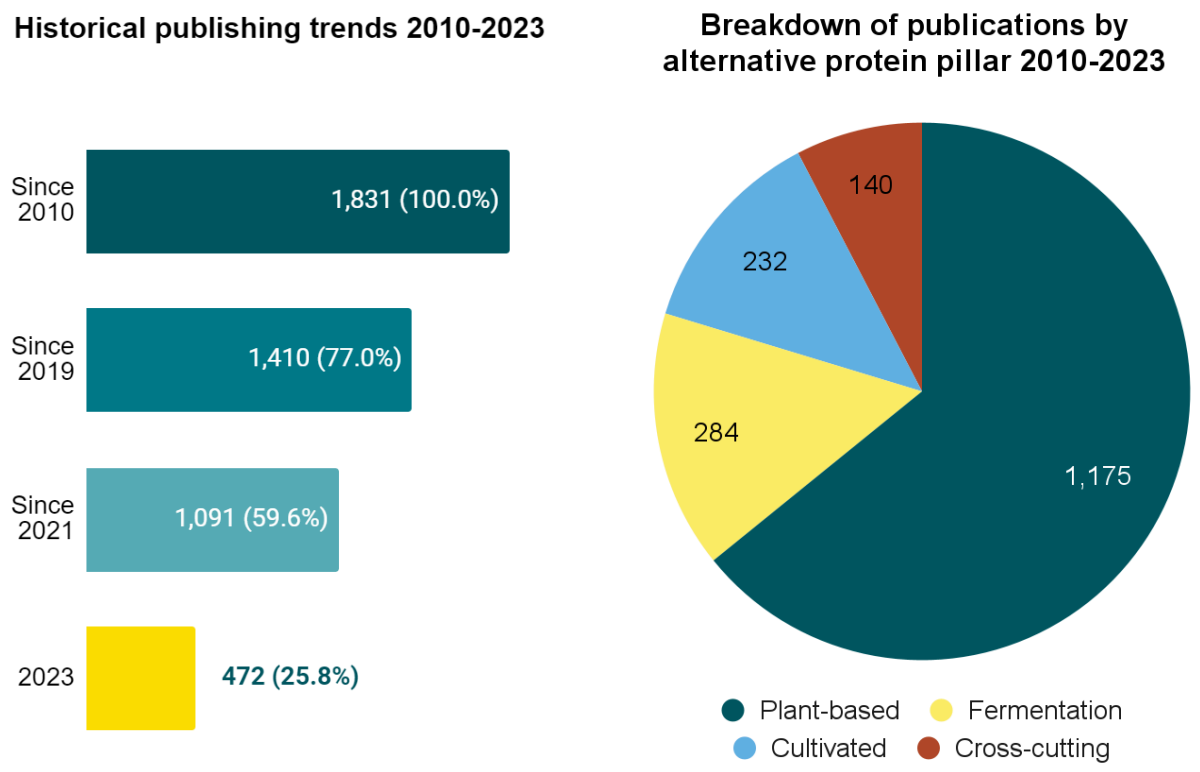
Figure 1. Number of unique publications per year, 2010-2023



Since 2010, when only 19 research papers were published on alternative proteins in Europe, the field has undergone rapid expansion, with 472 papers in 2023 alone, a 2,484% increase (Figure 2). Of the 1,831 total publications in the period 2010-2023, 77% have been published since 2019 and 26% were published in 2023 alone. A total of 5,800 researchers have contributed to this output, representing 1,250 organisations from 84 countries, including 29 of the 30 European countries analysed in this report and collaborators from an additional 54 external countries.

Plant-based protein research has been the dominant alternative protein pillar in this timeframe, contributing 64% of all publications. Meanwhile, 16% of publications focused on fermentation-made proteins and ingredients, 13% on cultivated meat and seafood, and 8% on cross-pillar topics.

Figure 2. Trends in historical research output by the alternative protein scientific community since 2010. Alternative protein research has seen a surge in activity in recent years, with 77% of the total output coming in the years 2019-2023 inclusive and 26% coming in 2023 alone. Plant-based protein research dominates this space, with 64% of publications.



Geographic breakdown

The United Kingdom leads Europe in research output with 14% of all publications since 2010, followed by Germany (13%), and the Netherlands (11%) (Figure 3, Table 1). Italy has the largest number of researchers working on alternative proteins (504), followed by the UK (448), and Germany (409).

When examining the number of publications on a per capita basis, the top countries are Denmark, Ireland, and Finland (Figure 4) with a similar trend observed for researchers per million inhabitants. Interesting trends can be observed here, with larger countries such as the UK and Germany ranked 12th and 17th on the basis of publications per million inhabitants, respectively, despite their strong overall output. This shows that some smaller countries are punching above their weight in research output and that larger countries have the capacity to contribute more to this research field.

A clear example that reinforces this point is when we look at the four largest countries in the European Union (Germany, France, Italy, and Spain), which collectively contributed 56% of overall EU research output in 2022 across all scientific disciplines. In comparison, this analysis indicates that their contribution to the overall EU output in alternative protein research stands at 41% for the years 2010-2023. While these figures do not provide a fully like-for-like comparison given the relative nascency of the alternative protein field, they do give some sense of the degree to which larger countries have a significant margin to increase their activity in this space.

When countries are ranked based on economic power (as measured by a country's gross domestic product (GDP) at purchasing power parity (PPP) per capita), the order is closer to that of the total outputs, with the UK in first place, followed by Germany and Spain. The top countries by number of researchers by GDP are Italy, the UK, and Spain.

Figure 3. Heat map of the most productive European countries in alternative protein research in the years 2010-2023 inclusive as measured by unique publications. The UK is the most productive, followed by Germany, the Netherlands, Spain, and Italy.

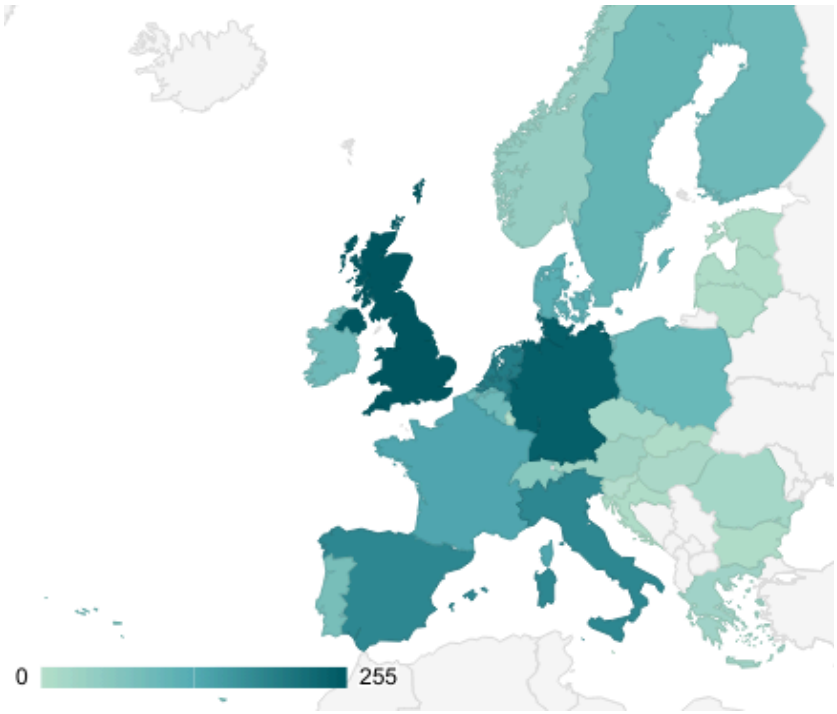


Figure 4. Heat map of the most productive European countries in alternative protein research in the years 2010-2023 (unique publications per million inhabitants). Denmark is the most productive per capita, followed by Ireland, Finland, the Netherlands, and Sweden.

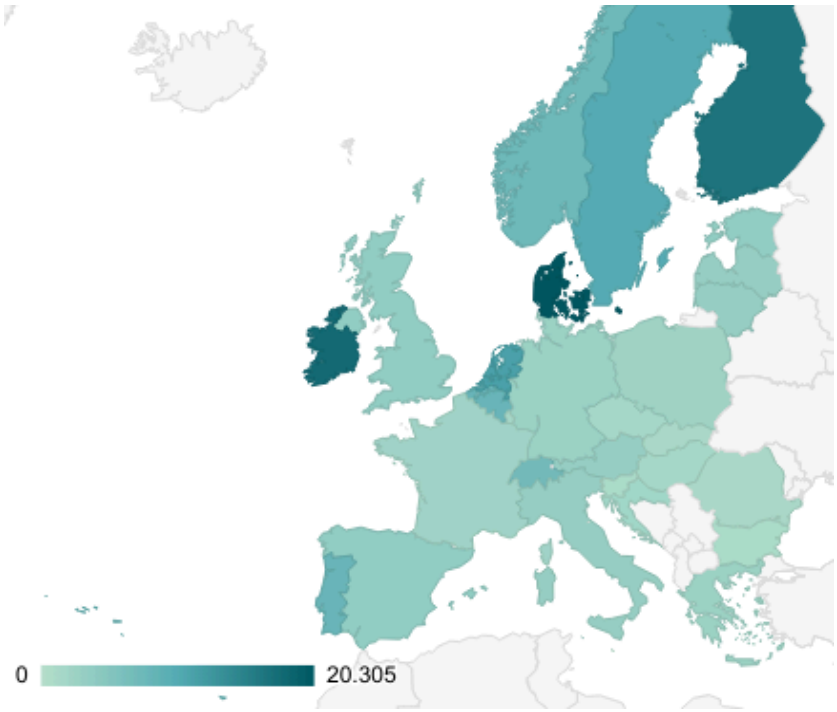


Table 1. Ranking of countries in Europe on the basis of total unique academic publications and total number of researchers in the years 2010-2023 inclusive.

Country	Total unique publications	Total researchers	Publications per million inhabitants	Researchers per million inhabitants	Publications/ $1k GDP (PPP) per capita	Researchers/$1 k GDP (PPP) per capita
United Kingdom	255	448	3.8	6.6	4.3	7.6
Germany	243	409	2.9	4.9	3.5	5.9
Netherlands	199	336	11.3	19.1	2.5	4.3
Spain	183	387	3.9	8.1	3.5	7.3
Italy	183	504	3.14	8.6	3.1	8.6
France	135	294	2.1	4.5	2.2	4.8
Denmark	120	210	20.3	35.5	1.6	2.7
Sweden	105	197	9.9	18.6	1.5	2.8
Poland	97	231	2.4	5.6	2.0	4.7
Belgium	94	184	8.0	15.7	1.3	2.6
Finland	93	174	16.8	31.4	1.4	2.7
Ireland	91	115	18.0	22.7	0.7	0.9
Portugal	82	220	8.0	21.5	1.7	4.5
Switzerland	61	96	6.9	10.9	0.7	1.0
Norway	41	78	7.5	14.3	0.4	0.8
Austria	30	60	3.3	6.7	0.4	0.8
Greece	26	64	2.5	6.2	0.6	1.6
Romania	23	84	1.2	4.22	0.5	1.8
Czechia	18	42	1.7	4.0	0.3	0.8
Hungary	15	51	1.5	5.0	0.3	1.1
Lithuania	9	34	3.3	12.5	0.2	0.7
Croatia	8	21	2.0	5.2	0.2	0.5
Bulgaria	7	22	1.1	3.3	0.2	0.6
Slovakia	7	9	1.2	1.6	0.2	0.2
Latvia	6	15	3.3	8.2	0.1	0.4
Estonia	5	5	3.8	3.8	0.1	0.1
Slovenia	2	12	0.9	5.7	0.04	0.2
Luxembourg	1	7	1.5	10.6	0.01	0.05
Cyprus	1	1	1.1	1.1	0.02	0.02
Malta	0	0	0.0	0.0	0.0	0.0

03 Recent trends and dynamics: 2019 to 2023

As the majority of publications on alternative proteins occurred in the period 2019-2023, we analysed this period in more detail to better assess the recent dynamics and trends. All subsequent sections of this report will be limited to this timeframe.

Figure 5. Summary data outlining the key community health indicators of the European alternative protein research ecosystem in the years 2019-2023 inclusive.

Recent trends

The European alternative protein research ecosystem underwent rapid growth in the period 2019-2023, with a total of 1,411 publications recorded in this timeframe (Table 2). The 472 research outputs in 2023 represented a 400% increase on the 118 published in 2019 and the number of publications increased each year with an average year-on-year growth rate of 38% (Figure 6A). 4,666 researchers from 1,092 institutions in 79 countries contributed to this output, including all but one of the 30 European countries included in the scope of this report and collaborators from 50 other external countries. Plant-based protein publications account for 63% of the total, followed by fermentation-made protein and ingredients (16%), cultivated meat and seafood (13%), and cross-pillar publications (9%) (Figure 6B).

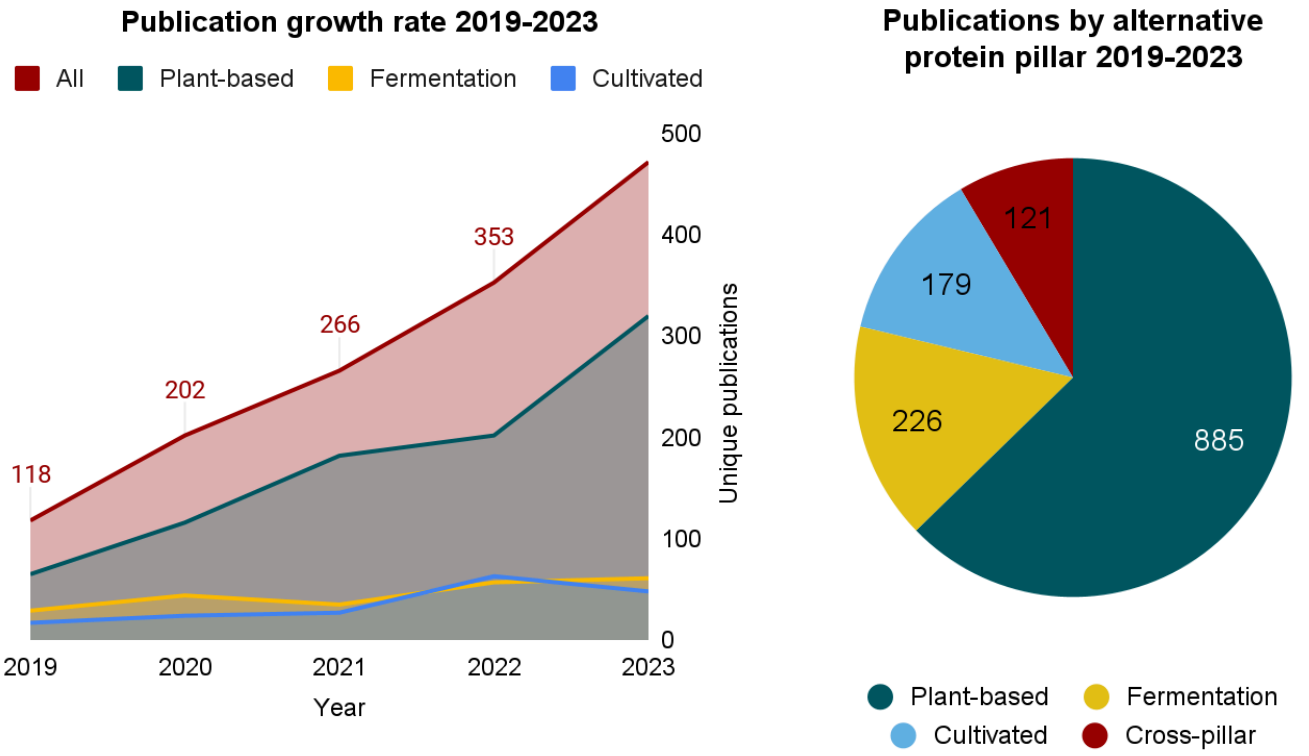
While the overall volume of publications has increased steadily, there are differences in growth rate across the alternative protein pillars. Plant-based research output has shown strong and consistent growth over the period 2019-2023 and accounts for the majority of the overall growth in alternative protein research output in this period, with an average annual growth rate

of 42% and an overall increase of 492% when comparing the 2023 output to the 2019 baseline.

Conversely, while research on both fermentation-made and cultivated proteins has increased in this time, these increases have been less pronounced and more variable year-on-year. Fermentation publications showed an average annual growth rate of 34% while for cultivated proteins this was 41%. However, fermentation publications output declined by 21% in 2021 compared to 2020, while cultivated protein research output declined by 24% in 2023 compared to the previous year. The overall increase in publications was 210% and 282%, respectively, when comparing 2023 to 2019.

These fluctuations in output from researchers in the fermentation and cultivated fields can partially be explained by the relative immaturity of these fields, whereby the community may not have reached the critical mass required to achieve sustained growth year-on-year. It is also likely that, given the smaller numbers involved overall, variation in the output from single researchers or research groups will noticeably impact the overall yearly output.

Figure 6. (A) Publications outputs from European institutions grew in the years 2019-2023 inclusive, increasing by 400% between 2019 and 2023, with an average year-on-year growth of 38%, (B) Plant-based protein research is the dominant alternative protein pillar in Europe, followed by fermentation-made protein and ingredients, and cultivated meat and seafood.



Geographic breakdown

The alternative protein research community is well-represented across a diverse mix of European countries, with all but one country in the scope of this analysis contributing to the academic literature. The UK was the most productive country with 194 unique publications, followed by Germany (182) and Italy (144) (Table 2). Italy leads Europe in the number of researchers with 403, followed by the United Kingdom (347) and Spain (292). The Netherlands has accumulated the highest number of citations with 5,490, followed by the UK (5,356) and Germany (4,433).

Table 2. Top 10 most productive European countries in the years 2019-2023 inclusive.

Country	Publications	Researchers	Total Citations
United Kingdom	194	347	5,356
Germany	182	287	4,433
Italy	144	403	3,108
The Netherlands	134	241	5,490
Spain	134	292	3,648
France	112	247	2,860
Denmark	106	181	2,617
Sweden	85	165	1,994
Poland	81	197	1,826
Finland	72	151	2,253

Most prolific institutions and researchers

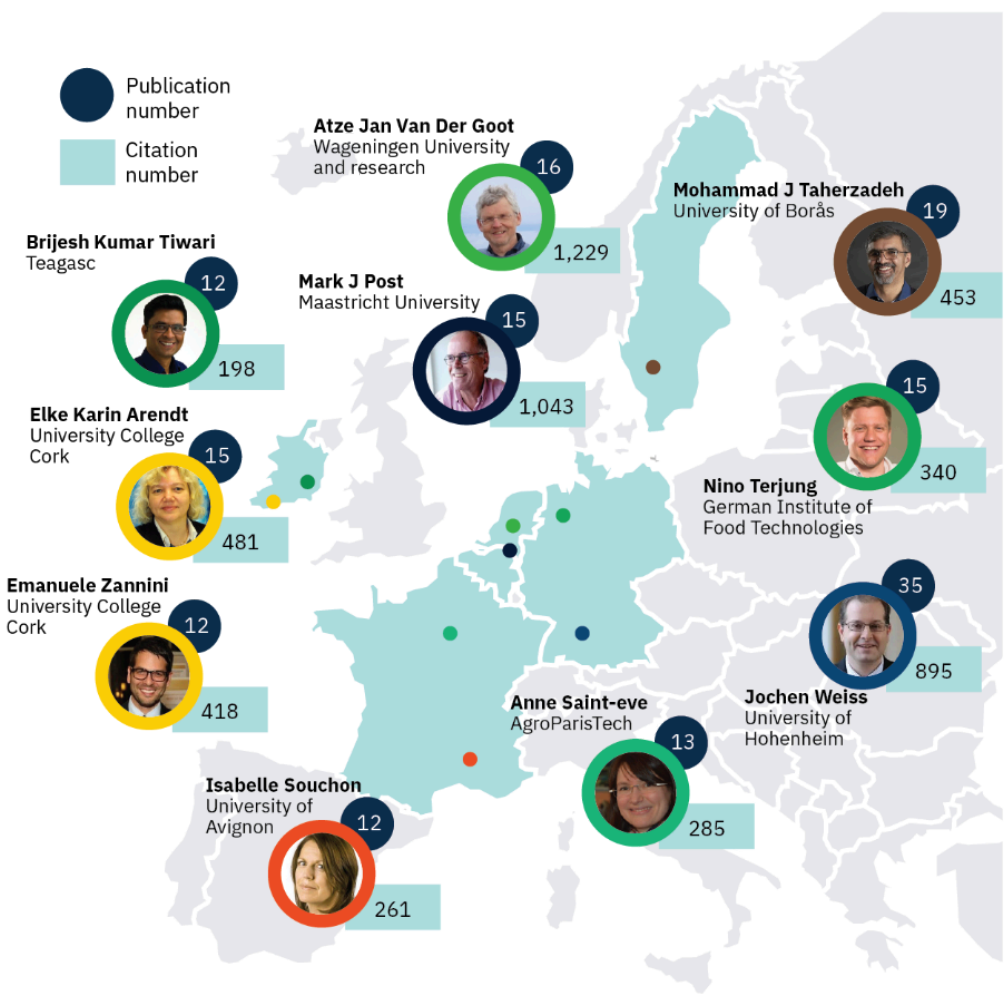
Wageningen University & Research (WUR) is the dominant institution for alternative protein research in Europe, both in terms of unique publications (87) and accumulated citations (3,657). Denmark has three institutions in the top 10, Ireland has two, and the Netherlands, Germany, Finland, Belgium, and Sweden all have one each (Figure 7). Jochen Weiss of the University of Hohenheim was the most productive researcher in this time period, with a total of 35 publications, followed by Mohammad J Taherzadeh (University of Borås, 19 publications), Atze Jan Van Der Goot (WUR, 16), Mark J Post (Maastricht University, 15), and Elke Karin Arendt (University College Cork, 15) (Figure 7). Atze Jan Van Der Goot is the most highly cited researcher with a total of 1,229.

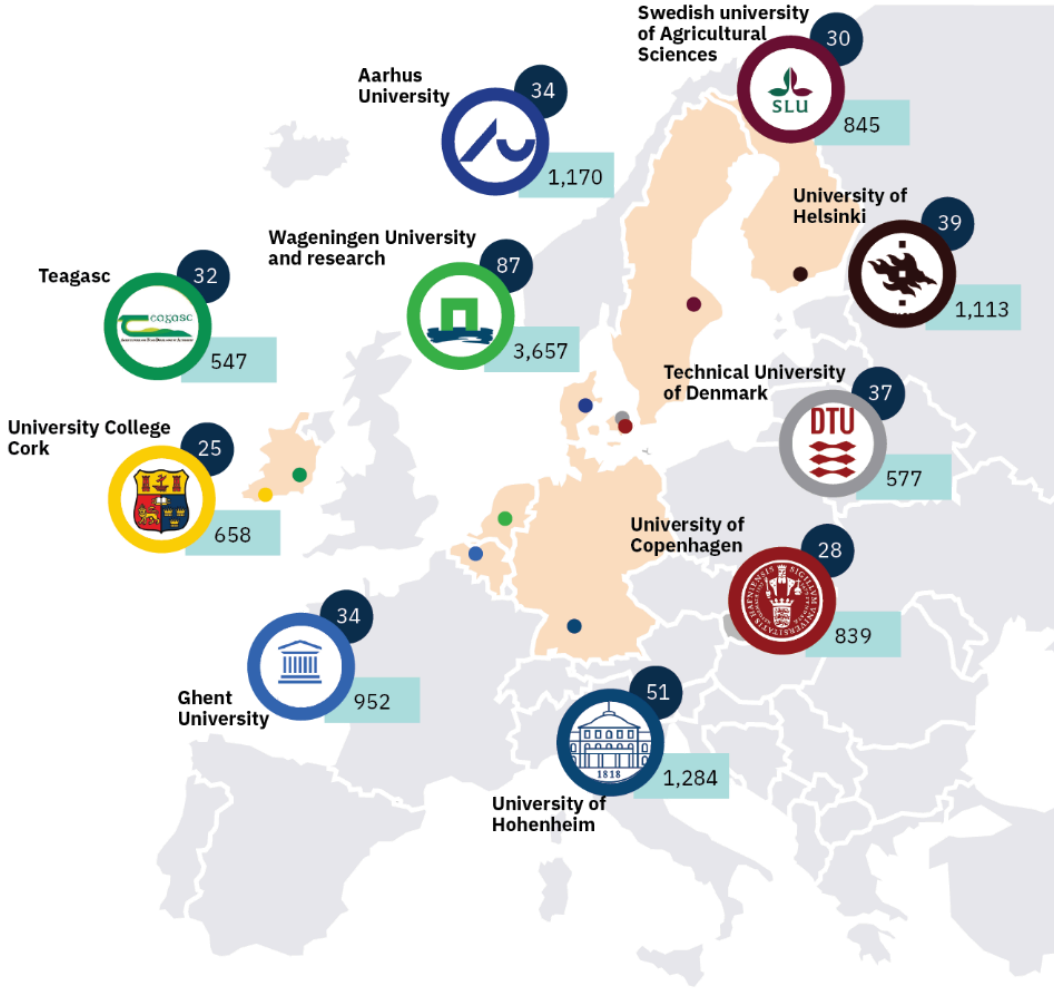
It is interesting to observe some of the patterns that emerge from this data. For example, in some countries, there is one clear leading institution or researcher that is contributing a disproportionate amount of the national or institutional output, such as Wageningen University & Research in the Netherlands, which contributes 65% of the total output from the Netherlands, or Mohammad J Taherzadeh at the University of Borås who has contributed 22% of the total Swedish output. Likewise, in small countries where research is concentrated in a small number of institutions, such as Belgium and Ireland, these institutions perform strongly in the institutional rankings, despite the fact that neither country is in the top 10 most productive overall.

While overall research output is not always a reliable indicator of research quality, these findings do indicate that individual researchers, departments, and institutions can have an outsized impact, independent of the overall activity of their surrounding country or region. This suggests that newer entrants to the field can rapidly build a strong profile in alternative protein research when they are focused on leveraging their respective strengths towards addressing research questions in this field.

Large countries such as the UK, Italy, and Spain rank highly in Europe on the basis of total publication output but do not have any individual researchers or research organisations in the respective top 10 lists, suggesting there is significant research activity happening in these countries but that it is relatively thinly spread out. In the context of some recent high-profile public investments in alternative protein research centres, such as the £12 million Cellular Agriculture Manufacturing Hub (CARMA) hosted by the University of Bath (UK), the £12 million National Alternative Protein Innovation Centre (NAPIC) hosted by the University of Leeds (UK), and the €7 million Centro de innovación en Proteínas Alternativas (CiPA) hosted by IRTA (Spain), it will be interesting to observe the impacts these highly focused and coordinated investments have in driving greater cohesion and impact for these institutions and their host countries, which can serve as an example for other European countries to follow.

Figure 7. Top 10 most productive European researchers[3] and research institutions in the years 2019-2023 inclusive.





[3] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Citations & global impact

Publications involving European researchers have accumulated a total of 18,401 citations in 144 countries since 2019. The top 10 citing countries are a mix of European and non-European countries, demonstrating that European research is having a wide-reaching influence both locally and globally. By far the country that has cited European research more than any other is China, followed by the United States and India (Figure 8).

Over 70% of publications had some form of open-access[4] publishing status (39% gold, 8% green, 26% hybrid) which, while encouraging, is slightly lower than the EU average of 80% in 2020. 94% of publications have been cited at least once, with an average of 13 citations per publication. Unsurprisingly, given their total number, plant-based publications accumulate the highest number of citations with 11,999, followed by fermentation-made (3,576), cultivated (2,270), and cross-pillar (556).

Alternative protein publications show an outsized impact in their research fields, as demonstrated by high Field Citation Ratio (FCR)[5] scores. When assessing the top 500 publications on the basis of their citations in the last two years, all of those that qualify for an FCR have a score above 1.0, indicating that they outperform the average number of citations in their field of research, in some cases by a factor of 100-fold or more. These data underline that alternative proteins are attracting a disproportionately high degree of interest and attention in food and engineering research and that these fields provide an exciting opportunity for academics looking for a research area in which to build a successful and high-impact career.

Of the 10 publications that have received the highest number of citations over the past two years, the majority (seven) relate to plant-based proteins, reflecting the dominance of plant-based research in Europe and the relative maturity of this field (Table 3). Broadly, these publications focus on technical aspects of plant protein functionality or the development of plant-based end products. Of the remaining three publications, two are commentaries on the consumer acceptance of novel proteins and, while important, do not explicitly contribute towards the technical advancement of alternative proteins, beyond pointing towards how future technical research could improve acceptance. The final publication is a review of the

[4] Contrary to other sections of this report where the term 'open-access' is used to refer to all results which are published in an academic journal and therefore accessible to the wider scientific community, in this instance 'open-access' refers specifically to publications which are delivered to readers free of access charges or other barriers.

[5] Field Citation Ratio (FCR) indicates the relative citation performance of an article, when compared to similarly-aged articles in its subject area. The FCR is normalised to 1.0 for this selection of articles. An FCR value of more than 1.0 shows that the publication has a higher than average number of citations for its group (defined by its field of research subject code and publication year). For example, an article with an FCR of 10.0 has received 10 times more citations than the average. Articles that are less than two years old do not have an FCR and an article with zero citations has an FCR of 0.

scientific, sustainability, and regulatory challenges in bringing cultivated meat to market published in 2020. The lack of highly cited research papers on recent technical advances in cultivated meat and fermentation in the top 10 is a concern and reflects the growing but still limited body of publicly available knowledge on these topics.

Figure 8. Heat map of countries where European alternative protein researchers are being cited in the years 2019-2023 inclusive, as measured by unique citing publications.

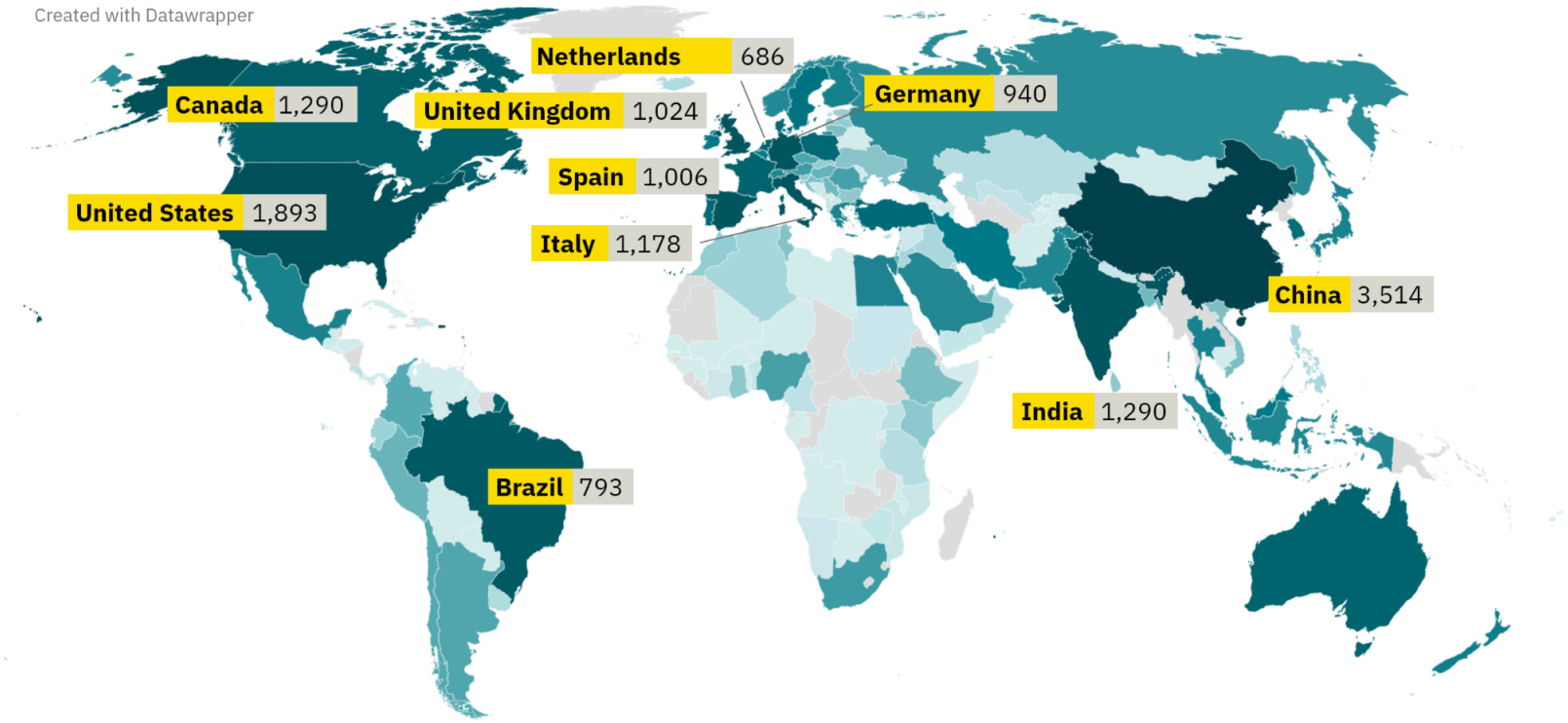


Table 3. The 10 publications from the period 2019-2023 that have received the highest number of citations over the past two years.

Publication title	Year	Source title	Recent citations[6]	Field citation ratio	DOI
A systematic review on consumer acceptance of alternative proteins: Pulses, algae, insects, plant-based meat alternatives, and cultured meat	2020	Appetite	337	86.43	10.1016/j.appet.2020.105058
Modification approaches of plant-based proteins to improve their techno-functionality and use in food products	2021	Food Hydrocolloids	242	62.22	10.1016/j.foodhyd.2021.106789
Consumer acceptance of novel food technologies	2020	Nature Food	215	63.48	10.1038/s43016-020-0094-x
Scientific, sustainability and regulatory challenges of cultured meat	2020	Nature Food	210	126.69	doi.org/10.1038/s43016-020-0112-z
Plant-based food and protein trend from a business perspective: markets, consumers, and the challenges and opportunities in the future	2020	Critical Reviews in Food Science and Nutrition	210	71.03	10.1080/10408398.2020.1793730
Functionality of Ingredients and Additives in Plant-Based Meat Analogues	2021	Foods	207	135.97	10.3390/foods10030600
Foods for Plant-Based Diets: Challenges and Innovations	2021	Foods	202	93.1	10.3390/foods10020293
Chapter 6 Plant-Based Meat Analogues	2019	Sustainable Meat Production and Processing	175	73.43	10.1016/B978-0-12-814874-7.00006-7
Plant-based meat analogues: from niche to mainstream	2020	European Food Research and Technology	166	58.46	10.1007/s00217-020-03630-9
Advances in the plant protein extraction: Mechanism and recommendations	2021	Food Hydrocolloids	157	32.04	10.1016/j.foodhyd.2021.106595

[6] Dimensions.ai classifies publications on the basis of a recent citations value which refers to the number of citations the publication has received in the last two years. This indicates the degree to which a publication has been influential in the research community in the recent past. However, this figure may not reflect the total number of historical citations the publication has received.

Most popular journals

The most popular academic journals for publishing alternative protein research are *Foods*, *Food Hydrocolloids*, *Food Research International*, *Nutrients*, and *Food Quality and Preference* (Table 4). For some journals, citation metrics for alternative protein research performed very strongly when compared to the average citations for all publications in that journal. For example, alternative protein publications in *Frontiers in Nutrition* attracted an average of 51.96 citations, 422% more than the average, with other examples including *Frontiers in Sustainable Food Systems* (317% above average), *Appetite* (194%), and *Foods* (146%).

For other journals, alternative proteins receive fewer citations than the journal average, such as *Food Chemistry*, at 411% less than the average. This possibly reflects the overall nascency of the field and inconsistencies in the degree to which the key technical bottlenecks are being addressed by researchers across the spectrum of scientific disciplines. Given the wide range of technical and societal research questions that need to be solved to move alternative proteins to taste and price parity with their conventional counterparts, it is important that support mechanisms are put in place to grow these research communities and make them aware of the most pressing research questions in their respective fields.

Table 4. The most popular academic journals for publishing alternative protein research in the years 2019-2023 inclusive.

Journal name	Publications	Avg Citations – AP	Avg citations – all	% Variation
Foods	142	29.4	12.0	146%
Food Hydrocolloids	61	28.4	47.7	-41%
Food Research International	55	20.7	29.9	-31%
Nutrients	38	35.1	22.8	54%
Food Quality and Preference	36	32.9	37.6	-12%
Food Chemistry	33	27.2	46.0	-411%
Trends in Food Science & Technology	27	69.4	61.4	13%
Journal of the Science of Food and Agriculture	26	19.4	26.6	-27%
Frontiers in Nutrition	23	52.0	10.0	422%
Molecules	21	21.0	18.9	11%
Critical Reviews in Food Science and Nutrition	20	46.0	66.0	-30%
Sustainability	19	18.3	13.3	38%
Appetite	18	78.7	26.8	194%
LWT	18	26.2	32.2	-19%
Frontiers in Sustainable Food Systems	17	40.4	9.7	317%

Collaboration

Reflecting its relative degree of immaturity, the European alternative protein research community displays a lower-than-average degree of collaboration, with international co-authorships accounting for 39% of the total. This figure is slightly lower than the 40% international average for all scientific disciplines calculated in 2022 and is significantly lower than the corresponding figure of 56% in the EU and 64% in the UK. Despite this, European alternative protein researchers have managed to publish in collaboration with almost 1,000 researchers from a total of 50 countries outside of Europe (defined as those not within the scope of this report, which are the 27 EU member states, Norway, Switzerland, and the UK) (Figure 9).

There are many possible explanations for this low degree of international collaboration. As a relatively new and emerging research area, it may reflect the difficulty researchers face in finding the right research expertise to address the numerous technical and societal research questions poised by alternative protein research. Funding mechanisms that allow this type of large-scale interdisciplinary, cross-border collaboration are limited and can be exceptionally competitive. While a number of projects have been funded through the Horizon Europe mechanism which bring together diverse stakeholder groups to tackle important research questions in alternative proteins (including projects such as Giant Leaps, Smart Protein Project, NextGen Proteins, VALPRO Path, FEASTS, and HealthFerm), not all of this research is of a technical nature. It will be important to find ways to fill this funding gap to facilitate more international collaborations on the technical bottlenecks in alternative protein research. For more information on the current state of alternative protein research funding, see the companion GFI Europe report *Research and Innovation funding landscape analysis 2020-April 2024*.

Analysis of the author collaboration network reveals that the network is quite fragmented, suggesting it has not yet achieved a high degree of integration and cohesion. This analysis identified 90 collaboration clusters, accounting for a total of 1,804 unique publications, but very little connection between these clusters (Figure 10). Instead, it is characterised by pockets of collaboration, with many repeated collaborations between the same authors resulting in limited cross-pollination and information exchange. The low network density suggests there are numerous potential connections between researchers that remain unexplored, leaving room for further collaboration and interdisciplinary research.

Table 5 summarises the most productive researcher collaborations in Europe over the time period analysed. It is notable that many of the researchers who feature in this table are also among the most highly cited researchers in Europe, providing evidence for the importance of effective collaboration in achieving research impact. However, it is also important to note that

most of these collaborations are from single institutions, and the remainder are domestic. This further underlines the degree to which this research community requires greater support to stimulate and sustain cross-border, interdisciplinary research collaborations. Mechanisms such as COST Actions can play an important role here in helping to grow the research ecosystem and fill knowledge gaps, but alternative protein research remains underrepresented in the COST ecosystem at present.

Figure 9. Heat map indicating countries with which European alternative protein researchers have collaborated on research publications in the years 2019-2023 inclusive. The United States is the country where most collaborations were formed, followed by China, Brazil, India, and Australia.

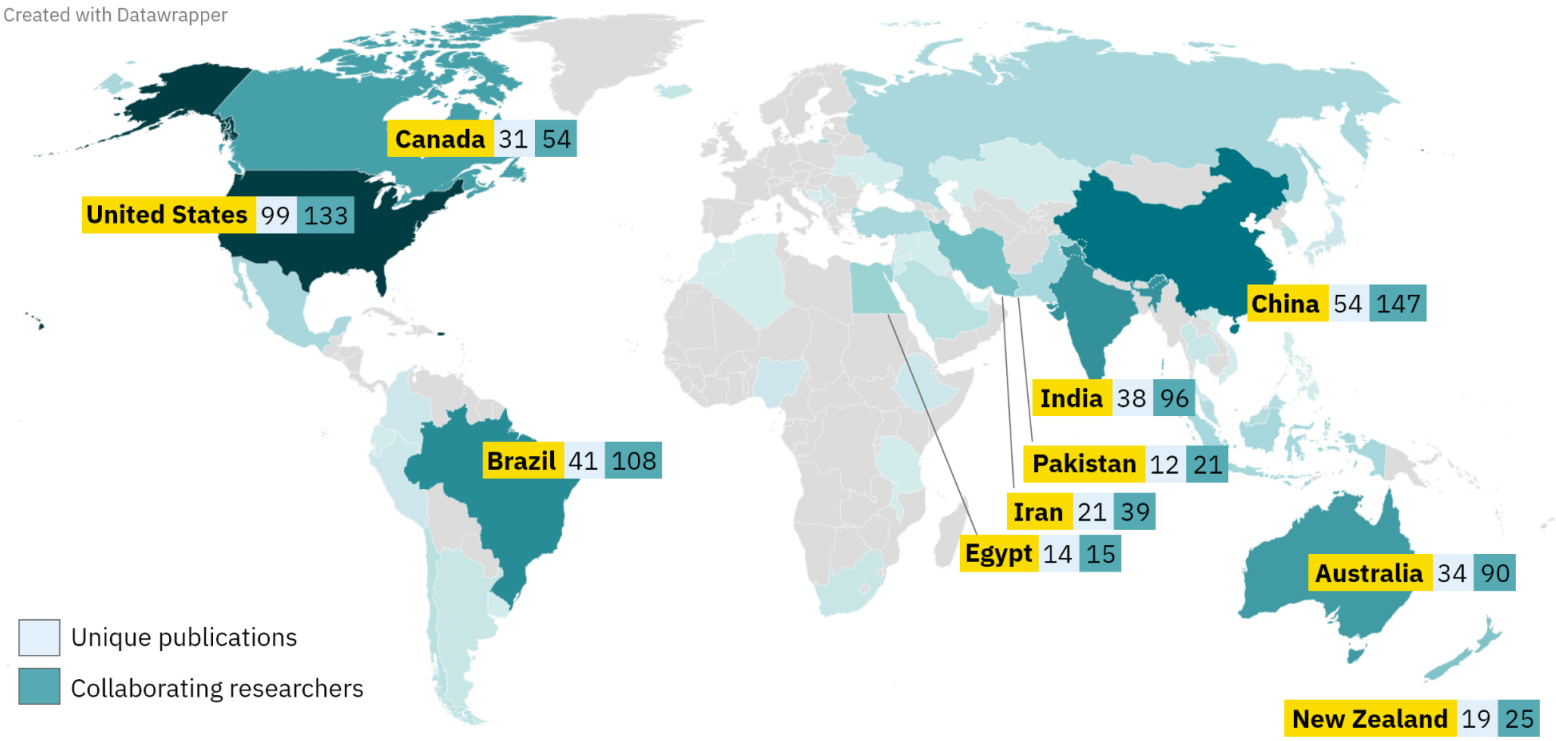
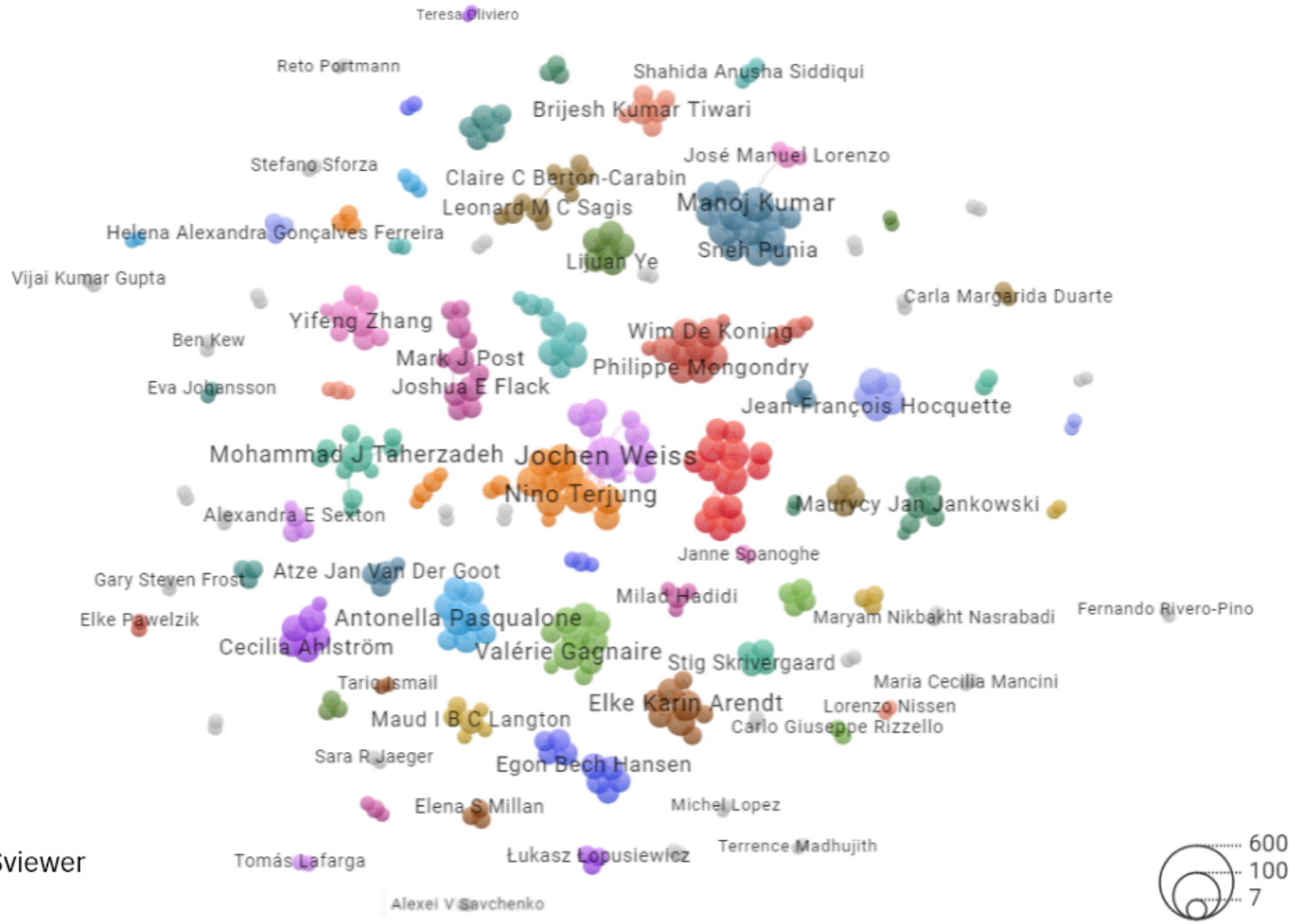


Figure 10. Collaboration network map of researchers conducting alternative protein research in Europe in the years 2019-2023 inclusive. Colour coding indicates the clustering of individual researchers in collaborative groups while bubble sizes indicate the number of publications each researcher has produced.

Items	348
Links	500
Unique Publications	1,804
Clusters	88



Visualisation created with VOSviewer

Table 5. Most productive research collaborations in the years 2019-2023 inclusive.

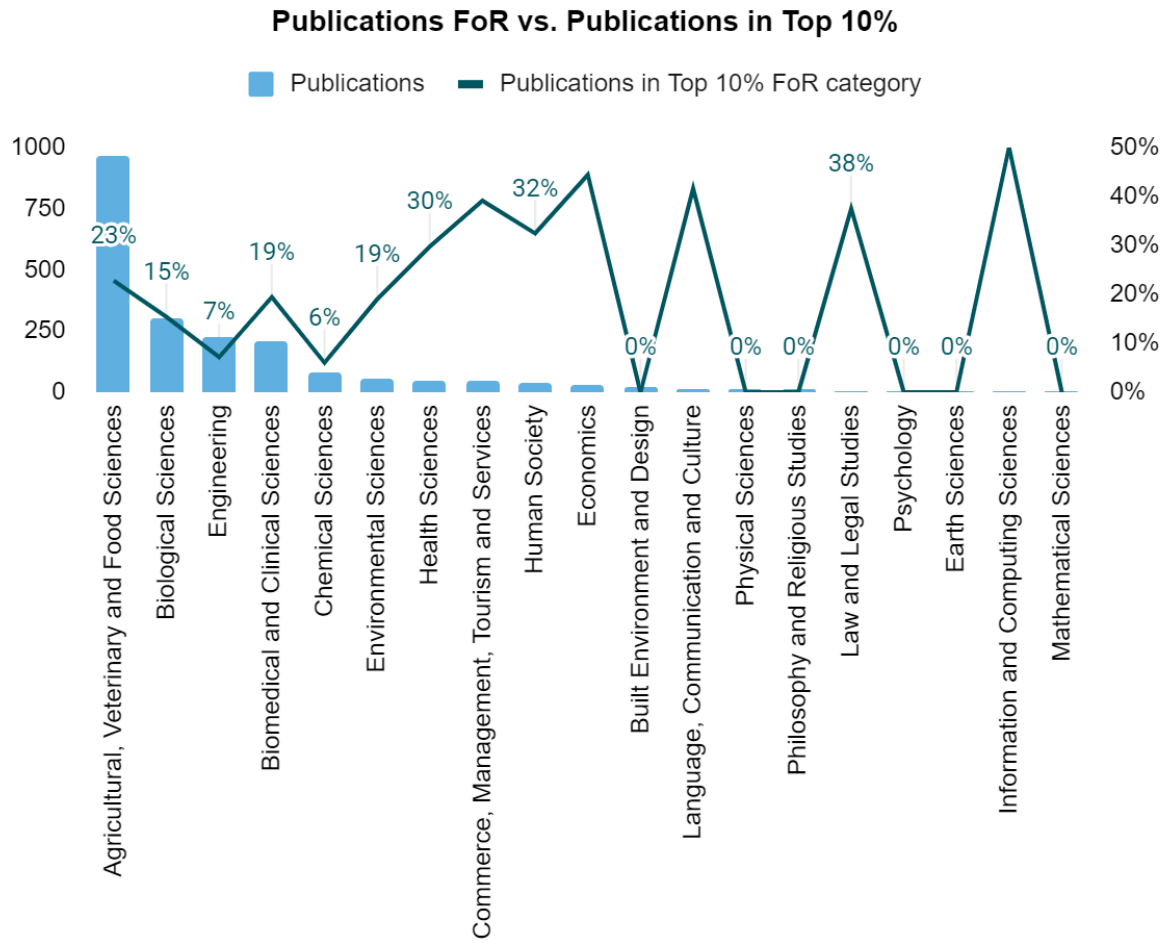
Researcher name and affiliation		Publications	Citations
Jochen Weiss University of Hohenheim	Nino Terjung German Institute of Food Technologies	12	281
Emanuele Zannini University College Cork	Elke Karin Arendt University College Cork	11	334
Jochen Weiss University of Hohenheim	Monika Gibis University of Hohenheim	10	264
Jochen Weiss University of Hohenheim	Jörg Hinrichs University of Hohenheim	10	238
Anne Saint-Eve AgroParisTech	Isabelle Souchon University of Avignon	10	187
Jean-François Hocquette VetAgro Sup	Sghaier Chriki ISARA-Lyon	9	493
Monika Gibis University of Hohenheim	Nino Terjung German Institute of Food Technologies	9	184
Jean-François Hocquette VetAgro Sup	Marie-Pierre Ellies-Oury Bordeaux Sciences Agro	8	184
Marie-Pierre Ellies-Oury Bordeaux Sciences Agro	Sghaier Chriki ISARA-Lyon	8	184
Carmine Summo University of Bari Aldo Moro	Antonella Pasqualone University of Bari Aldo Moro	8	162

Fields of research

Unsurprisingly, given the broad range of technical and socioeconomic research questions presented by alternative protein development, publications in this dataset span 19 separate fields of research (FoR), as defined by Dimensions. ‘Agricultural, Veterinary and Food Sciences’ was the most common FoR with 965 publications, followed by ‘Biological Sciences’ (299), and ‘Engineering’ (223) (Figure 11). When compared to the average numbers of citations for their respective FoR, publications on topics related to alternative proteins perform strongly, with 23% of ‘Agricultural, Veterinary and Food Sciences’ publications in the top 10% most highly cited for this FoR. For ‘Commerce, Management, Tourism and Services’ this figure was 39%, and for ‘Economics’ it stands at 44%.

The relative strength of non-technical fields is an interesting observation and can be explained in part by the high proportion of social sciences research in the European literature. Ultimately, it would be encouraging to see European research achieve greater impact in topics such as food science, biotechnology, and engineering, as a proxy measure for technological progress in alternative protein research.

Figure 11. Breakdown of number of publications per field of research (FoR) and the proportion of publications in the dataset which are in the top 10% most highly cited publications in their respective FoR in the years 2019-2023 inclusive.



04 Alternative protein pillar deep-dives

Overview

This section of the report examines the technical research efforts ongoing across the three alternative protein pillars in Europe to assess their relative stage of maturity and identify areas where greater research efforts are needed.

Table 6. Summary data outlining the key community health indicators of the European alternative protein research ecosystem in the years 2019-2023 inclusive, stratified by alternative protein pillar.

Metric	Plant-based	Fermentation	Cultivated
Publications	885	226	179
Average growth rate %	42%	34%	41%
2010-2023 % change	492%	210%	282%
Total citations	11,999	3,576	2,270
Authors	3,165	823	526
Organisations	776	256	203

As part of this analysis, it is helpful to assess the technological advancements that can move alternative proteins closer to taste and price parity with conventional protein sources. This report uses nine 'technology sectors' to classify these research areas (summarised in Table 7). Of the 1,411 publications from the period 2019-2023 inclusive, 950 (67%) can be assigned to at least one of these technology sectors. The remainder cover areas outside the scope of the technology sectors, including topics like consumer studies, regulatory and legal analyses, general discussions on alternative proteins, broad-scope life cycle assessments, and nutritional intervention studies which, with some exceptions, are not considered within the scope of this analysis[7]. Using this information, we can then assess the relative maturity of each alternative protein pillar and identify priority areas where research and development activity is most urgently needed.

[7] For a full explanation of how technology sectors were assigned and what topics were considered in scope, see the Methodology section.

Table 7. Alternative protein technology sectors.

Technology sector	Description	Relevant AP pillar(s)
Bioprocess design	Innovations in bioreactor design and media or feedstock utilisation strategies (including the use of alternative feedstocks) to achieve higher efficiency, greater scale, and bring down costs.	Fermentation Cultivated Plant-based[8]
Cell culture media	Reducing cell culture media costs and increasing their availability by characterising and validating novel sources of growth factors, amino acids, and other media components.	Cultivated
Cell line development	Optimising new and existing cell lines to achieve faster cell growth, greater stability and stress tolerance, and higher cell density in terrestrial and aquatic cell lines.	Cultivated
Crop development	Breeding of crops and increased use of underutilised protein crops for higher protein yields and functionality.	Plant-based
End product formulation & manufacturing	Process and formulation innovations, including (but not limited to) novel texturization methods such as extrusion, electrospinning, 3D printing, and enzymatic processing to match the texture of animal protein.	Plant-based Fermentation Cultivated
Strain development	Screening and optimisation of novel strains to identify the most efficient pathways for producing targets or modifying substrates.	Fermentation Plant-based[7]
Ingredient optimisation	Improved protein fractionation and functionalisation to achieve higher-quality ingredients with less processing. Also covers the development of novel ingredients to augment nutritional profiles and enhance the sensory experience of alternative protein products.	Plant-based Fermentation
Scaffolding	Improved scaffolding biomaterials that support cell adherence and differentiation to allow the replication of complex animal meat structures.	Cultivated
Target molecule selection	Target identification and validation to broaden the scope of food ingredients produced by precision fermentation.	Fermentation

[8] Refers to the use of traditional fermentation techniques to modulate or enhance the characteristics of plant proteins.

Plant-based meat, dairy, eggs, and seafood

Key countries, institutions, and researchers

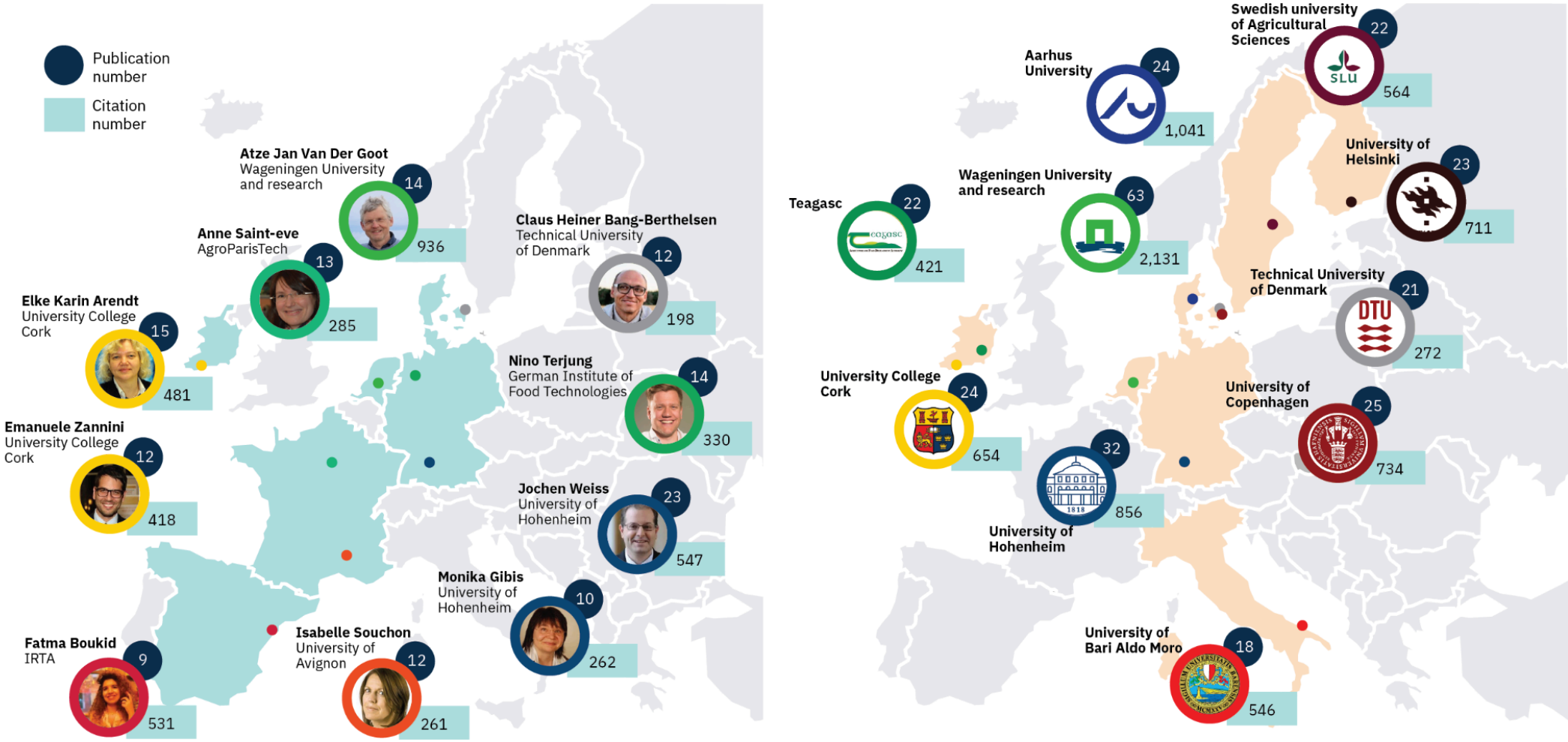
The leading countries in Europe for plant-based research are Germany (13% of 2019-2023 output), Spain (11%), and the UK (11%) (Table 8). Italy has the most researchers with 250, followed by Spain (229), and France (209). Wageningen University & Research leads in unique publications (63) and total citations (2,131), with the University of Hohenheim (32 publications), the University of Copenhagen (25), Aarhus University (24) and University College Cork (24) making up the top five (Figure 12). Jochen Weiss of the University of Hohenheim has been the most productive researcher with 23 unique publications, while Atze Jan Van Der Goot of Wageningen University & Research is the most highly cited researcher, with 936 citations (Figure 12).

The 10 publications which have received the highest number of citations over the past two years cover a range of topics on the techno-functional aspects of plant proteins, such as more efficient extraction and emulsification and the improvement of their sensory and nutritional characteristics (Table 9). Other publications cover commercial and consumer aspects of plant-based foods and track their emergence into the mainstream. This diversity provides a snapshot of a research field that is increasingly mature and underlines why plant-based research merits increased funding support to capitalise on the progress already made.

Table 8. Top 10 most productive European countries in plant-based protein research in the years 2019-2023 inclusive.

Country	Publications	Researchers	Total Citations
Germany	112	183	2,514
Spain	100	229	2,538
United Kingdom	94	195	2,001
Italy	83	250	1,893
The Netherlands	82	156	2,550
France	76	209	1,457
Denmark	72	139	1,964
Poland	60	141	1,370
Ireland	56	93	1,171
Sweden	51	118	1,064

Figure 12. Top 10 most productive European researchers[9] and research institutions in plant-based research during the years 2019-2023 inclusive.



[9] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Table 9. The 10 plant-based publications from the period 2019-2023 that have received the highest number of citations over the past two years.

Top 10 trending publications	Year	Source title	Recent citations[10]	Field citation ration
Modification approaches of plant-based proteins to improve their techno-functionality and use in food products	2021	Food Hydrocolloids	243	62.37
Plant-based food and protein trend from a business perspective: markets, consumers, and the challenges and opportunities in the future	2020	Critical Reviews in Food Science and Nutrition	210	71.00
Functionality of Ingredients and Additives in Plant-Based Meat Analogues	2021	Foods	207	135.92
Foods for Plant-Based Diets: Challenges and Innovations	2021	Foods	202	93.38
Chapter 6 Plant-Based Meat Analogues	2019	Sustainable Meat Production and Processing	175	73.4
Plant-based meat analogues: from niche to mainstream	2020	European Food Research and Technology	166	58.45
Advances in the plant protein extraction: Mechanism and recommendations	2021	Food Hydrocolloids	157	32.02
Fermentation of plant-based milk alternatives for improved flavour and nutritional value	2019	Applied Microbiology and Biotechnology	128	35.23
Pulses and food security: Dietary protein, digestibility, bioactive and functional properties	2019	Trends in Food Science & Technology	124	35.76
Sustainable food-grade Pickering emulsions stabilized by plant-based particles	2020	Current Opinion in Colloid & Interface Science	122	26.15

[10] Dimensions.ai classifies publications on the basis of a recent citations value which refers to the number of citations the publication has received in the last two years. This indicates the degree to which a publication has been influential in the research community in the recent past. However, this figure may not reflect the total number of historical citations the publication has received.

Technology sectors

78% of research outputs in the plant-based pillar were found to be relevant to at least one technology sector, demonstrating a high degree of relevance of this research output to solving the key technical challenges in this pillar. 'Ingredient optimisation' and 'End product formulation & manufacturing' dominate this pillar, with 43% and 42% of publications assigned to these technology sectors, respectively (Figure 13).

The concept network map of plant-based technology sector-relevant research shows that this research field is developing rapidly, with a diverse mix of topics and a high degree of interconnectivity between them (Figure 14). There are numerous publications on the technofunctional properties of plant proteins such as their gelling and emulsification characteristics and methods to improve these attributes, technical areas which are critical in developing functional ingredients that can lead to improvements in the taste and texture of plant-based alternatives. Several new sources of plant protein are under investigation and many studies incorporate elements of sensory and nutritional analysis or aim to enhance these properties via innovations in extraction and processing technologies.

However, achieving taste and price parity remains the primary challenge for plant-based manufacturers. Consumer research shows that 53% of individuals agree that plant-based meat products should taste just like meat, but only 20% of people surveyed categorised plant-based meat products as 'tasty'. It is therefore critically important that research in this pillar receives continued support to enable these emerging technologies to mature to a point where they can be used to bring delicious and affordable new products to market.

Figure 13. Technology sectors covered within plant-based literature in the years 2019-2023 inclusive.

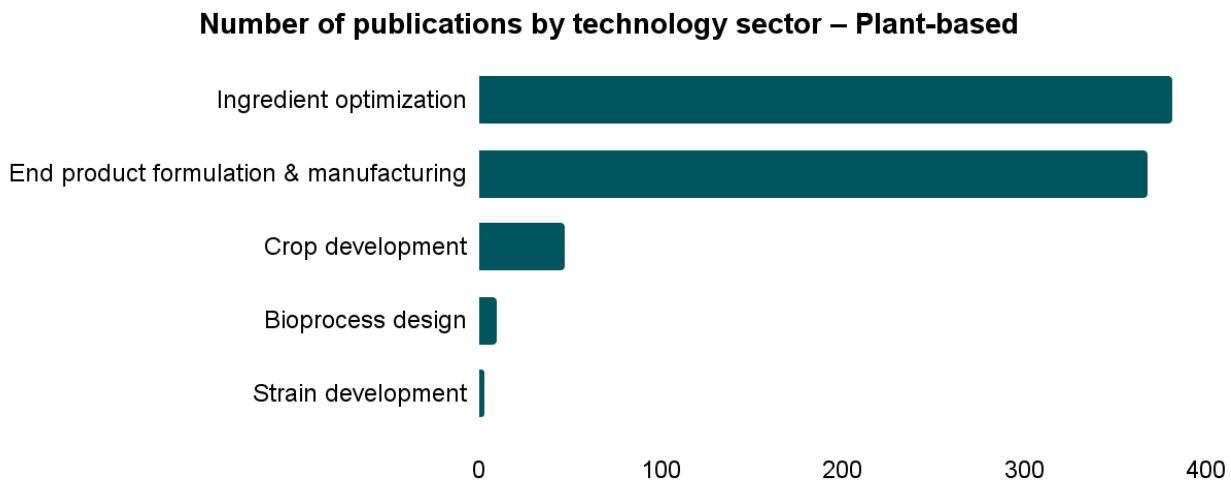
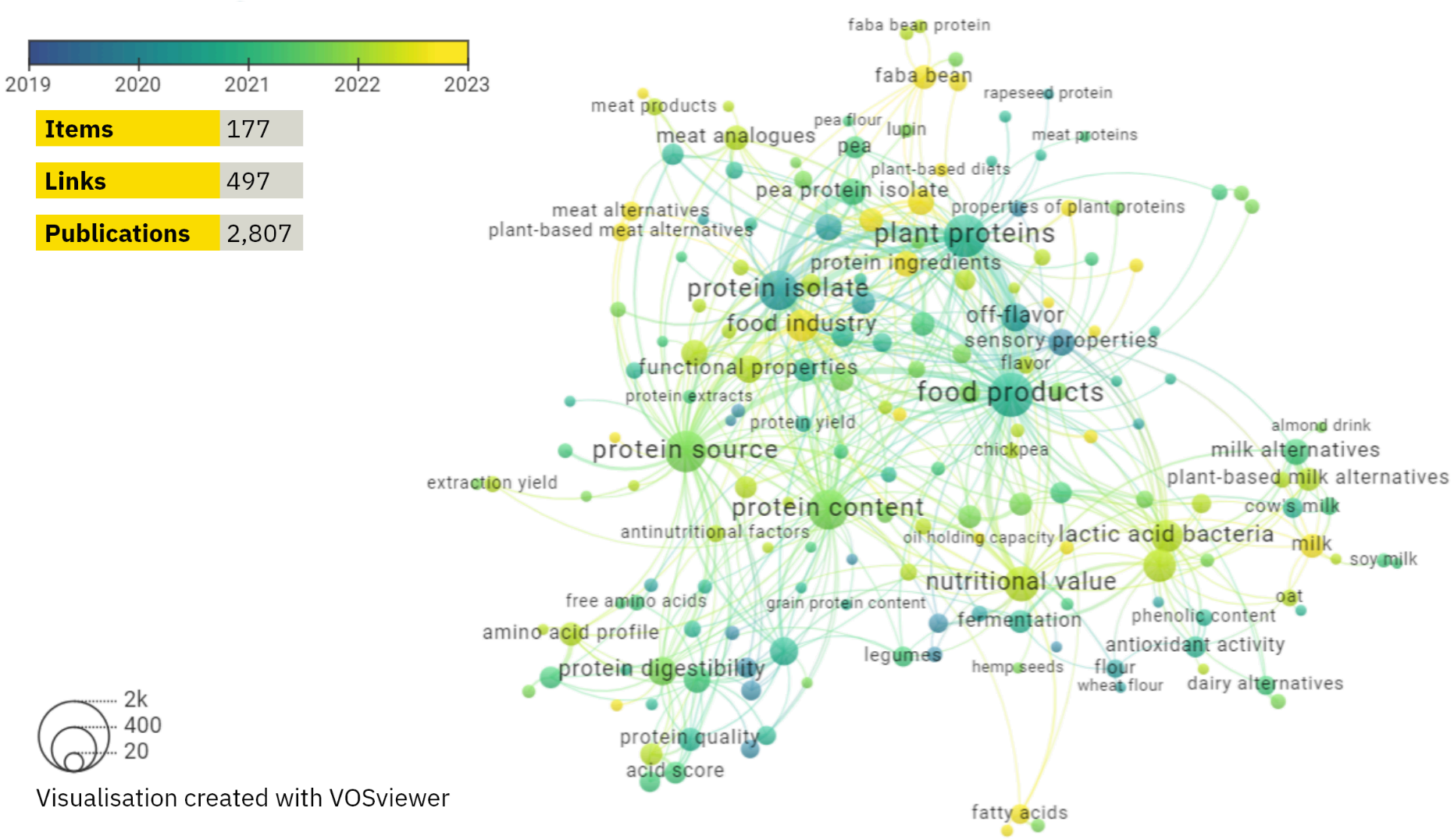


Figure 14. Concept network map of the technology-relevant plant-based protein research output in the years 2019-2023 inclusive. Colour coding indicates the year median year in which the concept appeared most in the literature while bubble sizes indicate the number of publications on each concept.



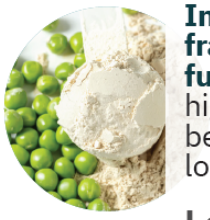
Visualisation created with VOSviewer

Research priorities in plant-based

While the plant-based pillar has seen strong growth in a diverse range of research areas in recent years, there are still numerous technical challenges that need to be overcome to capitalise on this progress. Core research priorities include:

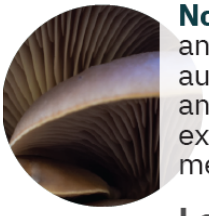
Better raw materials through breeding of crops and increased use of underutilised protein crops for higher protein yields and functionality.

Learn more >>



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

Learn more >>



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

Learn more >>

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

Learn more >>

Fermentation-made proteins and ingredients

Key countries, institutions, and researchers

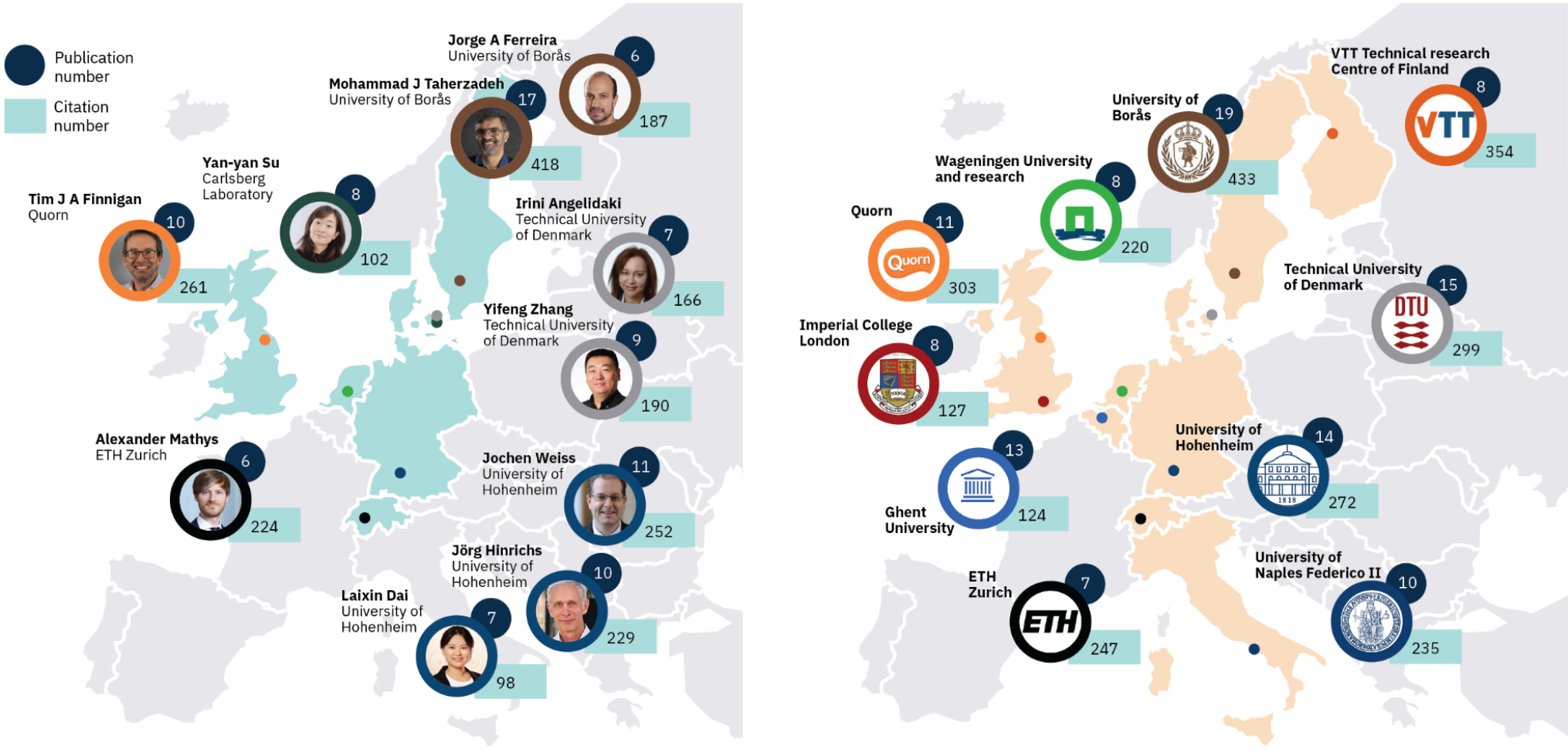
The leading countries in Europe for fermentation-made protein and ingredients research are the UK (14% of 2019-2023 total output), Germany (14%), and Italy (13%) (Table 10). Italy has the highest number of researchers with 81, followed by Germany (67), and the UK (65). The University of Borås leads on unique publications (19) and total citations (433), with Technical University of Denmark (15 publications), the University of Hohenheim (14), Ghent University (13) and fermentation company Quorn (UK) (11) making up the top five (Figure 15). Mohammad J Taherzadeh of University of Borås has been the most productive researcher with 17 unique publications and is also the most highly cited researcher, with 418 citations (Figure 15).

The 10 publications which have received the highest number of citations over the past two years cover topics on single-cell proteins, which include edible proteins from yeast, microalgae, or other microbes, with topics including the environmental benefits of these protein sources or their use as a source of novel ingredients for use in food formulations (Table 11). Overall the dataset lacks high-impact publications on precision fermentation and its use for the production of animal protein analogues, and this area should be a priority going forward.

Table 10. Top 10 most productive countries in fermentation research in the years 2019-2023 inclusive.

Country	Publications	Researchers	Total Citations
United Kingdom	32	65	664
Germany	31	67	712
Italy	29	81	590
Sweden	28	45	736
Belgium	20	48	387
Denmark	20	36	453
Portugal	17	54	584
Spain	12	41	318
The Netherlands	11	27	268
Finland	11	37	442

Figure 15. Top 10 most productive fermentation researchers[11] and organisations in the years 2019-2023 inclusive.



[11] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Table 11. The 10 fermentation publications from the period 2019-2023 that have received the highest number of citations over the past two years.

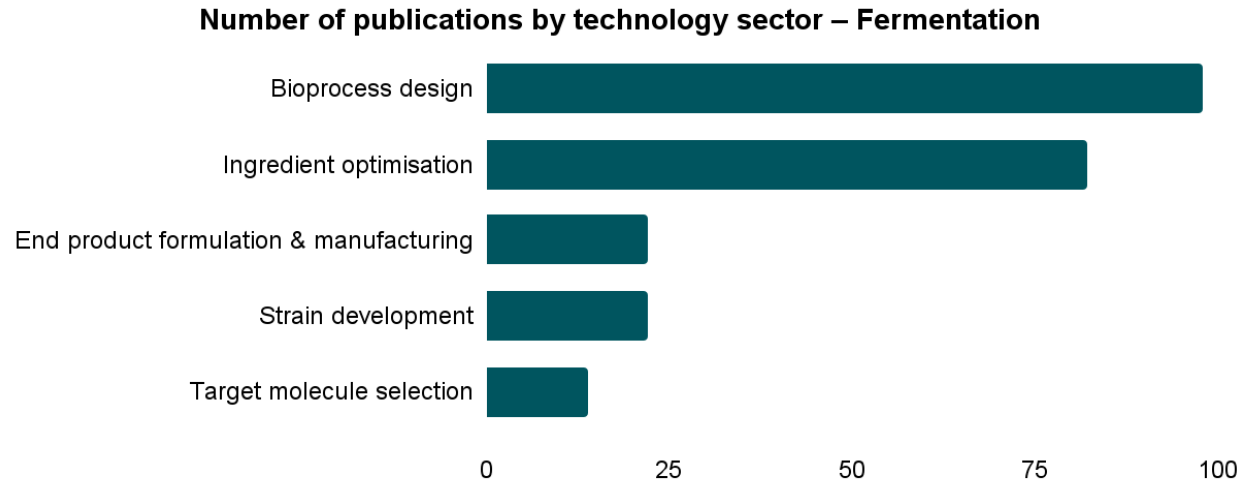
Publication title	Year	Source title	Recent citations[12]	Field citation ratio
Yeast Protein as an Easily Accessible Food Source	2022	Metabolites	84	33.28
Projected environmental benefits of replacing beef with microbial protein	2022	Nature	79	51.98
Edible mushrooms as a novel protein source for functional foods	2020	Food & Function	76	19.99
The potential of microalgae and their biopolymers as structuring ingredients in food: A review	2019	Biotechnology Advances	71	17.94
Extraction of lipids from microalgae using classical and innovative approaches	2022	Food Chemistry	63	29.98
Microalgae based production of single-cell protein	2022	Current Opinion in Biotechnology	60	22.84
Hypes, hopes, and the way forward for microalgal biotechnology	2023	Trends in Biotechnology	60	N/A
Single Cell Protein: A Potential Substitute in Human and Animal Nutrition	2021	Sustainability	58	16.13
The role of single cell protein in cellular agriculture	2022	Current Opinion in Biotechnology	55	20.88
Photovoltaic-driven microbial protein production can use land and sunlight more efficiently than conventional crops	2021	PNAS	55	15.74

[12] Dimensions.ai classifies publications on the basis of a recent citations value which refers to the number of citations the publication has received in the last two years. This indicates the degree to which a publication has been influential in the research community in the recent past. However, this figure may not reflect the total number of historical citations the publication has received.

Technology sectors

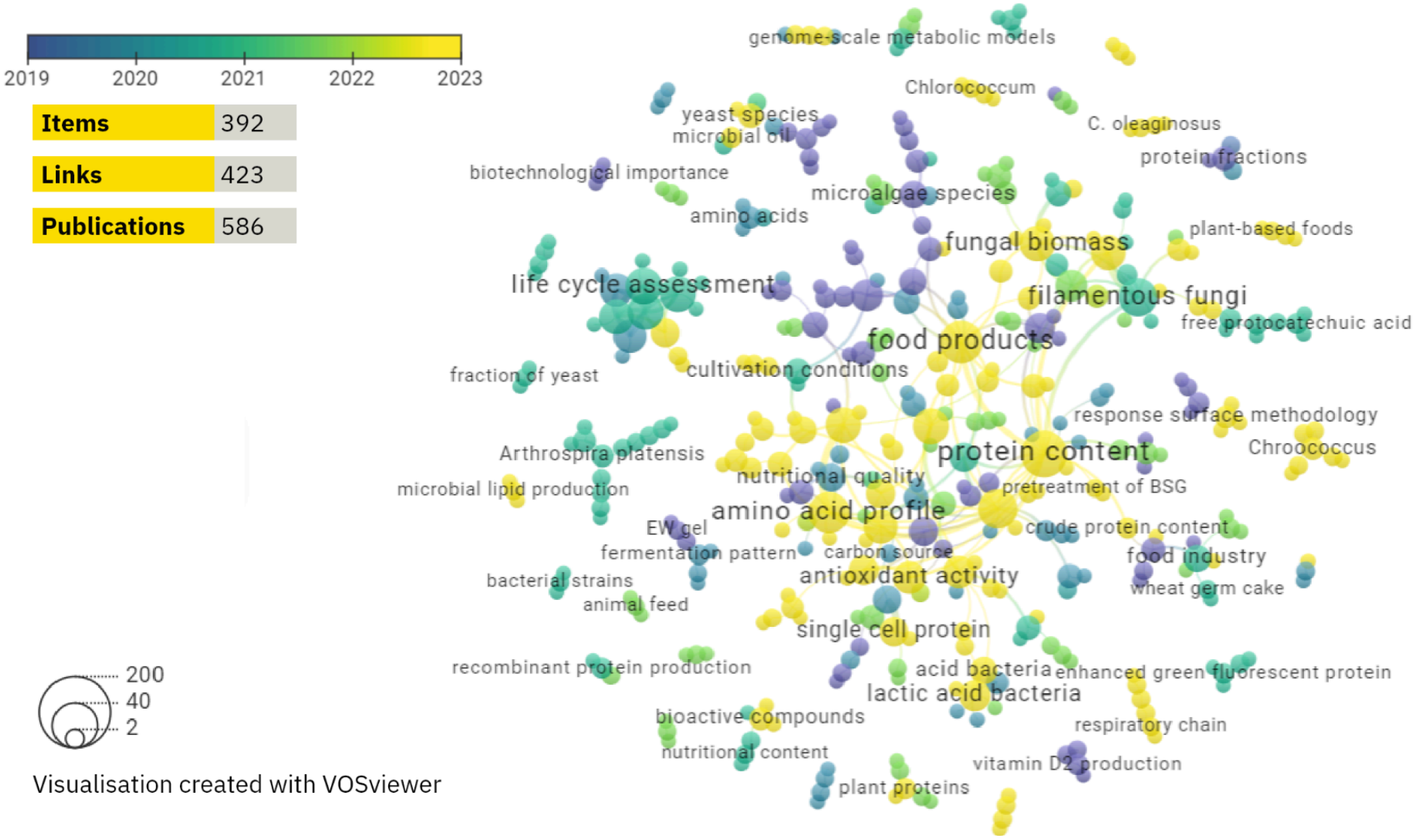
Similar to plant-based, 81% of research outputs in the fermentation pillar are relevant to at least one technology sector, demonstrating a high degree of focus on solving the key technical challenges in this pillar. 'Bioprocess design' and 'Ingredient optimisation' dominate this pillar, with 43% and 36% of publications assigned to these technology sectors, respectively (Figure 16). It is concerning to find only a small number of publications dedicated specifically to 'Strain development' and 'Target molecule selection' and demonstrates that while a significant proportion of fermentation research is focused on technology development, there are still significant knowledge gaps in this research area, particularly in relation to the use of precision fermentation technology as a means of producing animal protein analogues and functional ingredients, which remain largely underdeveloped in the scientific literature.

Figure 16. Breakdown of primary and secondary technology sectors covered within the European fermentation literature in the years 2019-2023 inclusive.



The concept network map of the fermentation research output reveals a diverse mix of topics but a low degree of interconnectivity between topics (Figure 17). Research themes span areas such as microbial protein production, recombinant protein production, evaluation and optimisation of strains (with a particular focus on microalgae) as well as bioprocess design and life cycle assessments. However, the low degree of interconnectivity between these topics is a concern as it points to a relatively immature scientific ecosystem that is still working in silos and has not yet developed a high degree of knowledge sharing and collaboration on key research challenges. While some of this may reflect the varied mix of different research disciplines that can fall under the fermentation-made protein and ingredients definition, it is still of concern and highlights the need for mechanisms enabling researchers to collaborate more effectively on the major technical bottlenecks.

Figure 17. Concept network map of the technology-relevant fermentation research output in the years 2019-2023 inclusive. Colour coding indicates the year median year in which the concept appeared most in the literature while bubble sizes indicate the number of publications on each concept.



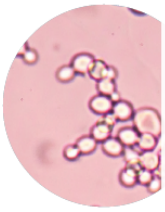
Visualisation created with VOSviewer

Research priorities in fermentation

Although fermentation is a relatively mature platform, using it in the context of alternative proteins presents new challenges and this report highlights several important areas where fermentation research is lagging behind. The main research priorities in fermentation are:

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

Learn more >>



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

Learn more >>

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

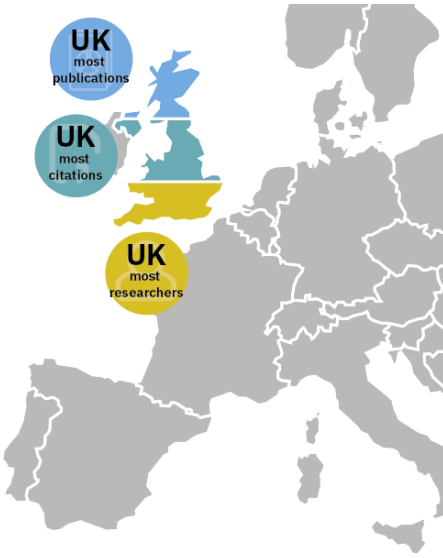
Learn more >>

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

Learn more >>

Cultivated meat and seafood

Key countries, institutions, and researchers



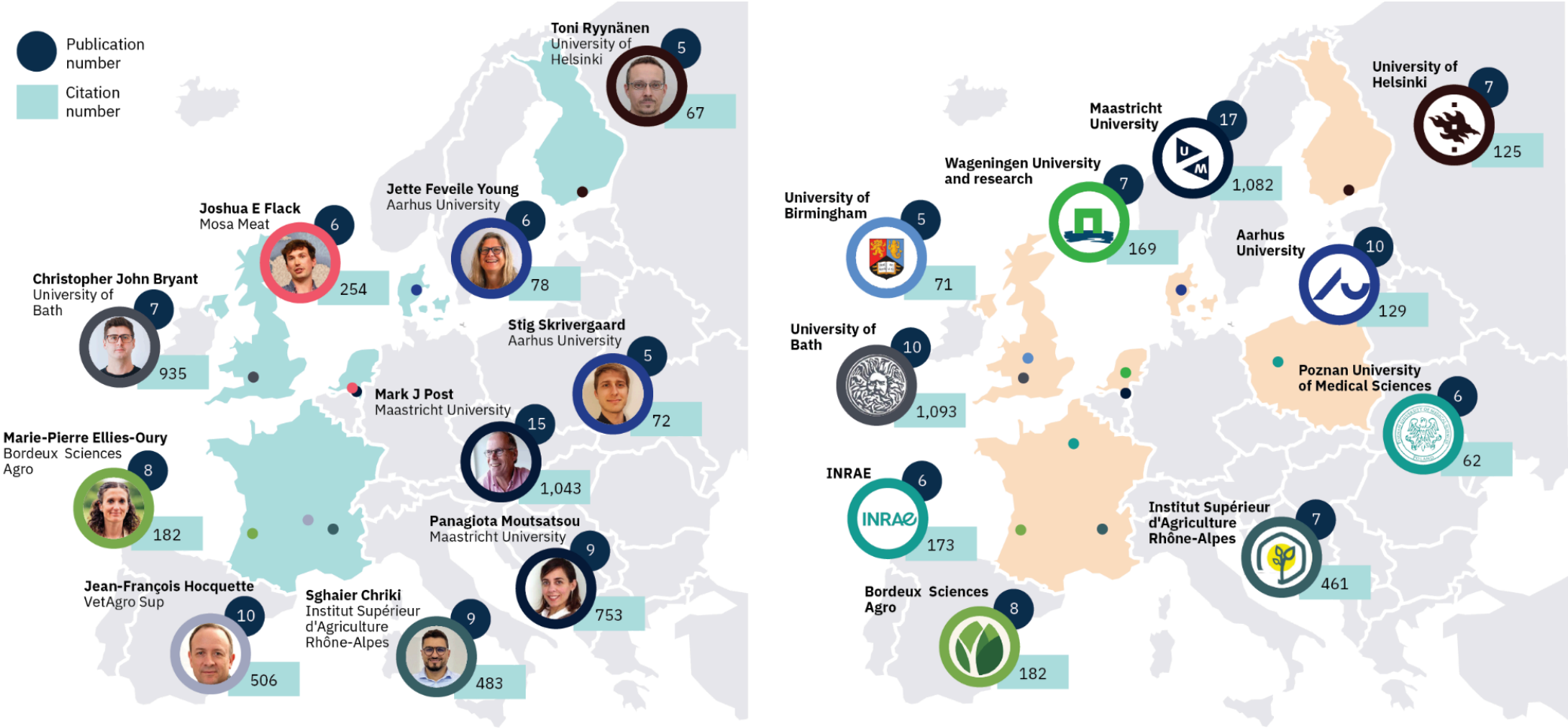
The leading countries in Europe for cultivated meat and seafood research are the UK (22% of 2019-2023 total output), the Netherlands (15%), and Germany (13%) (Table 12). The UK has the highest number of published researchers with 74, followed by Italy (61), and the Netherlands (43). Maastricht University leads on unique publications (17), with Aarhus University (10), University of Bath (10), Bordeaux Sciences Agro (8) and Institut Supérieur d'Agriculture Rhône-Alpes (7) making up the top five (Figure 18). The University of Bath has accumulated the most citations (1,093). Mark J Post of Maastricht University has been the most productive researcher, with 15 unique publications, and is the most highly cited researcher, with 1,043 citations (Table 13).

The 10 publications which have received the highest number of citations over the past two years largely do not focus on the technical developments in this field, with the majority of these publications focusing on consumer perceptions, or general discussions on the feasibility of this technology. To underscore this, the publication with the highest number of recent citations (those in the last two years) is a 2020 review entitled 'Consumer acceptance of novel food technologies', published in Nature Food by researchers from ETH Zurich, which has 215 recent citations and an FCR of 63.45. However, it is encouraging to see publications on the climate impact of cultivated meat and a review on advances in microcarriers for upscaling cultivated meat production, a key technical challenge in this field, included in the top 10.

Table 12. Top 10 most productive countries in cultivated meat and seafood research in the years 2019-2023 inclusive.

Country	Publications	Researchers	Total Citations
United Kingdom	39	74	1,771
The Netherlands	27	43	1,303
Germany	24	34	498
Italy	22	61	411
France	19	17	916
Denmark	12	11	169
Poland	11	39	94
Spain	9	12	171
Finland	9	6	260
Belgium	8	11	279

Figure 18. Top 10 most productive cultivated meat and seafood researchers[13] and research institutions in the years 2019-2023 inclusive.



[13] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Table 13. The 10 cultivated publications from the period 2019-2023 that have received the highest number of citations over the past two years.

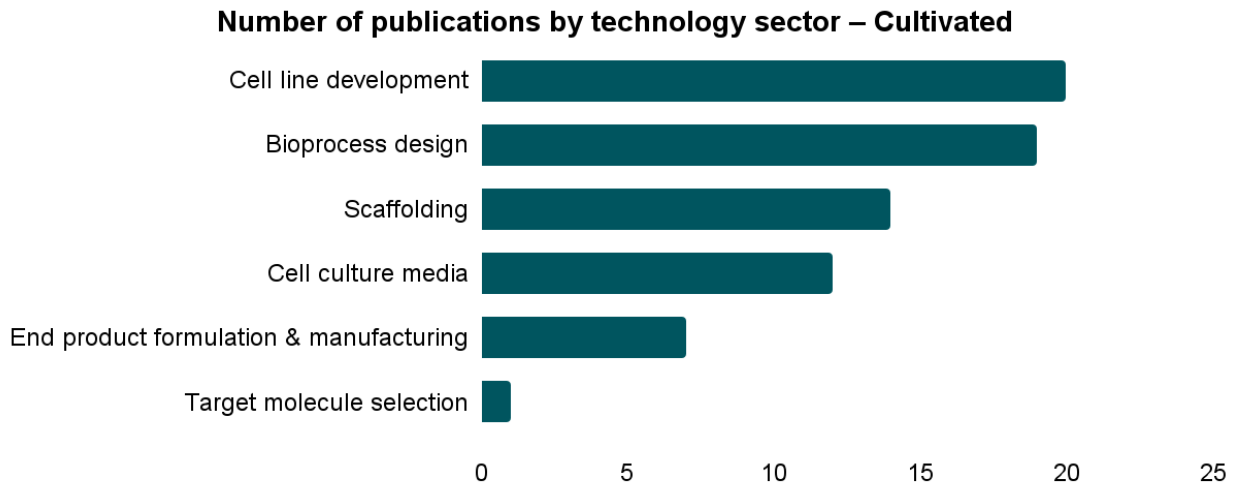
Publication title	Year	Source title	Recent citations[14]	Field citation ratio
Consumer acceptance of novel food technologies	2020	Nature Food	215	63.45
Scientific, sustainability and regulatory challenges of cultured meat	2020	Nature Food	211	127.01
The Myth of Cultured Meat: A Review	2020	Frontiers in Nutrition	150	80.58
Review of factors affecting consumer acceptance of cultured meat	2021	Appetite	106	41.65
Sensorial and Nutritional Aspects of Cultured Meat in Comparison to Traditional Meat: Much to Be Inferred	2020	Frontiers in Nutrition	98	41.89
Perceived naturalness, disgust, trust and food neophobia as predictors of cultured meat acceptance in ten countries	2020	Appetite	92	28.68
Climate Impacts of Cultured Meat and Beef Cattle	2019	Frontiers in Sustainable Food Systems	88	49.33
Microcarriers for Upscaling Cultured Meat Production	2020	Frontiers in Nutrition	77	40.29
Cultured Meat: Promises and Challenges	2021	Environmental and Resource Economics	74	63.99
What's in a name? Consumer perceptions of in vitro meat under different names	2019	Appetite	74	47.44

[14] Dimensions.ai classifies publications on the basis of a recent citations value which refers to the number of citations the publication has received in the last two years. This indicates the degree to which a publication has been influential in the research community in the recent past. However, this figure may not reflect the total number of historical citations the publication has received.

Technology sectors

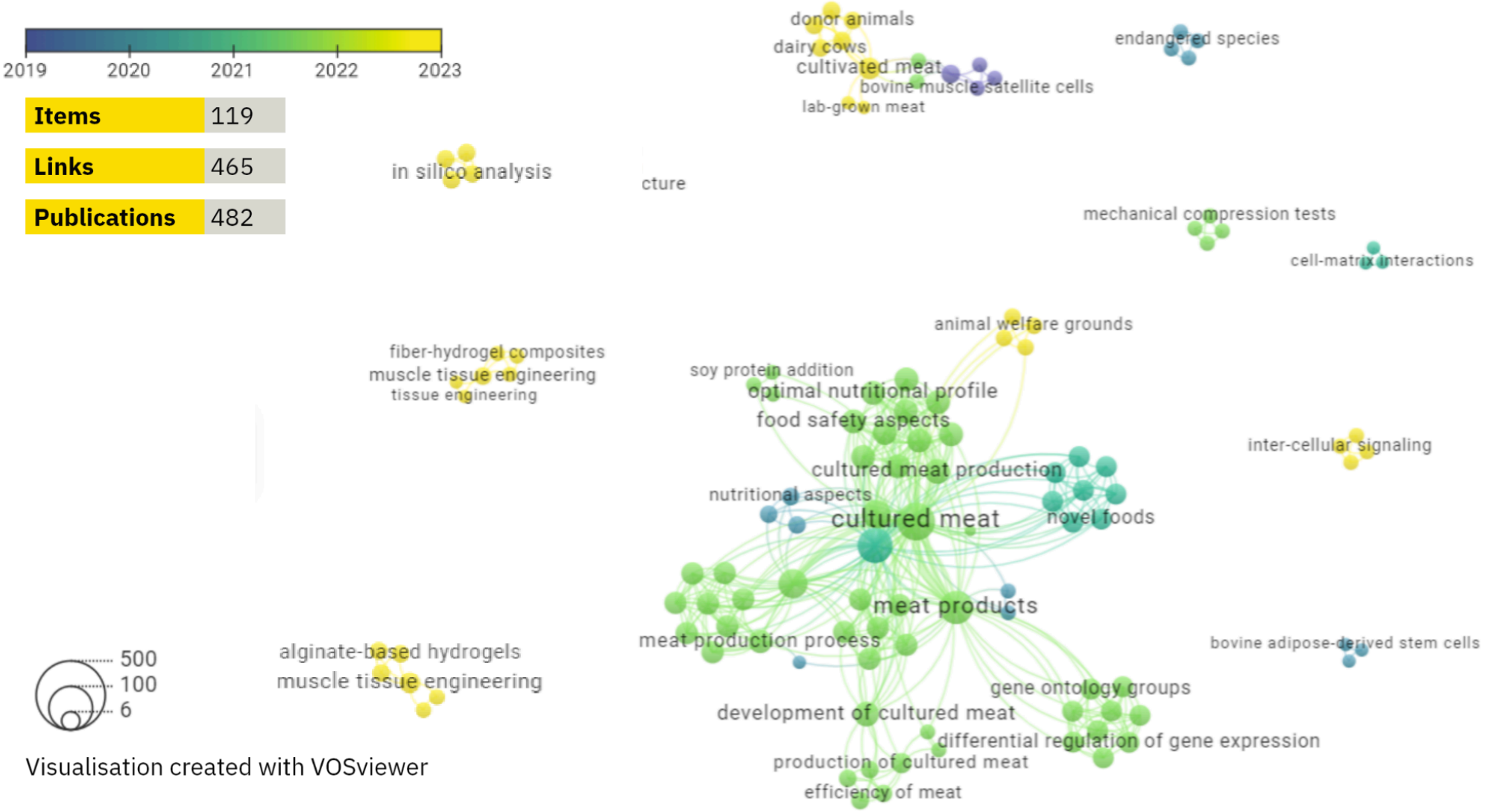
In stark contrast to the other pillars, only 34% of cultivated meat and fish outputs can be assigned to a technology sector. This is because the majority of the publications on cultivated proteins to date in Europe focus on concepts such as consumer acceptance, regulation, and policy, rather than on technical aspects which can contribute to moving cultivated meat towards taste and price parity with conventional products. 'Cell line development' and 'Bioprocess design' were the most common technology sectors, but only accounted for 11% and 10% of all publications, respectively (Figure 19).

Figure 19. Breakdown of primary and secondary technology sectors covered within the European cultivated meat and seafood literature in the years 2019-2023 inclusive.



Analysis of the concept network map of the cultivated meat and seafood research output reinforces the impression that this field of research is still in its infancy in Europe (Figure 20). Topics such as cell culture media and scaffolding are highly underdeveloped, with low concept diversity and weakly connected clusters. Even accounting for the possibility that this dataset is an underrepresentation of the true body of research being undertaken in Europe, this shows the need to prioritise these technology areas for increased funding and mechanisms through which researchers can collaborate more effectively.

Figure 20. Concepts network map of the technology-relevant cultivated meat and seafood research output in the years 2019-2023 inclusive. Colour coding indicates the year median year in which the concept appeared most while bubble sizes indicate the number of publications on each concept.



Visualisation created with VOSviewer

Research priorities in cultivated

This analysis reveals that research activity must be significantly ramped up to reduce costs and increase yields for cultivated meat and seafood. The main research priorities here are:

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

Learn more >>

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

Learn more >>

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

Learn more >>

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

Learn more >>

05 Conclusions and recommendations

Alternative protein research shows rapid growth in Europe

This analysis shows that the alternative protein research field has undergone tremendous growth in Europe, with strong and consistent increases in research outputs in recent years. Exciting developments can be observed in the literature, especially in the plant-based protein field, where researchers are exploring a diverse range of technological and socioeconomic topics.

However, the alternative protein field is still in its infancy and has only recently begun to attract significant numbers of researchers. Of the 1,831 publications on topics relevant to alternative proteins published in Europe since 2010, 77% have come in the period 2019-2023, and almost 26% were published in 2023 alone. While some countries and institutions are clearly contributing a much larger proportion of this work than others, it is encouraging that all but one of the countries analysed in this report have contributed in some way to advancing the field of alternative protein research.

It is important to note that the majority of the public funding for alternative protein research in Europe has come in the last two years, so this report almost certainly significantly underrepresents the degree of research activity that is currently ongoing. We can therefore expect this growth in research output to continue in the near future as this increased funding starts to bear fruit.

Community cohesion and interconnectivity must be prioritised

Reflecting its relative degree of immaturity, the European alternative protein research community displays a lower-than-average degree of collaboration. International co-authorships account for 39% of the total – slightly lower than the 2022 international average of 40% and significantly lower than the average figure of 55% in the EU and 64% in the UK.

The research community is quite fragmented and has not yet achieved a high degree of integration and cohesion. Instead, it is characterised by pockets of repeated collaborations between the same authors whereby existing relationships can be leveraged repeatedly and longer-term research partnerships can be formed.

It is notable that many of the researchers who have been able to establish such long-term collaborations are also among the most highly cited in Europe, indicating the importance of collaboration in achieving impact. However, it is also important to note that most of these

collaborations are from single institutions and the remainder are domestic, further underlining the degree to which this research community requires greater support to stimulate and sustain cross-border, interdisciplinary research.

Networking mechanisms such as COST Actions have an important role to play in growing this field of research and can help investigators to come together to find collaborative solutions to the key challenges in this space. Analysis from GFI Europe has shown that, while this mechanism is particularly well suited to growing the alternative protein community, topics related to this field are hugely underrepresented in the COST Action ecosystem. As such, there is a real need for COST Actions focused on alternative protein science to help grow the research ecosystem and address networking and knowledge-sharing gaps. Other initiatives that can also help with increasing network cohesion include dedicated conferences and scientific exchange missions to enable greater mobility and information sharing.

Regional disparity is a challenge in alternative protein research

The growth in alternative protein research and funding observed in recent years is encouraging to see. However, considerable differences in output can be observed between countries, especially on a per capita basis, with some smaller countries performing strongly while their larger neighbours have the capacity to expand their activity in this field.

It is also clear that despite the outsized impact that small countries can have, opportunities for career development are mostly to be found in the largest European countries. Again, researchers in smaller countries should explore mechanisms such as COST Actions (which has specific inclusiveness targets for underrepresented countries) as well as Twinning projects (which bring together EU member states and external beneficiary countries to build up capacity in the latter by tapping into the expertise of the former). These can help them develop links with institutions in countries with more developed research ecosystems to stimulate collaboration and knowledge transfer. Governments in underrepresented countries should explore mechanisms through which they can stimulate greater research activity in alternative proteins to capitalise on the follow-on economic benefits of innovation.

Key technology areas remain significantly underdeveloped

This analysis reveals large discrepancies in some technology areas that will be key to moving alternative proteins towards taste and price parity with conventional animal products. Plant-based protein research is by far the largest area of alternative protein research in Europe and also shows the strongest and most consistent growth year-on-year. Conversely, fermentation and cultivated meat and seafood are at a much earlier stage of development and their growth has fluctuated over time, even showing negative growth in some years.

Stark contrasts in the maturity of certain technology sectors can also be observed. The plant-based research field is developing rapidly, with numerous new avenues of research being explored. This is very encouraging to see and it is important to support the growth of this area to capitalise on the advances that have been made in recent years so they can lead to impact in the food system.

However, topics on cultivated meat and precision fermentation, such as cell culture media and scaffolding or host strain development, are highly underdeveloped with a low diversity of technological areas being explored and weak links between these research areas. While to some degree this reflects the continued nascency of this research field, it shows the need to urgently prioritise these technology areas for increased funding and develop mechanisms through which research groups can collaborate more effectively on solving the major research challenges in these areas.

06 Methodology

Search criteria

Data was sourced from Dimensions, an interlinked research information system provided by Digital Science (https://www.dimensions.ai). Given the interdisciplinary nature of alternative protein research and the wide range of potentially relevant publications that could fall under that definition, complex search terms were devised that allowed us to trigger numerous publications that may be relevant to our analysis. These search teams were:

1. ***Plant-based meat and seafood:*** "food" AND ("protein") AND ("plant" OR "plant based" OR "plant based meat" OR "vegetable" OR "vegetarian" OR "vegan" OR "plant based seafood" OR "plant based fish" OR "algae" OR "algal" OR "macroalgae" OR "kelp" OR "microalgae" OR "seaweed" OR "crop")
2. ***Plant-based eggs and dairy:*** ("plant based milk" OR "non dairy milk" OR "oat milk" OR "soy milk" OR "rice milk" OR "plant based cheese" OR "plant based dairy" OR "vegan dairy" OR "vegan cheese" OR "vegan milk" OR "dairy substitute" OR "milk substitute" OR "dairy alternative" OR "milk alternative" OR "dairy replacement" OR "milk replacement" OR "cashew cheese" OR "plant based egg" OR "egg substitute" OR "egg replacement" OR "egg alternative" OR "vegan egg")
3. ***Fermentation-made proteins and ingredients:*** "food" AND ("protein") AND ("precision fermentation" OR "fermentation derived" OR "fermentation made" OR "biomass fermentation" OR "fermentation" OR "mycoprotein" OR "single cell" OR "microbial" OR "fusarium" OR "quorn" OR "fusarium venenatum" OR "fungus" OR "fungi" OR “fungal” OR "mycelium" OR "mycelial" OR “recombinant protein” OR “microbial cell factories” OR “recombinant expression” OR "microalgae" OR "microalgal" OR "yeast" OR "cellular agriculture" OR "synthetic biology" OR "edible filamentous fungi" OR "fungal hyphae" OR "bacteria" OR "bacterial" OR "engineering biology" OR "hydrogen oxidizing bacteria" OR "microbial biomass" OR "saccharomyces cerevisiae")
4. ***Cultivated meat and seafood:*** ("cultivated meat" OR "cultured meat" OR "cell cultured meat" OR "lab grown meat" OR "cell-based meat" OR "cellular agriculture" OR "synthetic meat" OR "cell grown meat" OR "cellular meat" OR "stem cell meat" OR "cultivated seafood" OR "cultured seafood" OR "lab grown seafood" OR "cell based seafood" OR "lab grown fish" OR "cell-based fish" OR "cell cultured fish" OR "cell cultured seafood" OR "cellular aquaculture" OR "cell grown seafood" OR "cell-grown fish" OR "cellular seafood" OR "in vitro meat" OR "cultivated fat" OR "cultured fat")

The time period was limited to 2010-2023. Countries selected for analysis were Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the

Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden, Norway, Switzerland, and the United Kingdom.

Preprints and proceedings were excluded for the search scope, and the 'Title and abstract selected' search setting was used to ensure results were more specific to the scope of the keywords, as per guidelines from the Dimensions technical support team. All data was downloaded from Dimension.ai on 22 April 2024 and screened offline in a spreadsheet format.

Data screening

Results of the publications searches were screened against a set of inclusion/exclusion criteria to determine whether they were in scope for this study. Publications on plant-based, fermentation-made, or cultivated proteins and ingredients that satisfied the following **inclusion criteria** were considered to be within the scope of this analysis:

Publications on the classification or characterisation of a plant, algal or microbial species or cultivated animal cells as a source of protein or other ingredients (including, but not limited to, lipids, enzymes, or fibres) which can contribute to improving the sensory and techno-functional properties of an alternative protein ingredient or product with a stated use case for human food.

Publications on how the processing of plant, algal, microbial, or cultivated animal tissue affects protein functionality or quality for use as a food.

Publications on crop or strain optimisation or agronomic or bioprocessing practices that examine or aim to improve protein quality or yield or improve ease of processing.

Publications on the characterisation and/or optimisation of alternative feedstocks or cell culture media or bioprocessing methods, which examine strategies for their utilisation, including life cycle assessments, with the aim of improving the sustainability, efficiency, and/or economic viability of the process.

Publications on the characterisation of hybrid products where the stated aim is the reduction or substitution of animal products and/or the improvement of the functionality of plant, microbial, or cultivated proteins.

Publications that compare the functional properties of plant, microbial, or cultivated protein ingredients or products with conventional animal proteins where the findings are relevant for optimising the techno-functional attributes of the alternative protein ingredient or product.

Publications on the biochemical properties (flavour, aroma, nutritional properties, allergenicity) of plant, algal, microbial or cultivated proteins.

Publications on the societal, policy, and regulatory aspects or studies relating to consumer acceptance

or techno-economic analysis of alternative proteins.

English language publications

Publications that met one or more of the following **exclusion criteria** were judged to be outside the scope of this analysis:

Publications on broad-spectrum comparisons of animal- and plant- or microbial-based protein diets, or consumer attitudes towards these diets, where the outcomes were not relevant for the development of alternative protein products.

Publications on the classification of a plant, algal, microbial species, or cultivated animal proteins, with a stated use case for pet food or animal feed only.

Publications on the general characteristics of underutilised plant, algal, or microbial species as foods where protein is not a focus or is only a minority focus.

Publications on the characterisation of blended products where the aim is the improvement of the functionality of animal products or ingredients.

Publications on the characterisation of a plant, algal, or microbial protein ingredient functionality where the stated aim is the development of nutraceuticals, bioactive peptides, or some other health-promoting ingredient.

Publications on the characterisation of plant, algal, or microbial proteins, or associated processing techniques, where the stated aim was the development of a food that does not substitute animal proteins (e.g. bread, pasta, snacks).

Publications on the on the biochemical properties (flavour, aroma, nutritional properties, allergenicity) of plant, algal, or microbial proteins where the stated use case is not substituting animal products (meat, egg, dairy analogues) or no specific use case is given.

Publications on the development of plant-, algal-, or microbial-based foods as medical nutrition solutions or publications on the development of alternative protein products where the stated end user is a vulnerable person (e.g. children, end users with a diagnosed medical condition).

Corrections to previously-published studies already included in the dataset.

Publications on any other topics not listed in the inclusion criteria.

Non-English language publications.

Data processing

For the respective search terms described above, the following results were obtained:

Plant-based meat and seafood: Of 9,964 returns, 1,087 were found to be within scope (8,877 removed from search).

Plant-based eggs and dairy: Of 820 returns, 352 were found to be within scope (468 removed from search).

Fermentation-made proteins and ingredients: Of 7,674 returns, 454 were found to be within scope (7,220 removed from search).

Cultivated meat and seafood: Of 378 returns, 342 were found to be within scope (36 removed from search).

The high number of publications judged to be outside the scope of this analysis indicated the broad depth of search returns that were triggered by the search terms used, and can give us a high degree of confidence that the results presented here are relatively exhaustive, notwithstanding the caveats and limitations outlined below.

Following screening, the results were sorted into four groups based on their corresponding alternative protein technology pillar:

Plant-based meat, seafood, egg, and dairy publications, which incorporated results from search terms 1 and 2 and any results from the other search terms that were judged to be more relevant to plant-based protein research.

Fermentation-made proteins and ingredients publications, which incorporated results from search term 3 and any results from the other search terms that were judged to be more relevant to fermentation-made protein and ingredients research.

Cultivated meat and seafood publications, which incorporated results from search term 4 and any results from the other search terms that were judged to be more relevant to cultivated meat and fish research.

Cross-pillar publications, which incorporated results that covered more than one alternative protein pillar or addressed alternative proteins in a general sense, and which did not fit squarely into one of the previous groups.

Following sorting on the basis of alternative protein pillar, duplicates were removed. This resulted in the following breakdown of groups:

Plant-based meat, seafood, eggs, and dairy: 1,175 publications (64.2% of total)
Fermentation-made proteins and ingredients: 284 publications (15.5% of total)
Cultivated meat and seafood: 232 publications (12.6% of total)
Cross-pillar: 140 publications (7.6% of total)
TOTAL: 1,831

Bibliometric data were then analysed using the Dimensions Landscape & Discovery application by inputting the relevant publication IDs to this platform and extracting the results. Data is correct as of August 2024. For regional deep-dives, results were filtered offline in spreadsheet format to include all publications from researchers in the corresponding regions and these results were incorporated into the Landscape & Discovery application in the same way. When analysing publications on the basis of technology sector, this was done by manually assigning publications to a primary (and optionally, a secondary technology sector where more than one was applicable) in spreadsheet format.

When assigning technology sectors, publications describing consumer studies, regulatory and legal analyses, general discussions on alternative proteins, broad-scope life cycle assessments, nutritional intervention studies, or food safety studies that were not related to end product formulation or ingredient optimisation were considered out of scope. However, consumer studies where there was a clear link to end product formulation, such as sensory testing and optimisation of a specific product or ingredient, were considered in scope. Likewise, life cycle assessments on discrete, well-defined technologies, such as the optimisation of a specific bioprocess, were considered in scope.

When ranking countries based on a per capita or per gross domestic product per capita based on purchase power parity (GDP PPP) basis, figures for country populations were sourced from Statista while figures for GDP per capita (PPP) were sourced from the World Bank.

Where figures are presented as a percentage, they are rounded to the nearest whole number. Figures and tables were generated in Google Sheets while network map visualisations were generated using the embedded VOSviewer application in Dimensions Landscape & Discovery.

Caveats and limitations to this analysis

Limitation	Rationale and possible implications
Ongoing activities are not captured	The majority of the public funding for alternative protein research in Europe has come in the last two years. As such, this report almost certainly significantly underrepresents the volume of research activity that is currently ongoing. Equally important is the fact that most of the historical R&D work on this topic has been done in the commercial realm by startups, established industry, and contract research organisations, and as a result the body of knowledge presented in this analysis does not give a full overview of the total body of research that has been done on alternative proteins in Europe.
Data limitations	This report aims to give the reader the best understanding of the characteristics and dynamics of this research area that is currently available. While this analysis was developed using a rigorous protocol (described in detail above), due to inevitable limitations around the identification of appropriate search terms and the total number of publications available in the Dimensions.ai platform, it is likely an underestimate of the true size of the alternative protein research community in Europe.
Researcher classification	We acknowledge that not all of the researchers included in this analysis would necessarily consider themselves 'alternative protein researchers' and this exercise is not about labelling them as such. Rather, it aims to understand which researchers are contributing to moving alternative proteins towards taste and price parity with conventional animal proteins and what can be done to better support this community.
Measuring impact	Throughout this report we rank researchers, countries, and institutions on the basis of their total research output as measured by unique publications. We acknowledge that overall research output is not a reliable indicator of quality or impact and, as a result, the overall contribution that specific individuals have made to the growth of this field may not be accurately represented.
Author affiliations	While all efforts have been made to ensure the data presented in this report is accurate, the organisational affiliations assigned to researchers may not always accurately reflect where they are currently employed. For all tables and figures in this report, researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

07 Regional deep-dives

More in-depth analysis of the research trends and key actors within the DACH region, Benelux countries, the UK and Ireland, the Nordics, and France, Italy, Portugal and Spain can be accessed here.

08 Appendix

Data tables

Table S1. Top 10 most productive European research institutions in the years 2019-2023 inclusive

Organisation	Publications	Citations
Wageningen University & Research	87	3,657
University of Hohenheim	51	1,284
University of Helsinki	39	1,113
Technical University of Denmark	37	577
Aarhus University	34	1,170
Ghent University	34	952
Teagasc	32	547
Swedish University of Agricultural Sciences	30	845
University of Copenhagen	28	839
University College Cork	25	658

Table S2. Top 10 most productive European researchers[15] in the years 2019-2023 inclusive.

Researcher name	Organisation	Publications	Citations
Jochen Weiss	University of Hohenheim	35	895
Mohammad J Taherzadeh	University of Borås	19	453
Atze Jan Van Der Goot	Wageningen University & Research	16	1,229
Mark J Post	Maastricht University	15	1,043
Elke Karin Arendt	University College Cork	15	481
Nino Terjung	German Institute of Food Technologies	15	340
Anne Saint-Eve	AgroParisTech	13	285
Emanuele Zannini	University College Cork	12	418
Isabelle Souchon	University of Avignon	12	261
Brijesh Kumar Tiwari	Teagasc	12	198

[15] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Table S3. Top 10 countries where European alternative protein researchers are being cited in the years 2019-2023 inclusive as measured by unique citing publications.

Country	Citing publications
China	3,514
United States	1,893
India	1,290
Italy	1,178
United Kingdom	1,024
Spain	1,006
Germany	940
Brazil	793
Canada	748
The Netherlands	686

Table S4. Top 10 external countries where researchers have formed collaborations in the years 2019-2023 inclusive.

Country	Unique publications	Collaborating researchers
United States	99	133
China	54	147
Brazil	41	108
India	38	96
Australia	34	90
Canada	31	54
Iran	21	39
New Zealand	19	25
Egypt	14	15
Pakistan	12	21

Table S5. Top 10 most productive organisations in plant-based protein research in the years 2019-2023 inclusive.

Organisation name	Unique publications	Total citations
Wageningen University & Research	63	2,131
University of Hohenheim	32	856
University of Copenhagen	25	734
Aarhus University	24	1,041
University College Cork	24	654
University of Helsinki	23	711
Swedish University of Agricultural Sciences	22	564
Teagasc	22	421
Technical University of Denmark	21	272
University of Bari Aldo Moro	18	546

Table S6. Top 10 most productive plant-based protein researchers[16] in the years 2019-2023 inclusive.

Researcher name	Organisation	Publications	Citations
Jochen Weiss	University of Hohenheim	23	547
Elke Karin Arendt	University College Cork	15	481
Atze Jan Van Der Goot	Wageningen University & Research	14	936
Nino Terjung	German Institute of Food Technologies	14	330
Anne Saint-Eve	AgroParisTech	13	285
Emanuele Zannini	University College Cork	12	418
Isabelle Souchon	University of Avignon	12	261
Monika Gibis	University of Hohenheim	10	262
Fatma Boukid	IRTA	9	531
Claus Heiner Bang-Berthelsen	Technical University of Denmark	9	103

[16] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Table S7. Top 10 most productive organisations in fermentation research in the years 2019-2023 inclusive.

Organisation name	Publications	Citations
University of Borås	19	433
Technical University of Denmark	15	299
University of Hohenheim	14	272
Ghent University	13	124
Quorn (United Kingdom)	11	303
University of Naples Federico II	10	235
VTT Technical Research Centre of Finland	8	354
Wageningen University & Research	8	220
ETH Zurich	7	247
Imperial College London	8	127

Table S8 Top 10 most productive fermentation researchers[17] in the years 2019-2023 inclusive.

Top 10 researchers	Organisation	Publications	Citations
Mohammad J Taherzadeh	University of Borås	17	418
Jochen Weiss	University of Hohenheim	11	252
Tim J A Finnigan	Quorn (United Kingdom)	10	261
Jörg Hinrichs	University of Hohenheim	10	229
Yifeng Zhang	Technical University of Denmark	9	190
Yan-Yan Su	Carlsberg Laboratory	8	102
Irini Angelidaki	Technical University of Denmark	7	166
Laixin Dai	University of Hohenheim	7	98
Alexander Mathys	ETH Zurich	6	224
Jorge A Ferreira	University of Borås	6	187

[17] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.

Table S9. Top 10 most productive organisations in cultivated meat and seafood research in the years 2019-2023 inclusive.

Organisation name	Publications	Citations
Maastricht University	17	1,082
Aarhus University	10	129
University of Bath	10	1,093
Bordeaux Sciences Agro	8	182
Institut Supérieur d'Agriculture Rhône-Alpes	7	461
University of Helsinki	7	125
Wageningen University & Research	7	169
Poznan University of Medical Sciences	6	62
INRAE	6	173
University of Birmingham	5	71

Table S10. Top 10 most productive cultivated meat and seafood researchers[18] in the years 2019-2023 inclusive.

Researcher name	Organisation	Publications	Citations
Mark J Post	Maastricht University	15	1,043
Jean-François Hocquette	VetAgro Sup	10	506
Panagiota Moutsatsou	Maastricht University	9	753
Sghaier Chriki	Institut Supérieur d'Agriculture Rhône-Alpes	9	483
Marie-Pierre Ellies-Oury	Bordeaux Sciences Agro	8	182
Christopher John Bryant	University of Bath	7	935
Joshua E Flack	Mosa Meat	6	254
Jette Feveile Young	Aarhus University	6	78
Stig Skrivergaard	Aarhus University	5	72
Toni Ryynänen	University of Helsinki	5	67

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[18] Researcher affiliations reflect the organisation where the majority of the publications assigned to each individual researcher in the dataset were generated and may not reflect their current affiliation.