Unlocking the potential of microbial fermentation for food systems

Market & policy landscape report for beta-carotene

Julia Martin, Samra Mariam, Katie Jones

Written by 3Keel for the CAROWIA project

A report for the UKRI ESRC/BBSRC Multidisciplinary Food Systems Commercialisation Catalyst Award

Contents

Disclaimer

3Keel Group Ltd (3Keel) has exercised due and customary care in preparing the report but has not, unless explicitly stated, verified the information provided by the companies included in this report. No other warranty, express or implied, is made in relation to the contents of this report. The use of this report, or reliance on its content in decision making processes shall be at your own risk, and 3Keel accepts no responsibility for the outcomes of those decisions. Any recommendations, opinions, or findings stated in this report are based on the facts and information provided to 3Keel or otherwise available in the public domain as they existed at the time the report was prepared. Any changes in such facts and information may adversely affect the recommendations, opinions, or findings.

3Keel does not provide legal or regulatory advice, including with regards to reporting requirements. Any services provided by 3Keel shall not be deemed or treated to constitute any advice of this sort, in any form whatsoever, or as a substitute for such advice. The client is solely liable for the conclusions it draws from the use and receipt of services provided by 3Keel.

Acknowledgements

Rebecca Lamb (FSA), Ben Rayner (FSA), Craig Leadley (IFST).

Glossary

Bioavailability	The proportion of a substance (such as beta-carotene) that enters the circulation when introduced into the body and is thus able to have an active effect.
Bio-based	Products or ingredients derived from biological sources (such as algae, fungi, or yeast) as opposed to petroleum or synthetic chemical reactions.
Blakeslea trispora	A fungus used in industrial fermentation to produce natural beta-carotene.
Cis/Trans isomers	Different structural forms of a molecule.
Clean-label	A consumer-driven trend referring to food products with fewer, simpler ingredients that are easy to recognise by the general public.
Downstream processing (DSP)	The stages of processing that occur after the fermentation or growth phase to isolate, purify, and concentrate the desired compound from the biological broth.
Dunaliella salina	A type of micro-algae cultivated in open ponds to produce high-quality, natural beta-carotene.
Food formulation	The precise qualitative and quantitative composition of a product, defining the specific ingredients and proportions required to meet safety, labeling, and technical standards.
Food supplement	A concentrated source of nutrients or substances with a nutritional/physiological effect, marketed in dose forms (like capsules or liquids) to supplement the normal diet.
Label-debt	An informal industry term referring to the undesirable lengthening of a product's ingredient list.
Native encapsulation	A technical advantage where the target compound is naturally contained or protected within the host organism's structure.
Novel Food	Under UK and EU law, a food or ingredient that was not significantly consumed by humans in the UK or EU before 15 May 1997.
Precision fermentation	A technology that uses genetically engineered microorganisms to produce specific, high-value functional ingredients.
Retinoids / retinol	Derivatives of Vitamin A used in nutrition and widely used in the cosmetic industry for anti-aging applications.
Yarrowia lipolytica	A specific species of yeast frequently engineered in precision fermentation to produce lipids and carotenoids due to its robust metabolic profile.

Introduction

The UK food system needs a fundamental transformation to create supply chains that are sustainable, self-sufficient, and resilient [1]. Central to this transition is the development and adoption of novel food technologies. One such technology is precision fermentation, which uses genetically engineered microorganisms to generate specific high-value compounds, thereby offering an alternative to existing methods for producing functional ingredients, food supplements, and sensory additives [2].

One relevant target for this innovative approach is beta-carotene, owing to its diverse and essential role in food product formulation and human health. The human body converts beta-carotene into Vitamin A during digestion, a process essential for vision, immune, and metabolic functions, showing its primary nutritional benefit. Consequently, beta-carotene is widely used as a critical fortifier, added to a wide range of food and nutrition products such staple foods and infant formula [3]. Beyond nutrition, beta-carotene is also used as a colorant for its strong red-orange pigment, providing a desirable yellow-to-orange hue across various consumer products, including dairy, beverages, baked goods, and confectionery [4].

The production of beta-carotene via precision fermentation, specifically via the engineering of the yeast Yarrowia lipolytica, presents itself as an potentially more sustainable and less geographically constrained alternative to meet its demand. However, the trajectory from a successful lab-based concept to commercially viable industrial production requires substantial upfront capital. To derisk the necessary investment for development and advancement of the technology, it is essential to assess the likelihood of it achieving successful commercial integration.

This report outlines the UK market and policy landscape surrounding the production of functional ingredients via precision fermentation, using beta-carotene as the model compound. Our research directly looks at two critical areas influencing commercial integration:

- **Market dynamics and appetite**: We review the existing global market size, segmentation, and pricing dynamics of beta-carotene, as well as the competitive environment, and the advantage needed to displace entrenched incumbents. Furthermore, we provide specific insights into consumer and corporate appetite for precision fermentation-derived beta-carotene to assess the likelihood of market uptake.
- **Policy and regulatory determinants**: We assess government policy and funding as crucial determinants of the realities of scaling-up emerging technologies. This includes examining support for access to facilities, as well as the necessary pace and specific requirements of regulatory approvals.

Market landscape

Market dynamics

This section aims to estimate the market opportunity within the carotenoids sector, and is based on trading data aggregators, as well as conversations with research & development (R&D) and supply chain operators in the food ingredients sector.

The UK represents an estimated 5% of total global beta-carotene demand, yet currently relies exclusively on bulk imports for the manufacturing industry

According to Polaris Market Research, the global beta-carotene market is valued at $638 million (in 2024 base year), and is projected to grow to $822 million by 2029, at an annual growth rate of 5.20% [5]. Europe is the leading regional market for beta-carotene, accounting for about 50% of total demand, while UK demand for beta-carotene is estimated at about 5% of the total global demand. However, accurate internal consumption figures are harder to estimate as records of UK-domiciled global operators can overestimate these figures due to inaccurate trade flow data.

The United Kingdom primarily operates as a net importer of beta-carotene rather than a major primary producer. The most significant domestic economic activity therefore lies in the downstream value chain, particularly in formulation and packaging of the imported raw materials. This activity is split into two core segments:

- **Supplement manufacturing**: Companies like Nature's Best exemplify this sector, manufacturing and packaging beta-carotene-containing food supplements within UK facilities. This segment relies heavily on natural beta-carotene from biomass.
- **Food and feed formulation**: Companies using nutritional supplementation in animal feed, and for the sensory improvement of consumer-finished goods through its use as a colour additive. Formulators in both of these areas typically depend on synthetic beta-carotene.

The import price of beta-carotene into the UK demonstrates wide variability, dictated largely by its production source, creating a clear distinction between synthetic and natural grades:

- **Standard synthetic**: Priced in the £10–£20 per kilogram range, this grade is widely deployed in large-scale food manufacturing as a sensory additive and as a cost-effective animal-feed supplement.
- **Premium bio-based**: Highly valued products like 10% beadlets sourced from algae or herbal extracts can command prices of £80–£150 per kilogram. Their high quality and natural origin make them the ingredient of choice for premium food supplements.
- **Purified bio-based**: this range undergoes intensive downstream processing to achieve very high purities. Prices for these specialised ingredients can climb above £200 per kilogram, catering to niche health brands and pharmaceutical applications.

The competitor landscape for beta-carotene is divided between synthetic and bio-based production, with cost-efficiency on one end and bio-availability on the other

Production strategies determine not only the market price, but deeply divide the competitor landscape. Table 1 below summarises the three main strategic approaches, including non-exhaustive examples of leading companies for each:

Table 1: Summary of incumbent strategies for the production of beta-carotene

Strategy	Positioning	Example company
Dunaliella salina (Algae) in open ponds	Very high-quality, "natural" beta-carotene.	Betatene Australia (BASF)
Blakeslea trispora (Fungus) Fermentation	Industrial scale and regulatory leader in natural beta-carotene, made in EU.	DSM-Firmenich
Chemical synthesis via Wittig reaction	High-volume, cost-optimised synthetic production.	BASF

Overall, the microbial platforms sector has experienced significant growth over the past 15 years, largely due to supportive regulatory precedents. A key turning point was the 2011 ruling by the Joint FAO/WHO Expert Committee on Food Additives (JECFA), which established that beta-carotene derived from Blakeslea trispora fermentation was toxicologically equivalent to the chemically synthesised version [6]. This decision triggered a major industry movement: the acquisition of Spain-based Vitatene SA by the global ingredient leader DSM-Firmenich in 2011, with the intention to use their patent of producing beta-carotene via Blakeslea trispora fermentation for pharmaceutical and food applications [7]. The patent expired in 2023 [8], releasing the protection of this production method, which has since rapidly extended for bulk production in China and India, with leading producers like Divi's Nutraceuticals.

Despite the growth in fermentation-based production processes, cost efficiency remains the primary moat of chemical synthesis. Industrial chemical synthesis routes, such as those based on the Wittig condensation method for synthetic beta-carotene, achieve very high chemical yield of 85% [9]. This sets a demanding economic benchmark that even bio-based processes based in nations with lower associated costs of production struggle to meet.

At the same time, a compelling case can be built for bio-based carotenes based on product composition and bioavailability. Synthetic beta-carotene is composed almost entirely of trans-isomers. In contrast, natural extracts contain a beneficial mixture of cis and trans isomers, which are widely regarded as enhancing bioavailability and have thus become the gold standard for food supplements [10]. Consequently, research efforts in recent years have been intensely focused on bridging the cost gap by increasing fermentation yield and reducing the complexity of downstream processing in an attempt to achieve improved bioavailability alongside economic competitiveness.

In terms of early ventures, there are currently no companies in the UK solely dedicated to the production of beta-carotene via microbial factorisation. However, companies targeting yeast platform development could eventually target this compound, as could be the case with Novya Biotech, a Netherlands-based startup engineering baker's yeast for food ingredients [11].

Market appetite

The following section focuses on market appetite in consumers and corporations and is derived from published studies as well as conversations with R&D and supply chain operators in the food ingredients sector.

Consumers are prioritising health-improving beliefs in their purchasing behaviours, driving growth of clean-label and functional products

Consumers' purchasing decisions globally are moving beyond taste and convenience to prioritise products aligned with proactive health-improving beliefs. This change is powerfully evidenced in purchasing behaviour towards clean-label and functional foods. Clean-label or 'better-for' products are consistently outperforming traditional categories, a trend confirmed by published insights showing an approximate 8% year-over-year sales increase for clean-label products [12]. This preference extends across various product forms, with clean-label functional beverages being a particularly rapidly growing category, where there is a pronounced demand for ingredients that align with consumer perception of "naturalness", notably driving the uptake of bio-based colours over synthetic alternatives [13].

This trend is magnified in the United Kingdom, where manufacturers are rapidly committing to ingredient transparency. According to the Ingredion ATLAS study, 52% of UK manufacturer ingredient portfolios were already clean-label in 2021, a figure confidently projected to reach 70% by 2026 [14]. This confidence is supported by consumer spending: the UK organic food & drink sector (closely aligned with "natural" product positioning) generated approximately £3.7 billion in value sales in 2024, achieving a robust year-over-year increase of 7% [15]. Furthermore, according to NIQ, the organic market grew 6.4% in 2024, outpacing conventional food and drink sales (5.4%) during the same period [16]. This indicates that UK consumers are willing to invest in products that meet these health beliefs.

Food ingredient manufacturers do not see carotenoids as a focus priority, but see opportunities in native functionality

In the background research of this report, technical staff at global food manufacturing companies consulted expressed that from both a nutritional or a sensory point of view, beta-carotene and related carotenoids are not research or sourcing priorities, as sources that can be claimed as "natural" are widely available. However, opportunities for innovation in beta-carotene applications could be of interest. Apparently, when applied in polar systems (i.e. beverages or creams), beta-carotene needs to undergo encapsulation and emulsification, which comes with a rather undesirable "label-debt", as emulsifiers and other additives increase the length of the ingredients lists on products, going against their directives of enabling "cleaner products". The American market, and the "Make America Healthy Again" (MAHA) push against additives, is having ripple effects in R&D priorities of some global companies. In this context, "natively encapsulated" beta-carotenes that do not require pre-encapsulation could be a product for consideration.

Key market barriers to commercialisation of fermentation-derived beta-carotene and derivatives

1. The modest scale of the global and UK carotenoid markets presents a financial constraint for a high-CAPEX biotechnology venture. Relying solely on beta-carotene as a proof-of-concept means that there is likely a ceiling on potential returns. The scale of the beta-carotene market suggests that commercialisation strategies focused on a single molecule may face limitations in terms of scale. This highlights the importance of considering broader portfolios or platform-based approaches when assessing long-term commercial viability.

2. The beta-carotene sector is a mature, highly competitive landscape dominated by large players using scalable synthetic production or low-cost natural cultivation methods (all with liberated intellectual property). While a viable entry path could be achievable by combining demonstrably superior bioavailability with cost-competitiveness, this is a combination that requires unprecedented technological breakthroughs in both yields and downstream processing efficiency.

3. The established carotenoid market, particularly for bulk beta-carotene, is not considered a priority pain point for the corporate manufacturers consulted for this report. Since existing synthetic and natural supply chains provide adequate availability and cost-competitiveness for their distinct purposes, there may be insufficient commercial pressure to justify the complex and potentially higher-cost transition to a novel, fermentation-derived source.

Key market enablers to commercialisation of fermentation-derived beta-carotene and derivatives

1. The multi-billion dollar carotenes market is consistently expanding globally and in the UK. This growth is driven by manufacturers shifting portfolios toward high-value, naturally-sourced ingredients, fuelled by a clear consumer pull for natural products. This alignment creates a compelling opportunity for precision fermentation to capture significant market share by delivering reliable, high-purity, and naturally-derived alternatives.

2. The UK's high reliance on imported carotenoids creates a supply chain vulnerability, exposing the market to price volatility and geopolitical shocks. Developing a domestic bio-extraction platform, therefore, offers a compelling strategic opportunity: to use precision fermentation to establish a local source, thereby enhancing national resilience and increasing self-sufficiency for key ingredients.

3. There are technical gaps in the application of carotenoids that could potentially be uniquely served by novel technology such as precision fermentation and choice of host (e.g. native encapsulation requiring minimal processing and reducing "label-debt").

Policy & regulatory landscape

Regulation will have a highly significant impact on the time and expense associated with bringing compounds to market. In the case of food, ingredients and additives that are produced via new methods must obtain regulatory approval prior to commercialisation. Regulatory bodies, such as the Food Standards Agency (FSA), set out the requirements for authorisation, define approval processes, and ultimately decide whether approvals are granted.

Communications released by the UK government and regulatory bodies indicate that the UK's policy and regulatory landscape may be becoming increasingly favourable towards technologies that underpin development of the UK's bioeconomy. However, public investment and regulatory decisions ultimately dictate the reality of commercialising novel compounds and production processes. This section explores the policy and regulatory landscape as it relates to precision fermentation and beta-carotene.

Policy considerations

The UK government is demonstrating commitment to advancing biotechnological innovation, with a particular focus on new food products

Recent government communications signal that biotechnology (and the UK food and drink manufacturing industry specifically) is being positioned as a national growth opportunity. In June 2025, a government review identified precision fermentation as an approach with leading potential for the production of more environmentally sustainable dietary protein [17]. The subsequent "Good Food Cycle" strategy for England, further highlighted the strategic importance of innovation in the food sector, and explicitly recognised the development of new food products and markets as a prioritised opportunity for 'good growth [18].

Public funding decisions validate the government's favourable position towards biotechnology. According to an analysis by the Good Food Institute, between 2021 and the beginning of 2025, the UK government invested £75 million into sustainable food innovation, with a particular focus on alternative proteins. This investment has supported the development of plant-based food products, cell cultivated foods and fermentation-derived ingredients [19]. Within this period, three UK-based biotechnology research centres have been established with public funding. A further privately funded research centre, the Bezos Centre for Sustainable Protein, has also opened. These research centres are focused on research into new ingredient development, from processes such as precision fermentation and cellular agriculture, and how these can be scaled and brought to market [20].

Whilst the majority of investment is targeting alternative proteins, research into precision fermentation-made ingredients is also included. Precision fermentation-made ingredients are also recognised for their potential to enhance the consumer appeal of products, such as by altering taste and/or appearance. As a result, continued product development in the sector is likely to create opportunities for the integration and commercialisation of fermentation-made ingredients in novel products. Overall, continued investment into biotechnological innovation in the food sector suggests a national landscape supportive of novel approaches and ingredients.

Support for industrial biotechnology and investment in scale up facilities is consistent across the UK's central and devolved governments

Strategic positioning of the UK's devolved governments (Scotland, Wales and Northern Ireland) reveals consistent support for driving forward biotechnological advancements. For example, the Scottish government backed the adoption of bioscience and biotechnology through the Scottish National Plan for Industrial Biotechnology, which established a pipeline for industrial transformation from 2013 to 2025 [21]. The Life Sciences Strategy for Scotland was further published in 2017. This subsequent strategy identified scaling of the industry as a crucial opportunity for growth and outlined how this growth can be driven by commercialisation and collaborations between industry and academia [22]. Likewise, the Wales Innovates 2023 innovation strategy outlines Wales' ambitions to grow this sector, including through a £20 million Wales Technology Seed Fund, set up to support start-up businesses to transition from proof of concept to commercialisation [23].

In Scotland, the Industrial Biotechnology Innovation Centre (IBioIC) operates the FlexBIO Scale-Up Centre, a publicly funded scale-up facility specifically established to de-risk scaling of biotechnology and form a "dynamic bridge between early-stage R&D and industrial-scale production" [24]. In June 2025, this centre opened a 300L fermenter intended for use by start up and early stage businesses [25]. Similarly, the AberInnovation facility located at Aberystwyth University, Wales is supporting the scale up of precision fermentation techniques, including via 500L capacity solid state fermentation and incubation facilities [26, 27]. Scale up facilities are likewise available in England, such as the fermentation scale-up facilities within the CPI National Industrial Biotechnology Facility (NIBF) [28].

Open-access to scaling facilities can actively support the translation of proof of concepts into real world applications. Both facilities and the biotechnology expertise they host is conducive to commercialisation. However, the extent to which these facilities can aid individual circumstances (e.g. scaling *Yarrowia lipolytica* fermentation of beta-carotene) will depend on various factors including access, costs, and the technical capabilities available at the sites. Furthermore, following initial scale up and production of manufacturable ingredients, full commercialisation necessitates further work, including production of a customer-ready product, pilot batches and verifications of product safety (such as evidence required for submission to regulators). Each of these subsequent stages rely on access to additional specialist facilities.

Regulatory considerations

Ingredients, food additives and food supplements require authorisation as if produced from previously unauthorised processes

- ### Food and feed products

Before being brought to market, food and feed products must be authorised by the Food Standards Agency (FSA) in England or Food Standards Scotland (FSS) in Scotland. When an ingredient, produced via a particular production method, has not previously been authorised, it is classed as a 'novel food' and must undergo the novel food authorisation process. A 'novel food' is defined as a food or ingredient not significantly consumed in the UK (or EU) before 15 May 1997 [29]. If intended for a technological function (e.g. colourant, preservative, stabiliser) the same compound may also require additional approval as a food additive.

Carotenes (E 160a) are already authorised as food additives [30]; however, this authorisation is unlikely to cover carotenes produced using new production methods, such as precision fermentation, or a previously unapproved microbes/microbial strains like *Yarrowia lipolytica*. Securing market authorisation will therefore represent a critical milestone in bringing beta-carotene produced via *Yarrowia lipolytica* fermentation to market in the UK.

- ### Food supplements

In the UK, food supplements are treated as distinct from food ingredients and additives, and are regulated by the FSA [31] and DHSC [32]. Food supplements produced from novel processes, such as precision fermentation, may have to seek approval from both organisations. However, the process is unclear due to the novelty of this technology and the lack of precedents for this specific case.

- ### Cosmetic ingredients

In the UK, regulations applicable to cosmetic products and ingredients are distinct from those covering foods. Cosmetics products must comply with the UK Cosmetics Regulation (Schedule 34 of the Product Safety and Metrology Regulations 2019) [33]. Unlike food ingredients, the production method is not, by itself, a trigger for regulatory pre-approval. As such, there is no equivalent of 'novel foods' requiring pre-market authorisation in the UK.

Once a significant administrative burden, regulators have responded to the need for regulatory modernisation and increased support for businesses bringing innovative products to market

Regulatory approvals depend on the submission of information, or evidence dossiers, covering the ingredient seeking approval. Once an application is submitted to the FSA/FSS, it is channelled through a multi-stage approval process, including risk assessments and risk management reviews. Regulators can also request supplementary evidence at any point, which can materially extend approval timelines. In the past, some authorisations have experienced extended delays. For example, soy leghemoglobin, a protein derived via fermentation of genetically modified yeast, and already in use in Impossible Meat products in the US, has yet to receive UK approval, despite being submitted to the FSA in 2021 [34].

As a result, the process had been widely regarded as lacking in clarity around data submission requirements and a hurdle to commercialisation [35]. The evidence base required for authorisation could continue to be a bottleneck for scale-up to start ups and early innovators in particular, as significant investment from private sources often occurs only after approvals are obtained [36]. However, regulators are embracing reform to remove these barriers. As of October 2025, the government has implemented new regulatory reforms as essential for fostering business-led growth and increased private sector investment [37]. As outlined in the government's regulatory reform 'action plan', reducing the administrative burden and cost of market authorisations falling on businesses is a key priority [38].

In March 2025, £1.4 million was granted to the FSA to establish a new innovation hub, dedicated to developing expertise on regulating emerging technologies [39]. The hub is providing industry guidance on the evidence submissions required for regulated and novel food products. Subsequently, in September 2025, the broader Market Authorisation Innovation Research Programme (IRP) was launched. This is a one year programme designed to help the scientific knowledge of the FSA and FSS keep pace with innovation and industry requests for authorisation. The IRP houses both the Innovative Food Guidance Hub and the Precision Fermentation Business Support Service (BSS), an accompanying and ongoing pilot programme providing pre-submission guidance directly to businesses applying for, or intending to apply for, authorisation of precision fermentation-derived products [40].

The impact of these programmes on ingredient authorisations, and the pace at which regulatory modernisation will translate into practical benefits for businesses, remains uncertain. However, improved regulatory understanding of emerging production methods has the potential to support the adoption of streamlined standards for assessing novel ingredients. Clearer guidance on the evidence required for approval will be crucial for accelerating authorisation pathways for companies bringing new products to market.

Uncertainty still remains over the impact of UK-EU alignment on the regulation of novel foods in the UK

UK-EU negotiations are ongoing over the UK–EU Sanitary and Phytosanitary (SPS) agreement, a deal proposed to create frictionless trade of animal, plant and food products. The extent to which this deal will require alignment of the UK with EU food standards remains unclear. Transparency on negotiations has been limited, with UK officials only indicating that the agreement will contain a small number of exemptions.

There is a risk that alignment with the EU may constrain approvals of novel foods and production processes. Some stakeholders have recommended that the UK secure an explicit exemption to retain regulatory autonomy, particularly for ingredients integral to next-generation alternative proteins [41]. However, given the government's strategic focus on food innovation, it can be hoped that efforts will aim to minimise restrictions imposed by regulatory alignment. Moreover, alignment will not necessarily impose new restrictions, but more likely, prevent reduction in administrative burdens. This is supported by active ongoing EU investment in biotechnologies within the food sector, including fermentation [42].

Pre-market authorisation presents less of a challenge for cosmetic uses of carotene and its derivatives

In the UK, beta-carotene (CI 40800) and related carotenoids are already authorised for use as a colourant and an active ingredient, respectively, for use in cosmetic products [43]. Restrictions apply to finished products, based on product type, derivative form, and concentration limits, rather than on ingredient production method. Therefore, when intended for cosmetic use, several carotenoid-based ingredients can be brought to market under existing regulatory frameworks, provided that relevant manufacturing and safety requirements are met.

Key policy and regulatory barriers to commercialisation

1. Novel production methods (e.g. precision fermentation using new microbial strains) trigger novel food authorisation, even for previously approved functional ingredients such as beta-carotene. Significant time, cost and administrative burden is associated with gaining market approval, especially for food ingredients.

2. Despite new innovation hubs and regulatory support services, the practical impact and speed of reforms on the scaling of specific functional ingredients, such as fermentation-derived beta-carotene, remains uncertain.

3. The future of novel food regulation is difficult to predict due to a lack of transparency over ongoing international negotiations.

Key policy and regulatory enablers to commercialisation

1. Strategic commitments and public funding allocations indicate strong ambitions to support commercialisation of biotechnological solutions across the UK's food and drink sector. Significant public investment, including into biotechnology scale up facilities, is increasing expertise and scaling opportunities across the UK.

2. Regulatory reform is underway across the Food Standards Agency (FSA), focused on enhancing regulatory pathways for market authorisation, which should shorten timelines, and potentially costs, of market authorisation.

3. Regulatory approval hurdles are reduced for beta carotene intended for use in cosmetic ingredients, even when novel production methods are used.

Conclusions

Market

- **The beta-carotene supply-chain is seemingly mature**: The sector is dominated by cost-optimised synthetic production and long-established low-cost bio-based incumbents. Corporate food manufacturers view existing synthetic and natural sources as sufficient and cost-competitive, with little immediate pressure to switch to a novel source.
- **Consumer drive towards natural ingredients and clean-label products keeps increasing**: Consumer demand and corporate pull towards naturally sourced, clean-label, and functional ingredients is growing, and thus the food space remains a robust testing arena.
- **A wider target market may be needed to support scale-up**: The limited annual revenue potential of beta-carotene may constrain strategies focused on a single molecule.

Regulation

- **There is a high-regulatory barrier for food ingredients and additives and a fragmented pathway for food supplements**: Gaining approval from the FSA food ingredients and additives is a complex, evidence-heavy and potentially lengthy process. The pathway for supplements is unclear and fragmented between agencies.
- **There appears to be a reduced barrier for cosmetic applications**: Not all fermentation methods may automatically require pre-market authorisation, both for beta-carotene, or other carotenoids.
- **Available infrastructure**: Publicly funded institutions and additional funding pathways are being deployed to enable biotechnology, including precision fermentation.

Closing remarks

While this report has explored the market and regulatory barriers and enablers for fermentation-derived beta-carotene as a case-study, long-term success in this area requires a clear and compelling strategic direction that aligns technological capabilities with intended impact ambitions. The beta-carotene case illustrates that fermentation-derived ingredients can be positioned in different ways within food systems, depending on the objectives they are designed to serve. For example:

- **A public health mission (global impact)**: fermentation-derived ingredients such as beta-carotene could be positioned as a tool to address nutritional needs through the development of a cost-effective, high-quality ingredient for fortification, potentially supported by public, philanthropic, or development-led funding mechanisms.
- **A national resilience mission (strategic self-sufficiency)**: fermentation-derived ingredients could be leveraged to establish a domestic precision fermentation platform. This could enhance national supply chain resilience and self-sufficiency for key ingredients, given the UK's current reliance on imports and the position of national food security and industrial capability as current policy priorities.
- **A commercial mission (commercial disruption)**: alternatively, fermentation-derived ingredients could be oriented toward the development of a highly specific, commercially differentiated product capable of attracting significant private investment by maximising technical advantages and targeting high-margin segments.

Ultimately, the choice of pathway will determine whether the technology is positioned as an essential utility for public good, a strategic national asset, or a high-value disruptive technology able to produce superior ingredients. Clarifying these pathways is an important step in informing future market, regulatory, and strategic considerations for fermentation-derived ingredients beyond beta-carotene.

References

1. Defra, 2025. A UK government food strategy for England, considering the wider UK food system
2. Good Food Institute Europe. What is precision fermentation?
3. Grune et al. 2010. ß-carotene is an important vitamin a source for humans.
4. FAO: Codex Alimentarius.
5. Polaris Market Research, 2025. Beta carotene market analysis.
6. USDA, 2011. Beta-Carotene: rules and regulations
7. Royal DSM, 2022. DSM, a world leader in biotechnology, pg 37.
8. Costa Perez et al., 2003. Method of producing beta-carotene by means of mixed culture fermentation using (+) and (-) strains of Blakeslea trispora EP1367131B1.
9. Pirwitz et al. 2015. Energy and operating cost assessment of competing harvesting methods for D. salina in a ß-carotene production process.
10. Gaziano et al. 1995. Discrimination in absorption or transport of beta-carotene isomers after oral supplementation with either all-trans- or 9-cis-beta-carotene.
11. Wageningen University and Research, 2025. Startup develops tiny yeast factories that produce valuable substances.
12. Nielsen IQ, 2024. The state of wellness and better for™ products.
13. Polaris Market Research, 2025. Clean label functional beverage ingredients.
14. Food Manufacture UK , 2024. Clean label products set to dominate food and drink portfolios within two years.
15. Defra, 2025. Defra Accredited official statistics: Food Statistics in your pocket.
16. Food Manufacture UK, 2024. Organic outperforms conventional food market.
17. Government Chemist, 2025. Quantitative review of sustainable novel food production.
18. Defra, 2025. A UK government food strategy for England, considering the wider UK food system.
19. Good Food Institute, 2025. Analysis finds government has invested £75 million in alternative protein innovation since 2021 National Food Strategy.
20. Good Food Institute, 2024. NAPIC is the latest in a string of UK alternative protein research centres – here's a whistle-stop tour of the exciting new projects.
21. Scottish Development International, 2013. National plan for industrial biotechnology driving progress to 2025.
22. Life Sciences in Scotland, 2025.
23. Welsh Government, 2023. Wales innovates: Creating a stronger, fairer, greener Wales.
24. Industrial Biotechnology Innovation Centre (IBioIC). FlexBIO Scale-Up Centre.
25. Scottish Enterprise, 2025. Scotland's bioeconomy boosted by launch of £850,000 scale-up technology.
26. AberInnovation. Biorefining Centre.
27. UKRI, 2025. AberInnovation: An innovation catalyst.
28. CPI. Fermentation scale-up facilities.
29. Food Standards Agency (FSA), 2025. Novel Foods Authorisation Guidance.

30. Food Standards Agency (FSA), 2020. Novel Food Register – carotenes.
31. Food Standards Agency (FSA), 2024. Food supplements.
32. Department for Health and Social Care, 2011, updated 2021. Food supplement use and labels.
33. The Product Safety and Metrology etc. (Amendment etc.) (EU Exit) Regulations 2019. Schedule 34.
34. Food Standards Agency (FSA). Register of regulated product applications, Soy Leghemoglobin.
35. Food Manufacture, 2024. Food Manufacture, 2024. Novel foods: UK gets unnecessarily bogged down by food safety
36. Food Manufacture, 2024. Novel foods: UK gets unnecessarily bogged down by food safety.
37. HM Treasury, 2025. New approach to ensure regulators and regulation support growth.
38. HM Treasury, 2025. New approach to ensure regulators and regulation support growth.
39. Food Standards Agency (FSA), 2025. FSA announces £1.4 million funding for launch of new innovation hub.
40. Food Standards Agency (FSA). Innovative food guidance hub.
41. Green Alliance, 2025. Recipe for resilience: the benefits of a thriving plant-based protein sector in the UK.
42. Innovation News Network, 2025. EU backs fermentation technologies with €350m to revolutionise food innovation.
43. European Commission, 2009. Regulation (EC) No 1223/2009 of the European Parliament and of the Council. Annex IV – List of colorants allowed in cosmetic products.

CAROWIA

CAROWIA
Fermenting the future of sustainable food and nutrition

Co-led by the University of Oxford and Imperial College London, CAROWIA is developing microbial fermentation for ß-carotene production and exploring how biotechnology can enable sustainable functional ingredients and contribute to healthier, more resilient food systems.

This work is funded by ESRC/BBSRC Multidisciplinary Food Systems Commercialisation Catalyst Award, and powered by Zinc, an impact-VC.

Environmental *Change* Institute
eci | UNIVERSITY OF OXFORD

3keel

BEZOS CENTRE FOR SUSTAINABLE PROTEIN
IMPERIAL | BEZOS EARTH FUND

MICROBIAL FOOD HUB
IMPERIAL | UK Research and Innovation

Explore the project