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# Biotechnology in the Food and Feed Sector – Bread and Butter or the Icing on the Cake?

A CLIB white paper written in the scope of the HiPerIn 2.0 project.

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CLIB – Cluster Industrial Biotechnology, Völklinger Str. 4, 40219 Düsseldorf, Germany.

Corresponding author: Dr. Tobias Klement

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*"The main facts in human life are five: birth, food, sleep, love, and death."* E.M. Foster

# Table of contents

# Zusammenfassung

Der Lebensmittelsektor ist ein wichtiger Wirtschafts- und Beschäftigungsfaktor für NRW und Deutschland. Eng gekoppelt mit dem Agrarsektor auf der einen und dem Endverbraucherhandel auf der anderen Seite hat die Lebensmittelindustrie entscheidende Bedeutung für die Ernährung der Bevölkerung, aber auch großen Einfluss auf die Nachhaltigkeit insgesamt und eine wichtige Rolle als Rohstofflieferant einer künftigen Bioökonomie. Eng damit verbunden nimmt der Futtermittelsektor die wichtige Funktion ein, um die Tierernährung sicherzustellen. Im HiPerIn 2.0-Projekt hat CLIB die letzten drei Jahre biotechnologische Entwicklungen in diesen beiden Marktsegmenten verfolgt.

Auch wenn die Biotechnologie seit Jahrtausenden untrennbar mit der Erzeugung von Lebensmitteln verbunden ist, sind in den vergangenen Jahren neue Trends zu beobachten, die grundsätzlich in drei Kategorien eingeteilt werden können (und grundsätzlich so auch in der Tierernährung zu finden sind). Die Biotechnologie kann neue Wege zu ermöglichen, um hochwertige Proteine auf platzsparende und nachhaltigere Weise zu produzieren. Dazu gehören verschiedene essbare Mikroorganismen, aber auch die Herstellung von künstlichem Fleisch aus Zellkulturen. Auch für die Prozessierung von Lebensmitteln spielt die Biotechnologie eine wichtige Rolle, hier sind vor allem Enzyme unabdingbar. Zuletzt können biotechnologisch produzierte Inhaltsstoffe Lebensmittel verbessern, indem sie spezielle Eigenschaften wie Geschmack, Farbe oder Haltbarkeit verbessern.

Von allen in HiPerIn2.0-Projekt betrachteten Marktsegmenten ist der Lebensmittelsektor wohl am meisten von den Querschnittshemen beeinflusst. Gerade die Regulatorik und die öffentliche Wahrnehmung können ebenso Hindernisse wie Treiber neuer Entwicklungen sein. Der künftige Erfolg der Biotechnologie in diesem Sektor hängt entsprechend auch von einer technologieoffenen Regulierung und einer erfolgreichen Kommunikation mit der Öffentlichkeit ab. Angesichts der starken regionalen Akteure aus Wissenschaft, Agrarsektor, Industrien und Netzwerken kann NRW hier seine Stärken ausspielen.

# Summary

The food sector is an important economic and employment factor for NRW and Germany. Closely coupled with the agricultural sector on the one hand and the end consumer trade on the other, the food industry is of decisive importance for feeding the population, but also has a major influence on sustainability as a whole and an important role as a supplier of raw materials for a future bioeconomy. Closely related to this, the feed sector takes on the important function of ensuring animal nutrition. In the HiPerIn 2.0 project, CLIB has been following biotechnological developments in these two market segments for the last three years.

Although biotechnology has been inextricably linked to food production for millennia, new trends have emerged in recent years that can basically be divided into three categories (these exist similarly in feed production). Biotechnology can enable new ways to produce high-quality proteins in a space-saving and more sustainable way. These include various edible microorganisms, but also the production of artificial meat from cell cultures. Biotechnology also plays an important role in food processing, where enzymes are indispensable. Finally, biotechnologically produced ingredients can improve food by enhancing special properties such as taste, colour, or shelf life.

Of all the market segments considered in the HiPerIn2.0 project, the food sector is probably the most influenced by cross-cutting issues. In particular, regulatory issues and public perception can equally be obstacles or drivers of new developments. Accordingly, the future success of biotechnology in this sector also depends on regulation that is open to technology and a successful communication with the public. In view of the strong regional players from science, the agricultural sector, industries, and networks, NRW can play to its strengths here.

# Introduction

Since the beginning of mankind, the question "What are we going to eat today?" has been of utmost importance not only for each human individual but also for humanity itself. During all times, food has always been one of the most important growth(-limiting) factors for humanity. Our ability to produce food in effective ways, to feed farm animals, and to process and conserve food has enabled us to enormously grow in numbers, to develop societies, and to settle in almost every habitat on earth. Moreover, agriculture is also an important economic factor, still employing one third of the world's working population. However, food production and agriculture have also caused severe environmental destruction of natural habitats, extermination of species, and the unnaturally high deployment of nutrients via fertilizers.

Although the premise of sustainable food production is not new (crop rotation, e.g. the three-field system, has been around for millennia), there has recently been an increasing awareness that the food sector is an important factor to achieve several of the Sustainable Development Goals (SDGs). Out of 17 SDGs, at least 8 are directly affected by the agricultural sector and the food and feed industry (Zero Hunger, Good Health and Well-being, Decent Work and Economic Growth, Responsible Consumption and Production, Climate Action, Life below Water, and Life on Land). To meet these Goals, the food sector must therefore undergo a huge transformation.

Of course, change is nothing new for the food industry. New agricultural raw materials have always been tapped, improved processes have been developed, and various diet and food trends have been followed by customers. In recent years, major themes include increased awareness of sustainability and of animal welfare, which goes hand in hand with the increasing demand for healthy food and meat-free alternatives. The industry has for decades had to deal with volatile pricing, as qualities and yields changed throughout the years. This challenge has increased with the added pressure of climate change, but also geopolitical instabilities.

Most recently, rising world market prices and ruptured supply chains in the shadow of the war on Ukraine made it challenging for the food industry to maintain its quality standards and, at the same time, not to scare off customers by charging too high prices. Vice versa, as today's global markets are interlinked, transformation actions in Europe will most certainly affects markets worldwide. Despite these global influences, many food producers still have strong regional ties and are thus bound locally. This also means that they must manage their transformation together with their respective region.

In a future circular bioeconomy, this sector would also have the additional task of providing the (carbon) raw material basis for other industries, at least in part. If the food industry is now to be integrated into larger value-added cycles, many rules of the game will change. Not only are there many technical challenges to overcome, but due to the importance of the topic, many environmental and social aspects must also be considered. Each region will probably need to prioritise its use of limited land and agricultural resources for the different uses. The general public "assigns" raw materials such as sugar to the food sector, so their usage in other sectors immediately raises concerns. In the context of bioethanol production, for example, there have been many discussions about the competition between food, feed, and fuel. Although significant parts of the world's population are still threatened by hunger (a trend that has unfortunately worsened again in recent years[1]), it should be noted that this is not only a production issue but also a problem of distribution. In 2021, as many as 828 million people were undernourished, that is 10 % of the world population. Given these numbers, it is disturbing that an estimated 33 - 40 % of the food produced is lost, disposed of, or wasted between the field and consumption[2].

The ecological challenges are also enormous: According to estimations, the food system (including agriculture, land use, storage, transport, processing, retail, and consumption) causes about 21–37 % of total greenhouse gas emissions[3]. Regarding the biodiversity crisis, competition for (agricultural) land is also a huge problem and needs to be considered.

Nevertheless, the upcoming transformation of the food sector has also attracted a lot of investment. A recent Nesta analysis shows that global venture capital investment into food technology and innovation start-ups increased about 40 times between 2011 and 2021, from £670 million/a to £26.9 billion/a [4].

## The food and feed industry in Germany and NRW

With an annual turnover of 185.3 billion EUR in 2020, the food sector is one of the most important industries in Germany. This turnover is generated by approximately 614,000 people in about 6,100 companies. The sector has a predominant share of small and medium-sized enterprises. The main products are meat and meat products (45.9 billion EUR), milk and dairy products (28.1 billion EUR), baked goods (18 billion EUR), confectionery, long-life bakery products and ice cream (13.2 billion EUR), and alcoholic beverages (11.3 billion EUR)[5].

In North Rhine-Westphalia, the agricultural and food industries (including suppliers, processors, and retailers) is one of the largest employers providing work for around 400,000 people. Moreover, the food processing industry in North Rhine-Westphalia accounts for around 1,000 companies with almost 96,000 employees and a turnover of around 36 billion EUR. Finally, the food trade sector adds around 5,000 enterprises in NRW with over 100,000 employees[6].

In line with the importance of this sector, it is also part of the coalition agreement at federal level: by 2023, the BMEL is to develop a nutrition strategy to promote a healthier, more resource-efficient and plant-based diet[7].

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1 https://www.globalhungerindex.org/

2 https://www.mckinsey.com/industries/consumer-packaged-goods/our-insights/reducing-food-loss-what-grocery-retailers-and-manufacturers-can-do

3 https://www.ipcc.ch/site/assets/uploads/sites/4/2019/11/08_Chapter-5.pdf

4 https://www.nesta.org.uk/data-visualisation-and-interactive/innovation-sweet-spots-food-innovation/

5 https://www.bmwk.de/Redaktion/DE/Artikel/Branchenfokus/Industrie/branchenfokus-lebensmittelindustrie.html

6 https://www.mlv.nrw.de/themen/landwirtschaft/ernaehrungswirtschaft/ (03/2023)

7 https://www.bmel.de/SharedDocs/Downloads/DE/_Ernaehrung/ernaehrungsstrategie-eckpunktepapier.html

Focus of this whitepaper

In the framework of HiPerIn 2.0, it was important to understand where and what biotech can contribute to improve the sustainability of the food and feed sector. As had been analysed in the original HiPerIn project, the name-giving high-performance ingredients are found in many places in the food industry, from enzymes to colours, flavours, and nutraceuticals. Consequently, these have been investigated more intensively in the project. However, it must be stated that the food sector is so multi-faceted, that only small sections of it could be looked at more closely within the project. As our focus has remained on industrial biotechnology and HiPerIns, the HiPerIn 2.0 project did not focus on biotechnology in agriculture or plant engineering.

# Biotech in food and feed

How does biotechnology come into play? Around the globe and in many different cultures, fermentation is one the oldest "technologies" to produce food and beverages. Over thousands of years, helpful microorganism such as yeast, bacteria, and fungi have assisted mankind in making for example beer, wine, cheese, sauerkraut, kimchi, salami, and huitlacoche. They have enabled us to make food edible in the first place, making it tastier, and elongating its shelf-life long before artificial additives (or even supermarket shelves) were invented. These microorganisms often process easily available ingredients such as sugar and convert them, for example via alcoholic fermentation or lactic acid fermentation. Ever since Louis Pasteur in the 1850s identified und isolated the first microorganisms, his successors have been looking for new strains that offer better yields, easier growth, or new industrial applications. Often, however, the selection is limited to a few microbial strains as most companies prefer to work with GRAS organisms which have been "Generally Recognized As Safe" by the Food and Drug Administration (FDA) in the USA.

Among the multitude of possibilities, we decided on the following three areas in particular, which were rich sources of new developments in HiPerIn 2.0:

- **Provide food**
- **Process food**
- **Improve Food**

# Provide food

Feeding the growing world population is still a great challenge of our time. Although 10 % of the world's population are undernourished, an increasing standard of living in many countries has led to an increased demand for protein-rich food. Securing an adequate supply is thus an important aspect. The most prominent source of protein, animal meat, has come under heavy criticism for reasons of animal welfare and sustainability. Reducing meat consumption is virtually unavoidable if the sustainability goals in agriculture are to be met quickly. However, it is important to understand that high-quality protein in the form of meat is also a sign of prosperity and a high standard of living, which is still very desirable for many people.

In order to align these contrasts, new ways to produce proteins have been developed that promise to be more sustainable. Under the umbrella term "artificial meat", two main branches can be found: One branch consist of cultured meat which includes *in-vitro* meat and single-cell protein. On the other branch, plant-based meat analogues are on the rise (Mateti, Laha, & Shenoy, 2022). And maybe the big money will soon be made (or lost): alternative proteins have seen a tremendous 800% increase in venture capital between 2017 and 2021[8].

One way to produce protein is the cultivation of single-cell microorganisms, so-called single-cell protein (SCP). A whole range of different organisms can be used, from yeast to bacteria, algae, and fungi (Ritala, Häkkinen, Toivari, & Marilyn, 2017). Accordingly, there are hardly any limits to the substrates used as long as they are cheap. Originally conceived 50 years ago and often only used as animal feed, this type of food production has received new attention in recent years, especially with regard to (biotechnological) improvements for use in human nutrition.

In contrast, *in-vitro* meat seems to be the more sophisticated way to replace animal meat, while keeping closest to the original substance. Animal cell cultures are used to reproduce muscle and fat tissue of the desired animal species as accurately as possible. For the consumer, this should ultimately mean a barely perceptible change to their beloved steak, but without slaughtering an animal for it. This development is currently being driven forward by large investments and has gained a lot of attention. In the process, hurdles such as expensive culture media, sensitive cells and complex handling are increasingly being addressed. However, it is still unclear whether such a yet complex process can even come close to replacing the huge amounts of meat, considering the fermentation capacities required alone.

Biotechnological substitutes are also being increasingly researched for other animal products. Biotechnological production ways have be reported for the egg white protein ovalbumin using *Trichoderma reesei* (Järviö, 2021), for animal-free milk and animal-free cheese products (Hettinga & Bijl, 2022) as well as non-animal whey protein. In the last three years, strong movements and investments could be observed in these areas[9].

In summary, the path to the supply of high-quality proteins will have to be more diverse in the future if it is to be sustainable. Agricultural land, which has so far been used mainly for the provision of animal feed, could then contribute directly to human nutrition, or be used in parts for nature conservation.

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[8] https://www.nesta.org.uk/data-visualisation-and-interactive/innovation-sweet-spots-food-innovation/

[9] https://www.brain-biotech.com/press/brain-biotech-and-formo-strategic-partnership-of-european-biotech-experts-for-the-production-of-animal-free-milk-protein

# Process food

For food processing, enzymes have proven to be efficient workhorses for decades and can be found in numerous processes. For many industrial enzymes, their production is well-established, cheap, and established at large scale. Accordingly, it is debatable if these bulk products can still be seen as real HiPerIns in these days, but they certainly have paved the way for biotechnological processes in former times.

The range of application of enzymes is impressive (Raveendran, et al., 2018): α-amylases and glucoamylases which are applied in starch processing, as flour additive, and in brewing beer. Proteolytic enzymes such as chymosin are used to produce cheese, beta-galactosidases are used to remove lactose. Lipases are known to modify the properties of lipids, so they are used in the production of different plant oils (e.g. from sunflowers, peanuts or olives). Also in dairy industry, lipases are used to enhance specific flavour characteristics of cheese or to increase the "creaminess". Lipases and esterases are also well-known for their enzymatic synthesis capabilities for flavours and other complex molecules where they present an alternative to chemical catalysts. In recent years, even more possibilities have become widely available for finding enzymes, improving them, making them more robust, and easier to produce on a large scale (Fasim, More, & More, 2021). It goes without saying that biotechnology plays the key role in this regard by identifying new enzymes and genetically engineering better enzymes (Zhang, Geary, & Simpson, 2019). Digital methods such as computer-aided search algorithms, 3-D structure predictions, and big data assisted process optimization are also making major contributions.

As a last significant contribution for food processing, biotechnological experts also have the important function of preventing contamination of foods through suitable measures, detecting contaminations, assisting quality control, or, in worst case, combating it as soon as possible at an early stage. Since food producers are highly vulnerable to contamination, they have well-equipped microbial laboratories as well as great expertise in sterile work, which gives them a good starting point for the coming transformation.

# Improve food

Humans have improved upon foods throughout history – by cooking meat, adding herbs for taste, or fermenting produce to yield not only longer lasting, but also better tasting food. In today's food industry, modern methods and ingredients have added precision and much more variety to this improvement. While food can still be cooked from scratch, the convenience food sector has seen a rapid increase in the last decades. In many countries, Germany included, this means that consumers for customers encounter many foods only in a more or less processed form. Through advertising and packaging, consumers are given an image that only vaguely corresponds to the actual production and ingredients. Safety and satiety have long been the focus of the food industry and its consumers, but for some time now the latter is being overachieved. Many processed foods contain too much salt, sugar, and fat and tempt us to eat far beyond just meeting our nutritional needs. If we rethink the food industry and want to replace meat as much as possible, for example, this will lead to even more processed foods. Nevertheless, it must be emphasised that the food industry – with the help of biotechnology - has reliably made it possible to provide safe and nutritious food for many people. So, as is so often the case, food processing is a matter of getting the balance right.

Many products of the food industry, as described, cannot be produced without microorganisms. Today, biotechnology has a whole range of methods at its disposal to specifically modify and improve food, including nutritional values, taste, smell, shelf life, texture, and health benefits. It has already been mentioned above that enzymes such as proteases or lipases can be important biotechnological HiPerIns which introduce these properties during the manufacturing process. Accordingly, processing and improvement overlap sometimes (e.g., for lactic acid fermentation of food which also greatly increase the shelf live), whereas in other processes, ingredients such as lactic acid are produced separately and added later. Also for newer products, biotechnology can make a big contribution to making artificial meat taste better and achieving a more meat-like texture. Health-promoting ingredients are currently very popular to improve sports nutrition or to better adapt the nutrition of certain age groups to their needs, e.g., to prevent malnutrition among senior citizens[10]. Biotechnology can help to personalize the nutrient to an individual's characteristics, such as age, lifestyle, genetics, gut microbiota, and metabolism.

Numerous biotechnological HiPerIns are already in use to make our food tastier, more colourful, and healthier. Biotechnology can provide **flavour** to food. Yeast extract has for years been a popular additive to improve the taste of processed food. Considering the high-price segment, flavours such as vanillin or raspberry are exceptionally good examples of biotechnologically produced high-performance ingredients. Even though they are used in the food industry, flavours represent their own market segment in the scope of the HiPerIn 2.0 project and are accordingly dealt with in their own white paper[11].

A prominent example of biotechnological **food colorants** are carotenoids. Astaxanthin, for example, enhances red pigmentation in species like salmon and shrimps and gives these species their signature colour. It is usually taken up through the animal's diet, and in aquaculture used as feed supplement to ensure the farmed animals have the bright colours consumers associate with fresh salmon or shrimp. Demand for these carotenoids as feed ingredient has greatly increased in recent years, triggering increased research into improving their production. Successful approaches to establish a biotechnological production using *Corynebacterium glutamicum* were reported (Henke, 2016) and are in the process of being scaled up.

Another important market for biotechnological processes includes those **vitamins** which, as complex molecules, are difficult to synthesise chemically. This is especially true for the essential vitamin $B_{12}$, whose complete chemical synthesis required 72 steps, and which is nowadays almost exclusively produced biotechnologically in a single fermentation step (Balabanova, 2021). Although

10 https://ec.europa.eu/research-and-innovation/en/projects/success-stories/all/tasty-and-nutritious-food-senior-citizens
11 https://www.clib-cluster.de/de/whitepaper/#toggle-id-1

it is produced with genetically modified organisms, this does not require labelling because the final product is free of these GMOs. In the food industry, vitamin $B_{12}$ is mainly used as a food supplement which is very important especially for a vegan or vegetarian diet. However, even for such a well-known process, there are still unresolved issues that could be improved (Fang, 2017).

For a healthier diet, biotechnology can also provide new **sugars** that have a sweetness similar to saccharose but are metabolised less efficiently and thus have fewer calories. Existing sweeteners are not ideal because they either have strong off-tastes (like Stevia) or have been reported to mess with the sugar sensing in humans. In particular, the monosaccharide allulose and the disaccharide cellobiose which could replace lactose have made great strides on their way into the market.

Within the framework of the project, it has once again become clear that the provision of high-quality ingredients for food is an exciting market of the future for biotechnology, in which it can play to its strengths.

# Feed

Due to the sheer size and sustainability impact of the livestock sector, improving the feed industry is an important lever to achieve the Sustainability Goals. The global animal feed market had a total value of 482.1 billion USD in 2021[12]. The demand for animal feed obviously correlates with the demand for animal products such as meat and dairy products. The global meat production continues to grow, even though this growth has slowed, and the discussion whether to reduce meat consumption is very present in Western societies. Compared to the 1960s, global meat production has increased fivefold[13].

Comparable to the food sector, the two developments discussed there can also be observed for the feed sector. Leaving aside the theoretically feasible genetic modification of animal feedstocks, or indeed of the animals themselves, biotechnology innovations can replace problematic feed sources, can improve feed quality, and reduce application of antibiotics, as well as reduce the environmental impact of animal farming.

For a long time, biotechnology has supported animal feeds through improving nutrient value as well as the digestibility of low-quality feeds. This enabled livestock farmers to keep animals fed throughout periods when less fresh feed was available, concentrate and keep more animals in a smaller area, and speed-up and increase their weight gain. Unrecognised microbial fermentation processes have been used to preserve fodder as silage and to initiate the digestion of biomass outside the animal. This is particularly relevant for monogastric animals such as pigs and poultry, which cannot digest poor quality feed, unlike ruminant animals. Nowadays, this can also be done by adding certain enzymes such as cellulases, which can break down the cell walls of hard-to-digest feed. Phytase is a vital enzyme that poses nutritional advancement properties in mono-gastric animal feeds: it hydrolyses phytate, the major form of phosphorus in plant tissues, and thereby makes phosphorus from the diet available for the nutrition of monogastric animals.

As discussed above, for human diets, biotechnology can help also to ensure a more sustainable protein supply for animals by growing single cell proteins, microorganisms, or insects. Particularly noteworthy, for example, is the feeding of aquaculture with biotechnologically produced feed instead of fishmeal, which greatly improves the sustainability and reduces the pressure on fish stocks. It can even improve the yield ratios of the farmed fish.

The addition of free amino acids to animal feed has major positive effects: First, they increase the nutrient value and thereby decrease the total demand for feed. As an improved balance between all amino acids means that less total protein is necessary, this addition will also reduce nutrient excretion by animals (especially nitrogen compounds). Biotechnology can provide all four essential amino acids such as lysine, methionine, threonine, and tryptophane which are added to animal feed to compensate for the lack of these nutrients in plant feed and, thereby, to increase the productivity (Sturm, Banse, & Salamon, 2022). Indeed, the industrial fermentative production of

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[12] https://www.businesswire.com/news/home/20220513005430/en/Global-Animal-Feed-Market-2022-to-2027---Industry-Trends-Share-Size-Growth-Opportunity-and-Forecasts---ResearchAndMarkets.com

[13] https://www.fao.org/3/cb9427en/cb9427en.pdf

amino acids was one of the first large-scale industrial biotechnology cases and has been established more than 50 years ago and has evolved into a multibillion business (US$19.5 billion in 2017) (Wendisch, 2020).

Even if their use urgently needs to be better restricted, the success of the use of antibiotics (which are also HiPerIns) in animal breeding is demonstrated. To curb their use, which carries with it the danger of creating antibiotic resistance in human pathogens, new methods instead aim to strengthen the resistance of the animals through tailor-made diets by probiotics and to use antibiotics only in a targeted manner. There are also tendencies to feed prebiotics which promote an improved rumen microbial flora to improve feed utilization.

In the long term, it remains to be seen if or at least to what extent animal farming itself and inevitably also the feed industry will be a dead end. For the foreseeable future, animal farming will continue to exist, so improvements need to be made as soon as possible.

# Cross-cutting topics

In the HiPerIn 2.0 project, CLIB has analysed the influence of five cross-cutting topics on the six target markets and the biotechnology sector as whole. The basic idea was that nowadays the success of products is no longer determined solely by the underlying technology, but that external factors play an important role. The role of these cross-cutting issues in the food and feed sector will be analysed in the following paragraphs.

## a) Regulatory frameworks

For the food and feed market, the cross-cutting topic "regulatory framework" turned out to be crucial. Although new technologies do not automatically pose a concrete risk, the legislator would like to rule out potential risks as far as possible. This is particularly true for the food market: governments must guarantee food security as well as food safety as main part of their mandate. At least since the Novel Food Regulation, new products face a major regulatory hurdle if they are to be introduced into the EU market. As stated, "Novel Food is defined as food that had not been consumed to a significant degree by humans in the EU before 15 May 1997, when the first Regulation on novel food came into force."[14]

Well-intentionally established as protection for European consumers, this regulation has also been accused to inhibit innovations. In the last three years, it has been often mentioned that the necessary process for admission of a novel food not only increases the costs, but also delays the market entry, and sometimes even prevents it altogether. Even large companies are looking for ways to avoid their products being labelled as novel food,

[14] https://food.ec.europa.eu/safety/novel-food_en

and this can have serious consequences for start-ups which do not have the resources to endure the admission process. This is not without consequences: In a globalized world, distortions occur when products that have been used in other parts of the world for years are not (yet) approved. Consequently, some companies are looking to serve markets other than the EU.

For the food and feed market, this is not the only conflict which ignites on the different preferences for safety concerns on the one hand and a drive to innovate on the other. In general, the question of how and when "genetic engineering" can be used, when and whether it must be declared, or whether it will be simply ignored, remains problematic. With Regulation (EC) No 1829/2003 on genetically modified food and feed, the European Parliament has declared rules on how genetically modified organisms (GMOs) are authorised and supervised, and on how genetically modified food and animal feed is labelled[15]. Similar to the Novel Food Regulation, this law is also often perceived as a hindrance and sometimes leads to seemingly bizarre detours to obtain a GMO-free label. It should also be seen against the background of a debate between science and the public that has gotten out of hand. To illustrate the disagreement in this area, the definition of a GMO alone is subject to heated debate. In recent years this definition has been criticized, as it sanctions targeted and controlled gene modifications, but accepts undirected methods in plant breeding as natural.

While this debate may seem alienated at times, it actually affects the lives of many people. As a prominent example, genetically modified "Golden Rice" was supposed to remedy the vitamin A deficiency in the developing world and promised to save and improve thousands of lives every year. Although this technology has been developed since the turn of the millennium, first significant amounts were only harvested in 2022, not least because of ongoing debates. In addition to their general concerns about the release of GMOs, opponents strongly criticised that Golden Rice does not solve the real problem of malnutrition and that it makes farmers dependent on large corporations and their patents. This long-deadlocked situation shows the importance of a proactive exchange between stakeholders. As a positive example, impressive regulatory progress has been made in a similar topic regarding the application of nanomaterials in the food sector which may serve as a role model for a successful dialogue between the policy makers, customers, and technology developers.

One of the great challenges of the next few years will be to master the tightrope walk between consumer safety and innovation in order to be able to continue to influence the world market in both respects for the better.

[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32003R1829

## b) Public perception

As already mentioned, the subject of food is an extremely sensitive one for consumers (Siegrist & Hartmann, 2020). Food is not only nourishment, but has an emotional aspect of culture, family, and pleasure. During the discussions within the project, it was noted several times that, apart from medicines, there is no other area in which innovations are viewed with such suspicion. These reservations may seem inappropriate or even ridiculous to scientists, but they should be addressed sensibly. Obviously, new technologies cannot be enforced against public reservations by force. Although customers are often hesitant towards new developments in the food sector, it is quite possible to convince them with suitable arguments (e.g. for more animal welfare) or to arouse their curiosity. Consequently, the consideration of public perception is crucial for this market segment.

As the sub-contract study in HiPerIn 2.0 showed, no general statement can be made that perfectly depicts "the consumer": age, level of education, gender, nationality, and personal experiences all influence the perception of new technologies. Nevertheless, it must be said that many of the contributions made by biotechnology in the food sector (and, even more pronounced, in the feed sector) are not recognizable to most consumers. If the product itself is clearly recognizable as new (such as burger patties made from cultivated meat), the consumer will notice it without a doubt. However, if the biotechnological contribution concerns “hidden” ingredients such as flavours or provides advanced production methods, this is unlikely to be noticed. This is where regulation comes into play, which must help consumers to make sustainable and healthy decisions, for example through trustworthy labels, but also through a general design of the framework conditions.

A successful communication with the public is a central component and a major challenge at the same time. The successes and possibilities of biotechnology have in the past decades not been showcased, but to the contrary, been hidden away, to be noticed as little as possible. If the transformation to a bioeconomy and a more sustainable food sector is to succeed, a change in strategy will be necessary. Only a public aware about biotechnology, informed about its benefits, will be willing to accept the new food coming to its plates.

## c) Digitalisation

As every industry, the food industry is also facing major upheavals due to digitalisation. Analogous to the term Industry 4.0, the term “Agri-Food 4.0” has been suggested (Lezoche, Hernandez, Díaz, Panetto, & Kacprzyk, 2020) which includes many different areas from farm to fork, for example the application of intelligent sensors in farming, the use of big data for improved predictions, RFID technology to improve the traceability of ingredients, or blockchain to ensure complete control of the value chain logistics (Creydt & Fischer, 2019). It almost goes without saying that the biotechnology applications described above also massively benefit from digitalisation (just think of synthetic biology), but this finding is not limited to a specific market segment. Even if we were not able to observe any special digital developments for the food & feed sector, it cannot be stressed enough that digitalisation is coming faster than expected and will offer more opportunities than dreamed of... if you don't oversleep this development.

## d) Circularity & End-of-life

For plant-based food, the end-of-life concept is rather negligible in the food sector. Being of purely biological origin, it degrades quickly in the environment. In contrast, animal products are subject to special legislation, so that further use is often ruled out and, on the contrary, disposal is necessary. The end-of-life topic becomes more important when it comes to supporting technologies such as seed protection, agriculture, and packaging. For the feed sector, massive efforts through tailored feed are being made to make animal excreta less harmful to the environment by minimizing the release of methane, nitrogen, or phosphates into the environment. There are also biotechnological approaches to utilize such side streams and, thereby, to minimize waste streams.

For a circular economy, the food and feed sector is of great importance – both as a challenge in terms of achieving sustainability, but also as a source of feedstock. It is estimated that 30-40 % of food is wasted along the entire chain from field to consumer. For more sustainability, it is therefore crucial to reduce the amount of food wasted and use the remaining waste streams effectively. On the one hand, there is the possibility of converting residues into food, on the other hand, residue flows from the food sector can be valuable raw materials for other industries. In principle, many waste materials can be converted into food by microorganisms, or insects, although the regulations (and especially waste legislation) still set narrow limits here. As already described above, it is urgently necessary for the legislation to take current technical developments into account. Even $CO_2$ can serve as a feedstock, for certain microorganisms, which can then be further processed into edible biomass or feed.

This massive potential of raw materials also shows how the transformation can spark new value creation networks. Traditional food processing companies can suddenly become suppliers of raw materials for the chemical industry. This can mean an opportunity for some companies if traditional but weakened sales markets are replaced, or market segments shift, but also means new competition for the animal feed industry, which has so far used the food industry's processing side streams as animal feed. In general, the HiPerIn 2.0 project has shown (as the RIN project did before) that very few raw material flows in the food industry are simply disposed of, but that most of the time, there is already a use for them. These residues are therefore rarely available for free, although they can quite often be used more profitably through biotechnology. In NRW, several initiatives and even startups act as platforms for food raw materials and are helping to connect raw material suppliers and food producers.

We noticed with concern that many companies (in particular, many SME) are still unaware of the upcoming change to the bioeconomy, the implications for existing business concepts, and the opportunities offered by biotechnology. But we also met many companies in the food sector that were actively looking for a network to find new strategic partners, create new alliances, and invest in new business models.

# Outlook

The food and feed sector are important backbones of the NRW economy. However, the food sector is facing many changes. In addition to the transformation to a circular and sustainable economy, eating habits are also changing – meaning the sector has to change and innovate accordingly. Biotechnology has always been and will continue to be an integral part of the food sector as it can help to feed the growing world population by directly producing new protein sources (as SCP, microalgae, or cultivated meat) or by making plant-based proteins tastier, healthier, or easier to process.

From a consumer point of view, many of these innovations can happen behind the scenes, almost unnoticed. Where innovations are noticed by the customers, they tend to be more polarizing than in other market segment since food security and food safety are fundamental needs of societies, and indeed a human right. In a circular economy, the food and feed industry will be both a buyer and a supplier of residues which is why companies must network with completely new stakeholders to a greater extent than before.

None of the other market sectors considered has shown be to be so closely intertwined with the cross-cutting issues. Future successes of biotechnology in this sector therefore also require a corresponding technology-open regulation and a successful exchange with the public if this branch is to continue to be one of the employment engines for NRW.

To achieve a circular bioeconomy, NRW has a strong base with players from the scientific community, the food industry, and other interlinked industries such as the chemical industry. This means that the conditions are excellent for managing the transformation here locally and serving as a model for other regions. It has been shown that crystallisation points for new ventures are forming both among start-ups and among the long-established food processing companies.

# Cluster Industrial Biotechnology e.V.

CLIB (Cluster Industrial Biotechnology) is an international open innovation cluster of large companies, SME, investors, academic institutes, and universities, as well as other stakeholders active in bioeconomy. The cluster comprises over 100 members with a share of about 25 % international members. The overall goal of CLIB is to network stakeholders in Germany and beyond and to identify new opportunities for innovation, projects, and business. Through this, the cluster develops cross-sectoral biotechnological solutions for sustainable processes and products. CLIB is a non-profit association, with its members shaping the cluster's interests and activities. The cluster is involved in several associated programs which cover different aspects of bioeconomy and invites members to become involved. To this end, CLIB organises several events throughout the year: the annual CLIB International Conference (CIC), the CLIB Networking Day (CND), forum events, topic-specific workshops, and dedicated small partnering meetings.

# HiPerIn 2.0

HiPerIn 2.0 is a project funded by the Ministry of Economic Affairs, Industry, Climate Action and Energy of the State of North Rhine-Westphalia (MWIKE). HiPerIn 2.0 reflects the rapid change in biotechnology and includes cross-cutting issues which had been identified and validated by CLIB and in an exploratory phase. The increasing digitalisation of biotechnology, the renewed concept of a circular economy, the end-of-life debate, the public perception of biotechnology, and increased regulatory requirements are cross-cutting topics which are of interest to many stakeholders. CLIB pursues the topics of biosurfactants, textiles, flavours and fragrances, and food/alternative proteins. Another focus in the HiPerIn 2.0 project is the support for project consortia and the identification of potential funding lines.

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