European Technology Platform

Strategic Research & Innovation Agenda - 2021 Update

Food for tomorrow's consumer

Step-changing the innovation power and impact of the European food and drink industry to the benefit of a sustainable food system

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Editorial and Foreword for the 2021 Update

The 2016 Strategic Research and Innovation Agenda (SRIA) for the European Food and Drink Sector was created with the 'Horizon Europe' Research and Innovation (R&I) Framework Programme still 4 years into the future. Whilst we are very pleased with the impact that the 2016 SRIA has had on the development of the objectives for 'Horizon Europe', some of the developments that have occurred over these 4 years have led us to rethink some elements and update the SRIA.

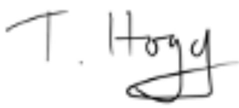
Certainly, the release of the EU 'Green Deal' with its key emphasis on a circular economy and its explicit 'Farm to Fork' strategy is one such development. It must be said that on reviewing the original SRIA 4 years later, it is heartening to note how pertinent it still is and that the updates required are more in terms of emphasis than of real strategic substance.

Indeed, in addition to the many impacts that the COVID-19 pandemic is having on food and drink businesses, many of the challenges that it poses emphasise the need to step up our efforts in R&I towards the vision that we already have presented in our 2016 strategy. The Implementation Action Plan that was developed in 2018 from the 2016 SRIA has also been updated accordingly.

We believe that with this update we can continue to provide important guidance to the European Commission, Member States, the food industry and the wider research community interested in food, to make a real difference to the Food and Drink Sector. The priorities that we have identified are more relevant than ever.

Prof. Dr Gert Meijer, Chair

Prof. Dr Tim Hogg, Co-Chair



Foreword

This Strategic Research and Innovation Agenda for the European food and drink industry was produced in a group effort by the members of the European Technology Platform (ETP) 'Food for Life'. The strategy development was preceded by a significant reorganization of the ETP 'Food for Life' that led to a new leadership team being put in place in October of 2015. This team formulated a work plan to develop a new Strategic Research and Innovation Agenda (SRIA) by the autumn of 2016.

To develop the Agenda, five scientific working groups were founded, each consisting of recognized experts from industry, academia and research institutions with a proven scientific track record. The workgroups met for two full day workshops in January and March of 2016 to develop and recommend new actions to be taken to tackle emerging challenges in the Food and Drink Sector. A workshop was held in May of 2016 to further refine the underlying strategy governing the call for action of the new ETP. Further revisions were developed in June and July 2016 resulting in a draft SRIA document.

The ETP engaged in a consultation process in August 2016 with key stakeholders to obtain feedback and further shape the draft SRIA document. The goal of these consultations was to set priorities and align activities with national initiatives, which will also form the basis for the Implementation Action Plan (IAP) to be developed in 2017.

Jointly with the Scientific Committee, the Leadership Team has carefully analysed the more than 20 contributions submitted in response to the public consultation. The very valuable input received has been integrated in this final version of the SRIA which contains key research and innovation action propositions that, if implemented in the remaining timeline of Horizon 2020 and thereafter, will make a real difference to the Food and Drink Sector.

Prof. Dr. Gert Meijer, Chair

Prof. Dr. Jochen Weiss, Co-Chair

2.Strategic Considerations

2.1. State of Play of the Food and Drink Sector

2.1.1. Economic Importance

The Food and Drink Industry is the largest manufacturing sector in the European Union (EU) in terms of turnover (€1,192 billion), added value (2.1% of EU gross added value) and employment.[1] It currently employs an estimated 4.72 million people, and it is the biggest manufacturing employer in half of the Member States. In each Member State the Food and Drink Industry ranks among the top three manufacturing industries in terms of turnover and employment.

The Food and Drink Industry is a highly diversified sector both in terms of product types (sub-sectors) and the dimension of the companies, many having just a few employees and others employing thousands of workers. Today, about 99% of food and drink companies in Europe are small and medium sized enterprises (SMEs). These generate 47.5% of the sector's turnover and provide over 60% of its employment, mostly in rural areas. SMEs are often more flexible than large scale enterprises and are therefore able to react more quickly to market changes, making them first indicators of potential future developments. They are also more vulnerable to supply chain challenges, as was seen during the lockdown phase of the COVID-19 pandemic. The special features of SMEs in the Food and Drink Sector often represent and extra burden to engage in R&I activities. These obstacles, and how to overcome them, have been extensively reviewed in a separate ETP Publication.[2]

EU food and drink exports nearly doubled over the past decade to a record of €110 billion in 2019, yielding a positive trade balance of almost €36 billion. Globally, that makes the EU the leading food and drink producer in terms of exports. Currently, more than one quarter of European food and drink products are sold to non-EU. The EU ships foods and drinks to all key global markets with market shares continuing to increase.[1]

Food and drink products represent the second largest expenditure of households in Europe totalling an estimated €1,155 billion. In 2017, the share of household expenditure on food and drink products (13.8%) remained stable compared to the previous years and varied from 10% to 31% across Member States [1], similar results have been observed in the United States of America (Fig. 1). Agricultural prices are more volatile than food manufacturing prices and food prices paid by consumers. Food manufacturing prices include other input costs than agricultural raw materials. Over the past 5 years, there has been a decline in profit margins for the food and drink industry and food prices paid by consumers (i.e., retail prices) have grown only slightly (1 - 1.5% per year) which has contributed to low inflation rates.[1]

However, the sector is about to undergo a startling transformation caused by a great variety of different drivers; amongst them a continued growth of the global population, climate change, water scarcity, an increased urbanization, and political instabilities fuelled by income inequality as a result of globalization (Fig. 2 and 3). The expected disruption will not leave Europe unscathed, but it also offers opportunities for growth.

4.2 million jobs

Recent events have raised further challenges to the economic sustainability of food and drink companies in Europe. Although the European Union and the United Kingdom reached a Trade and Cooperation Agreement in December 2020, the negative consequences for the agri-food sector should not be underestimated. Trade tensions at a

[1] FoodDrinkEurope (2019). Data and Trends of the EU Food and Drink Industry 2019. FoodDrinkEurope publications: https://www.fooddrinkeurope.eu/uploads/publications_documents/FoodDrinkEurope_-_Data__Trends_2019.pdf

[2] ETP 'Food for Life' (2017). Implementation Actions for the SMEs of the Food and Drink Sector. http://etp.fooddrinkeurope.eu/news-and-publications/publications/21-implementation-actions-for-the-smes-of-the-food-and-drink-sector.html

There is an urgent need for increased private and public investments in research and innovation in order to secure Europe's role as a leading global provider for safe, healthy and sustainable diets.

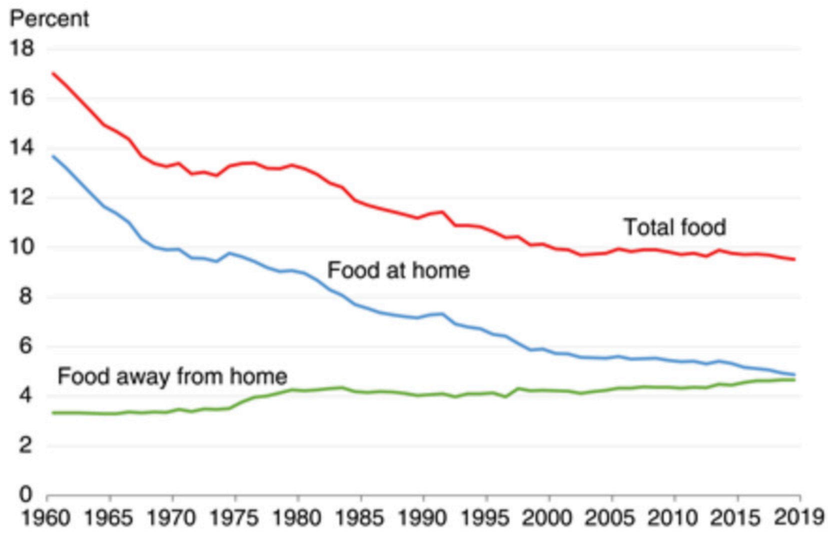


Figure 1. Development of average percentage of household income spent on food from 1960 to 2019. Adapted from USDA ERS, Food Expenditure series[1]

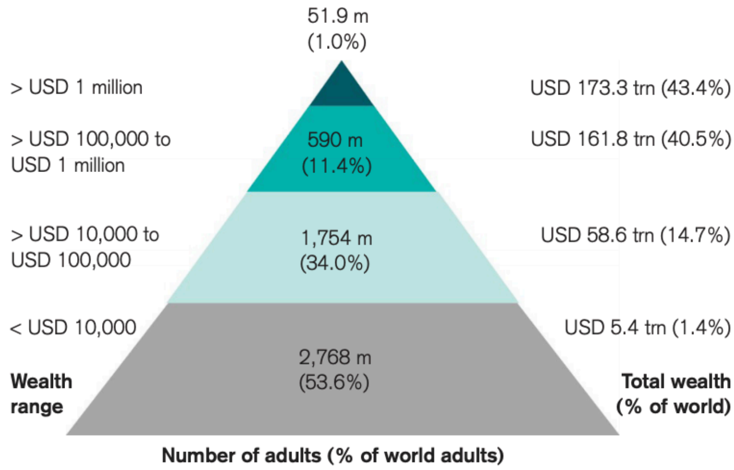


Figure 2. Wealth distribution as a function of percentage of adult population. Adapted from Global wealth report 2019 of the Research Institute.[2]

global level are leading to new rules being applied that clearly affect the balance of food production and food prices as they have been known in the last decade. More recently, the economic shock caused by the COVID-19 pandemic has been deeply felt by food and drink businesses. SMEs are feeling the effects of COVID-19 most acutely, in particular those supplying to the hospitality, tourism and leisure sectors, creating serious economic damage to the overall Food and Drink Sector. Labour shortages within business and the knock-on effects of the difficulties in agricultural production (e.g., workforce) put the whole food supply chain under considerable pressure. Without help, many of these SMEs will go out of business and many more will find it hard to survive the coming months and years, putting countless jobs and livelihoods at risk. The COVID-19 pandemic has also challenged the way we understand global food chains and in particular their robustness. It has certainly highlighted the need for policy makers and all partners in the food chain, to strengthen our common preparedness for any potential future shocks and challenges to providing access to safe food and drink for all. Europe is better positioned than any other region to do this in a manner that respects and maintains the integrity of ecosystems and environments. The notion of long-term sustainability is deeply anchored in the culturally-diverse European citizenry. It has taken root in local and individual lifestyles and given rise to an increasingly ethical consumerism. Moreover, there is a desire to adopt a healthier lifestyle in order to be able to live a more active and fulfilled life, and food is seen as a crucial means to achieve this. At first glance, the changes foreseen for the Food and Drink Sector might appear to be somewhat disruptive for established businesses. However, looking to the future, they potentially offer great opportunities to increase competitiveness and build a more trusted and secure European food supply if appropriate decisions are made and actions are taken. With this Strategic Research and Innovation Agenda (SRIA), the **European Technology Platform 'Food for Life'** looks forward to 2030 and issues a call to decision makers to take immediate actions to improve the global positioning of this important economic sector for Europe.

[1] USDA Economic Research Service, ERS (2020). Development of average percentage of household income spent on food from 1960 to 2019. Food Expenditure series. https://www.ers.usda.gov/data-products/ag-and-food-statistics-charting-the-essentials/food-prices-and-spending/

[1] Credit Suisse Research Institute (2019). Global Wealth Report 2019, http://www3.weforum.org/docs/GRR/WEF_GRR16.pdf

Taken together, the food system is currently under considerable pressure, and Europe risks losing its leading position in food manufacture.

2.1.2. Food Systems

In simple terms a food system is a network that integrates the food value chain up to consumption and goes beyond the farm to fork principle by including all activities, actors, drivers, boundaries as well as input factors and various dimensions and forms of outcomes.

As a concept, a food system is assumedly complex, in that there is a high degree of interconnectedness and interdependency of the various elements and continuously changing factors that influence it. The completeness of the description of food systems and the understanding of the interactions within them, is the basis for their successful transformation into sustainable systems. The detailed representation of food systems requires a high degree of interdisciplinarity and the inclusion and consideration of different scales, e.g., from local to global. The study of food systems in their complexity has the potential to precisely predict the effects and impact of changes in the system and provides the basis for responsible and transparent decisions.

The activities in food systems encompass primary production, processing, packaging, distributing and all steps up to consumption of food and comprises the diverse set of institutions, technologies and practices that execute and influence this material flow. Especially at the level of primary production, food systems intersect with other systems in areas such as agriculture, aquaculture, and fisheries. Food systems are integrated into the bioeconomy and use a significant share of global biomass, and are therefore also linked to other value chains that are based on biomass or produce biomaterials.

It is essential not to assume a linear sequence of discrete activities and processes in food systems, but rather that all the individual stages are interrelated. For example, food consumption patterns are often neglected as important drivers for activities at earlier stages in a food value chain. Furthermore, at the level of a food value chain, the principle of circularity of process steps must be integrated with the aim of avoiding waste and losses.

Food systems are based on various input factors, e.g., natural resources and social, political, regulatory and economic boundaries, which influence how they function. A broad array of factors that are of general importance for societal development influence the function of food systems, in particular population growth, urbanization, income distribution and social norms and values. Food systems influence not only what is being consumed and how it is produced and acquired, but also who is able to eat, and how nutritious their food is.

It is expected that technical innovations, research investments and breakthroughs will be both important drivers and enablers, which will allow the transformation of current food systems into sustainable ones. Furthermore, joint learning by actors in the system, according to the principle of systems thinking is the basis of empowerment of communities and opens up the perspective of evolutionary changes.
Food Systems generate outcomes which are strongly connected with health and sustainability and are demonstrated in various dimensions such as food and nutrition security, environmental security, and social welfare. These outcomes are connected with various priority topics like healthy and affordable diets, resource efficiency, climate-smart and environmental-friendly.

Sustainable food systems are those food systems that achieve food and nutrition security and healthy diets while compensating for negative environmental impacts and improving socio-economic welfare.

2.1.3. Global Position

The European Food and Drink Sector is unique in its very high regional and continent-wide cultural diversity, which is not only a source of pride and a key element of identity for many citizens, but also provides a framework ideally suited to foster creativity and innovations. The great variety of regional culinary traditions that have developed across Europe over the centuries ensure that the Food and Drink Sector is deeply embedded in society. The sector profits from a high-quality science ecosystem in the food, nutrition, sustainability and related areas formed by top level industry players, academic and research institutions. These have a proven capacity to carry out ground-breaking research and development activities of real consequence. Through this industrial and science ecosystem, the sector is supplied with a well-educated workforce that is highly motivated. Europe is also very much a leader in the development and implementation of effective regulations to ensure that its food supply is of the highest safety and quality. In this respect, the continent also benefits from its excellent scientific and educational base.

The ability to combine high standards with diverse and interesting food and drink products makes the European Food and Drink Sector competitive and its products very desirable around the world. With a clear focus on health and safety, the European food system is capable of formulating new food solutions and ensuring that consumers have access to a balanced diet.

Finally, through its diversity, the European food system is able to react and rise to new challenges, which is not the case in other, more “food-uniform” regions of the world.

Yet, the sector has been suffering the effects of a substantial lack of consumer trust. There is an increasing perception that its actions can be less than transparent and do not always benefit consumers but are mostly driven by a desire for higher profit. Moreover, the sector is generally thought to create products that do not effectively promote health - and in some cases even contribute to the development of non-communicable diseases. In addition, failures leading to food safety incidents and outbreaks also contribute(d) to a diminished trust on the part of the consumer.

The development of an unfavourable opinion towards the sector is often amplified by a (social) media environment emphasizing a disconnect between the interests of consumers and the activities of food manufacturers. Social media empowers consumers to communicate with each other in a fast and efficient way regardless of time and location, with all inputs having equal status, and this often amplifies critical or negative opinions. Rather than embracing social sciences to develop new ways to better understand the diverse needs and concerns expressed by consumers, and involve consumers as active agents in food production, some sector players focus solely on the development of better technical solutions which consumers are likely to reject due to the trust issues described here. In general, the sector lacks the deep understanding of what is happening in the consumer domain and how consumers’ lifestyles evolve. This lack of understanding works as a barrier to finding solutions that support consumers’ perception of value creation and empowers them to make choices that benefit well-being and health.

For these reasons, the rate of adoption of otherwise promising new processes is low. This leads to a reluctance to invest in food research, even though such investment is urgently needed to create new solutions for consumers.

The consequent reluctance of investors to fund exploratory and potentially risky ventures, closes the vicious circle in which an insufficient number of research results are transformed into innovations. The low degree of innovation then causes value additions to be low, resulting in smaller profits, which is a further disincentive to investment in research

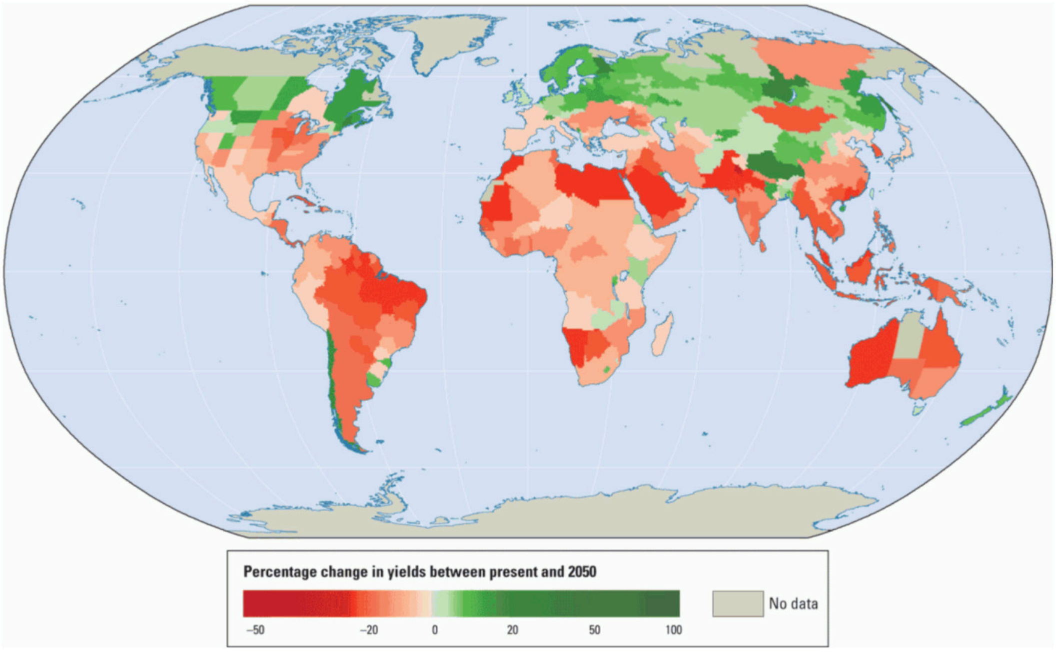


Figure 3. Development of agricultural production by 2050. Areas marked in red will experience a decrease in agricultural yields while areas marked in green will experience an increase. From World Economic Forum.*

and development. As such, the sector is in danger of experiencing a downward spiral that is accelerated by price decays.

A lack of new business models, in which consumers become an active part of the food supply system, and an insufficient integration of players ranging from primary production to retailers, similarly contribute to the perceived stagnation. This is exacerbated by an increasing dependence on raw material imports, making the sector very vulnerable to commodity price fluctuations.

Taken together, the food system is currently under considerable pressure, and Europe risks losing its leading position in food manufacture.

Notwithstanding this somewhat bleak assessment, there is a great number of opportunities on the horizon that– if materialized – could help the sector regain strength and prosper, and thereby benefit the European citizen. In general, the Food and Drink Sector has a tremendous potential for growth fuelled by the growing global population and the emergence of new markets with consumers who are becoming more affluent. Moreover, food is a unique product, it is essential to life and has strong physiological functions that influence health and wellbeing. It is proven that food plays an important role in both the development and risk reduction of non-communicable diseases. Malnutrition occurs both due to over-consumption and under-consumption, and has severe health effects.

Apart from affecting how well we grow and develop and how active and healthy we stay as we get older, food consumption has a strong social function. One positive outcome of COVID-19 has been a renewed interest in food as people explore their cupboards, discover new recipes, and re-think their lifestyles. Eating brings people together and can bridge cultural differences. Shared meals can strengthen family bonds, provide a distraction from work and be relaxing. Furthermore, food is a commodity that is incorporated into our bodies, which makes us feel concerned when uncertainty and unknown elements are introduced in our foods. In other words, food has a strong emotional significance, which explains the sometimes-adverse reaction to technology used to manufacture it. New digital technologies provide completely new ways of linking the consumer to technology and product providers. New food manufacturing approaches are on the horizon that will change the established roles of food producers and consumers. These approaches can allow consumers to experiment and take part in food manufacturing and thus lower the barriers that disconnect today's consumers and producers. This development has also raised the consumers' awareness that food is important and very much a matter worth focusing on.

While there are many opportunities that could truly advance the sector and guarantee growth for years to come, there are also considerable threats that need to be addressed. While a few territories will actually experience agricultural production increases over the next year, many other areas of the world – especially those already suffering from a precarious water supply - are predicted to experience a decline. For Europe, that means that imbalances will develop, with some regions reducing their self-sufficiency in food production.

* World Economic Forum (2016). The global risks report 11th edition. Climate Change and Risks to Food Security https://reports.weforum.org/global-risks-2016/climate-change-and-risks-to-food-security/

Making the European food system sustainable will therefore become an increasingly challenging task. Access to raw materials may become limited, and their quality might decline, which in turn would make it more difficult to maintain the high standard of quality and safety inherent to European food products. Coupled with an increased income inequality, the number of consumers having access to higher quality food items may further decline. The wealth gap may lead to, or turn into, a "food gap", and the increasing number of food banks across Europe is an early warning sign of that. Continued price volatility in raw materials may lead to a growing reluctance of investors and existing enterprises to take risks in developing new businesses, new technologies and new products. This would inevitably lead to global competitors overtaking leading European players.

On the consumer front, low engagement levels may further lower public trust and acceptance of food solutions. In turn, there is an even higher risk that decisions will be based on opinions rather than on scientific facts.

2.1.4. Policy Context

We are at a critical time in history. We must avoid a damaging rise in global temperatures and loss of biodiversity, while continuing to provide good food to a growing population. Sustainability and the well-being of citizens are therefore at the heart of the EU's policymaking and actions. With this purpose in mind, the EU Green Deal is an integral part of the EU strategy to implement the United Nation's 2030 Agenda and the sustainable development goals. It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from non-renewable resource use.

The EU Green Deal also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts.[1] The recently published Farm to Fork Strategy is a key component of the EU Green Deal, focusing on the challenges of sustainable food systems and the links between healthy people, healthy societies and a healthy planet.[2]

'Business as usual' is not a viable option. A sustainable food system is a food system that ensures environmental, social and economic sustainability[3] and the EU's ambition is to make the EU food system a global standard for sustainability. In the Farm to Fork strategy the European Commission recognizes research and innovation (R&I) as key drivers in accelerating the transition and achieving the strategy's objectives. R&I can help develop and test solutions, overcome barriers and uncover new market opportunities. In this spirit, the European Commission's FOOD 2030 framework[4] aims to employ R&I to find solutions to the challenges facing our food systems, such as obesity, malnutrition, hunger, climate change, resource scarcity and high levels of waste.

Prioritizing and integrating R&I on the four areas of the FOOD 2030 framework: (1) nutrition, (2) climate, (3) circularity, and (4) innovation communities, is necessary for EU food systems to become future-proof - that is sustainable, resilient, responsible, competitive, diverse and inclusive.

[1] European Commission (2019). The 'Green Deal' Communication. https://ec.europa.eu/info/sites/info/files/european-green-deal-communication_en.pdf

[2] European Commission (2020). The farm to fork strategy. https://ec.europa.eu/food/farm2fork_en

[3] European Commission (2020). Towards a sustainable food system. Moving from food as a commodity to food as more of a common good: independent expert report. https://op.europa.eu/en/web/eu-law-and-publications/publication-detail/-/publication/ca8ffeda-99bb-11ea-aac4-01aa75ed71a1

[4] European Commission (2018). Food 2030: Future-proofing our food systems through research and innovation. https://op.europa.eu/en/publication-detail/-/publication/76d1b04c-aefa-11e7-837e-01aa75ed71a1

2.2. Analysis of Key Challenges That Need to be Addressed

Based on the situation of the sector described above, there are four global key challenges that the ETP 'Food for Life' has identified as being critical, and for which the European Food and Drink Sector needs to develop solutions. The challenges below will need to be tackled by 2030 to ensure that the European food system increases in strength and becomes future-proof.

1. Consumer Engagement, Consumer Behaviour and Perception of Food

Surveys show that consumers increasingly distrust the Food and Drink Sector as a provider of food solutions that they want or need. This is not necessarily the fault of the players currently involved. The digital revolution has fundamentally altered the way we interact with each other or with industry and how we approach and perceive new technologies and products. Consumers are now used to having access to detailed information regardless of time and place. However, food manufacturers are still reluctant to share all information about a particular food product, since this could provide competitors with an unwanted advantage. Moreover, consumers are becoming increasingly diverse when it comes to making food purchase decisions due to an increasing number of drivers. In addition to price, taste and appearance, new intangible criteria attributes related to health, sustainability, authenticity, ethics, and emotional and social needs are playing an increasingly greater role.

Furthermore, based on sustainability and health promotion, consumers are being pressured to change their food-related behaviours which are deeply embedded in their social identity and emotional well-being. The SAPEA report on sustainable food systems[1] also points at the need for more research on the balance between consumers' positive and negative annotations of the food 'making' process, and the emotions related to food consumption. Due to this embeddedness, food choices are resilient towards changes: although consumers often wish to make changes in food-related behaviour, implementing them is difficult due to the amount of effort required and lack of external support. To date, there is an insufficient understanding of how to effectively support the consumers in making these lifestyle changes: which changes are best achieved by modifying food availability or developing new distribution models rather than targeting individual consumer's decision-making behaviour directly. More R&I is needed on understanding diversity in consumer attitudes and decision-making processes and how this relates to the food environment and the empowerment of different segments of consumers in different parts of the world.[2]

Urgently, the sector will need to implement measures to regain the trust of diverse consumer groups by better understanding and serving their needs and wants. To that purpose, adopting methods that allow food manufacturers to communicate more effectively with consumers is crucial. While food manufacturers can use the channels to educate and disclose decision-making facts with respect to the reasons for the choice of raw materials and processing technologies, the same channels can be used to gather consumers' feedback on how they perceive and value production and product attributes. A rekindling of the lost appreciation and understanding of the benefits of food processing in creating a safe and high-quality food supply is needed, but this process needs

[1] SAPEA (2020). Sustainable Food Systems for the European Union. https://www.sapea.info/wp-content/uploads/sustainable-food-system-report.pdf

[2] FIT4FOOD2020 (2019). Policy Brief 2. Key research and innovation questions on engaging consumers in the delivery of FOOD 2030. https://fit-4food2030.eu/wp-content/uploads/2020/04/FIT4FOOD2030-Key-Research-and-Innovation-Questions-on-Engaging-Consumers-in-the-Delivery-of-Food-policy-brief.pdf

to take into account consumer concerns. Some of this could come from a renewed focus on the exploitation of the cultural diversity of European food traditions.

A better collaboration, using modern media and new digital technologies will need to be put in place in the food arena. Privacy and data security issues surrounding the ethical use of Big Data for food development purposes need to be addressed. The long-term consequences of short-term marketing efforts need to be better understood and assessed. New, "effortless" solutions to support consumers' healthy and sustainable food choices and, thereby, their well-being, need to be developed.

By 2030, substantial progress must have been made in the communication and interaction with consumers so that technologies that are used are both beneficial for human health and for the environment but also accepted by consumers. Such approach should allow for a personalization and customization of food on a decentralized level. This could empower the consumer to become part of the food manufacturing system and create a common food ecosystem and, in so doing, the benefits of technologies for guaranteeing the long-term safety and quality of foods can then be better be aligned with consumer needs and wants.

2. Demographic Changes

The global population is undergoing a rapid change, not only in terms of size, but also with respect to composition. Modern medical achievements, along with successes of the Food and Drink Sector, have led to tremendous increases in the average lifespan of a person. Data from 186 countries shows that, in 1960, the average person was only expected to live for 52 years, while by 2010, this had gone up to nearly 70 years, and it continues to rise. In addition, there is ever more and more rapidurbanization, which is in contrast to most of human history, where humankind has lived in rural settings rather than in cities.

Urgently, new food solutions that address a growing but also an ageing and more concentrated global population will need to be developed. Food-specific responses to city growth have to be promoted. Indeed, in 2008, the world's population was for the first time evenly split between those living in urban and rural areas. The trend towards urbanization differs from region to region and differences between the developed and the developing world. Differences between cultural practices across regions also need to be considered.

By 2030, nutritious and health-promoting food will have to be affordable to everyone, which will be a challenge considering the projected demographic changes. While an insufficient caloric intake may decline as a reason for malnutrition, hidden hunger, that is, the deficiency of specific micronutrients in the context of a sufficient or even too high energy intake, may increase. In addition, it is likely that the inequality in wealth may become even greater, requiring that affordability and accessibility be considered to a greater extent.

3. Ensuring food security

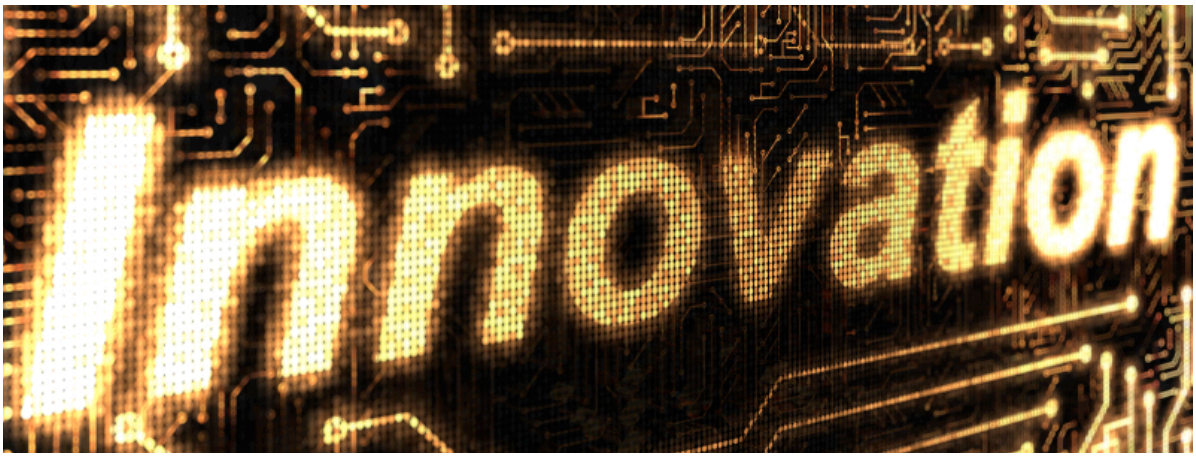
Even though there are currently sufficient or, in some cases, even abundant resources available to produce food – which has led to a decrease in undernutrition and a rise in overnutrition – this situation will likely not persist for much longer. With the number of natural resources that are gradually being depleted going up and the global population continuing to increase in size, securing a continued supply of high-quality raw materials will certainly become one of the great challenges of the 21st century. Climate change causes even more extreme weather occurrences.

Coupled with a decrease in water availability, these will decrease agricultural production in many areas. Environmental pressures also affect a continued resource supply from marine resources for the food industry. Finally, an increasing competition for agricultural sources from other sectors, such as the chemical and energy industries, will put additional pressure on the supply into the food system.

Between now and 2030 the sector will need to find new approaches to become more water and energy efficient. New methods and technologies to use resources more holistically will be needed. Moreover, the need for more biological resources must be balanced with environmental protection and sustainability considerations. The effect of the growth of power imbalance and income inequality will have to be considered when developing new food systems.

By 2030, flows in the global food system must be fully circular and enhance the use of side streams along the supply chain. New technologies, including the synthesis of food components from non-food materials or the use of non-traditional resources such as insects or microalgae, should be fully explored and embraced to supplement the diminishing supply of some raw materials. To overcome the growing gap between the haves and the have nots, measures should be taken to develop a shared profit food system.

4. Sector Maturity



There is a certain 'fatigue' within the sector as a result of its maturity. The industrialization of food manufacture dates back to the beginning of the 19th century following advances in chemistry and metallurgy which gave rise to great productivity increases in agriculture. As a result of a growing raw material supply, there was a need to develop new machinery and technologies to process and preserve agricultural products. As a consequence, food became widely available which, in turn, caused prices to decline. Today, households only spend about 10% of their income on food in Europe, while in 1900 a family would spend on average about 40% of its entire household income on food.* The wide availability of food at low prices has led to it being taken for granted and not sufficiently valued.

Urgently, the sector players will therefore need to find new ways to address the low translation of valuable research results into successful innovations. There is a need to become much more entrepreneurial to answer the upcoming changes in consumer needs and wants. The question of how to align the various stakeholders around the topic "food" so that solutions that serve European citizens needs to be addressed.

A means to revitalize the sector could involve making food much more diverse and thereby again responsive to various needs and wants; a practice that has of late led to a revitalization of, for example, the beer industry (e.g., craft manufacturing and microbreweries). In line with this, new approaches to making food more essential need to be developed, e.g., by creating a more non-uniform offering composed of not only low cost but also luxury goods. Here, an integration of recent developments in the culinary arts and in gastronomy into the wider Food and Drink Sector could be a valuable approach. The promotion of local and regional production could be another.

By 2030, food should become a highly desired product category again, comparable to the innovative, sought-after, and highly prized consumer electronics or fashion products. To that purpose, food should not just be nourishing, but also be engaging, fun and enrich people's lives. This may be accomplished by an increased 'virtualization', that is, by transforming it from a purely physical product to a both physical and virtual one. Technologies such as 3D printing have begun to be commercialized and facilitate such changes. Also, the continuous application of robotics, mechatronics, artificial intelligence, and similar technologies that are advancing fast through the technological sector, might allow for better tools for energy efficiency, process design, food hygiene, or business management. While disruptive to established business, this could lead to new enterprises which would make the sector fashionable and pioneering. As a consequence, instead of being driven by developments in other sectors, it could become a look-to and go-to one.

* 100 Years of U.S. Consumer Spending: Data for the Nation, New York City, and Boston. Bureau of Labor Statistics 2006, available at http://www.bls.gov/opub/uscs/report991.pdf

2.3. Our Vision - Create a Better European Working Food System for All

Our Ambition

The ETP 'Food for Life' will foster a thriving European Food System that builds on cultural diversity with consumers, the public sector and industry working in partnership.

The Food System of Tomorrow will use nature's resources in a responsible and sustainable manner, and be dynamic, flexible, fully transparent and accessible to all. Progress will be made by bridging modern social and natural science and technology approaches to benefit the greater public, making healthy and sustainable food alternatives not only effortless and affordable to all consumers, but also desirable and exciting.

Our Mission

n consultation with key stakeholders, the ETP 'Food for Life' has developed a pre-competitive research and innovation strategy composed of a targeted set of action items that will serve to holistically address European food system challenges that threaten the competitiveness of the sector.

Using a comprehensive consultation process, the ETP has generated an Implementation Action Plan (IAP) in 2018* to suggest measures, resource allocations and timelines, ensure proper execution of the plan and verify that its implementation creates a sustainable, healthy, safe and high-quality food supply by use of new food manufacturing approaches which, in turn, will create new employment opportunities. The IAP is kept up to date as new developments require new actions (e.g., on packaging materials in the context of reducing plastic waste). Focusing on the needs and wants of tomorrows' consumer, it will actively engage with consumers to address malnutrition and the rise in non-communicable diseases, and enhance appreciation of, and trust in, the European food supply.

* The ETP 'Food for Life' (2017). Implementation Action Plan http://etp.fooddrinkeurope.eu/news-and-publications/publications.html

3. Step-Changing the Innovation Power of the Food and Drink Sector: A Call to Action

To make progress towards the formulated vision, the ETP 'Food for Life' proposes a number of **targeted research and innovation actions** that are described below in detail.

The actions are intended to foster a shift from a conventional mass production model to a more personalized and customized one involving and engaging the consumer while simultaneously promoting flexibility and resource efficiency.

Figure 4 shows a schematic overview of the proposed action items along a future-oriented development space that intends to facilitate this fundamental shift. The proposed action items are designed in an integrated way to avoid segmentation or fragmentation of the sector.

A deeper understanding of consumer wants and needs based on modern data generation and analysis will aid the achievement of three specific research and innovation (R&I) targets:

- R&I Target 1: increase the engagement and involvement of consumers;
- R&I Target 2: create a more personally-relevant and customized food supply;
- R&I Target 3: develop a more flexible, dynamic and sustainable food system.

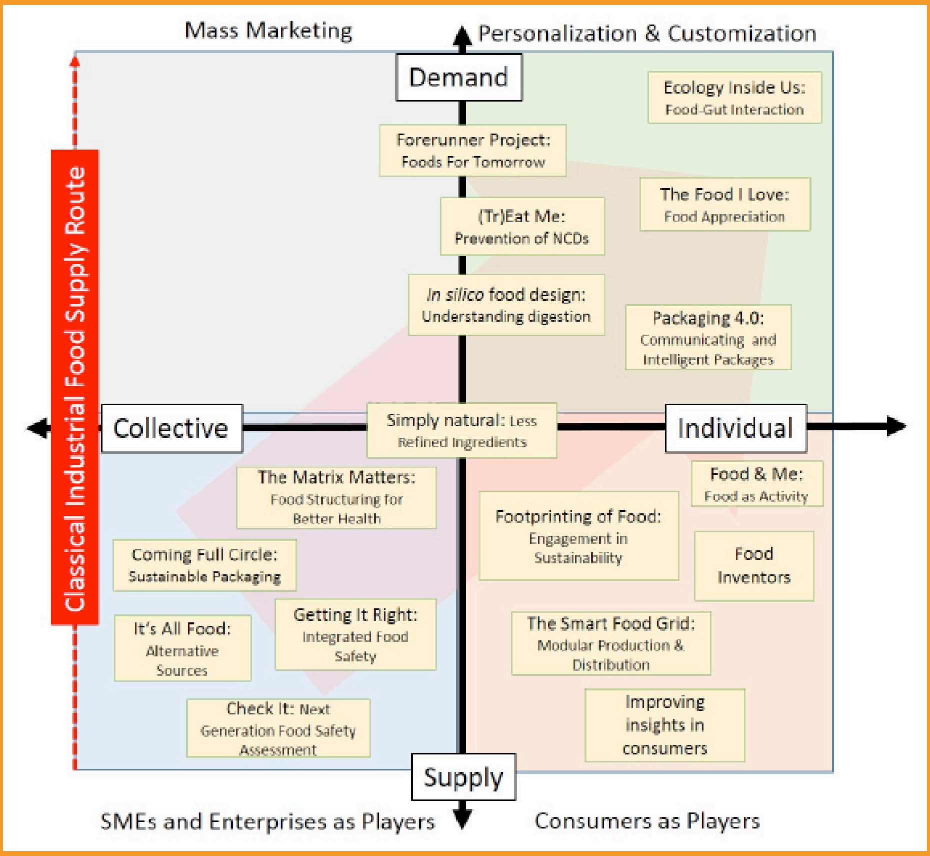


Figure 4. Schematic overview of proposed action items focusing on three research and innovation targets.

3.1. R&I Target 1

Increasing the Engagement and Involvement of the Consumers

Aim

In the future, consumers should feel that they are not only at the receiving end of the food supply system. They should not simply be seen as customers, but as an active agent driving the development of a future food supply system. As active players and participants, consumers will have a stake in the game and help make sure that solutions are developed that are not only accepted but also implemented by them.
To accomplish this, we need to find new ways to empower and engage consumers to become active.

R&I Target 1 aims at achieving this goal by carrying out R&I projects that can help overcome both technological and social hurdles stifling transformation. Five actions have been identified as priority measures to develop a new partnership between consumers and food business, fostering the creation of a decentralized food innovation space:

1. new and effective communication pathways and methods to better understand consumer wants and needs,
2. the realignment of consumers and the food chain by exploring and implementing new forms of two-way communication,
3. new food production and delivery models that can be implemented locally to provide better access to the food system;
4. new methods to allow consumers to better understand and directly contribute to the food system, and last but not least
5. new processing and packaging approaches that are modular and scalable thus allowing maximal flexibility empowering consumers or small groups to become producers.

Implementation

Improving Insights into Consumers

A thorough understanding of consumer and societal issues as they pertain to food is the basis for a rational forward-looking development in the Food and Drink Sector. Today, a myriad of new techniques has become available to accomplish this. These include not only traditional surveys and focus groups but involve physiological techniques as well. Combined with new developments in digital technologies, and Big Data in which purchase data, health data, output from self-monitoring devices will be incorporated and data analytics have led to unprecedented opportunities to better serve the consumer. A serious or educational game should be designed based on various scenarios, to increase awareness about certain riskier consumer practices and to assist consumers in decision making for improved food and risk management. A number of actions related to design and implement communication and training campaigns about the consumer-driven food safety initiative and approach e.g., the "Food Safety Culture" to a vast audience of consumers of different age groups, consumer associations, civil society groups, food authorities, market actors, food industry and other stakeholders, such as policy makers. The challenge is to integrate these new approaches and apply them to the Food and Drink Sector.

Food and Me: Making Food an Activity

Traditionally, food producers gain information about consumers' views on a specific product from their purchasing behaviour or through specialized market surveys. This one-way communication has contributed to a poor relationship between consumers and food manufacturers, as consumers are seen as sources of information, but are not given an active voice. As a result, high product failure rates and consumer distrust of solutions provided by food enterprises is not surprising. However, with the digital revolution, completely new means to foster more balanced, bidirectional and interactive communication have become available.

The challenge here is to establish appropriate and effective communication platforms and develop necessary content to facilitate the information flow between consumers and food producers for topics related to food purchase, preparation and consumption scenarios. The data obtained need to be processed in a meaningful way to extract trends and to identify gaps. For this, new data processing and transaction models will need to be developed.

Food Inventors: New Food Production and Delivery Models to Provide Better Access

In today's rapidly changing world, food consumption patterns are constantly changing. Food preparation in homes is declining, while food consumption through food services is increasing. This has left the consumer with a feeling of loss of control, being even more on the receiving end of a linear supply chain than before.

As a result, movements have emerged that propagate consumer-led distribution models, such as joint gardens and kitchens which, in a sense, turn consumers into producers themselves. New consumer-to-consumer business models have emerged as a result of this trend.

To date, though, these efforts remain uncoordinated and unsupported, thus requiring a lot of effort from the consumer. The challenge to be addressed is to better understand the extent and the variety of emerging business models in order to extract blueprints that enable consumers to become inventors and producers. Needs associated with logistics and micro-processing technologies have to be assessed, and the impacts on public health, food and nutrition security, and food waste have to be determined.

Footprinting of Food: Consumer Engagement in Sustainability

In a world where resources are becoming increasingly scarce, the need to enhance sustainability has become urgent. Food manufacturers have responded by developing many different sustainability indicators that, due to their great variety, have left the consumer quite puzzled. Individually defined terminologies such as animal welfare, food miles, carbon and water footprints have raised more questions than they have answered.

This is very unfortunate, since efforts in sustainability could do much to gain consumer trust and involve consumers in protecting the environment. The challenge is to come up with a data-driven information system which will structure and standardize sustainability information across the food production system. Specialized data security and anonymization approaches will have to be developed, keeping in mind that such systems must be fully accessible to the many SMEs of the Food and Drink Sector as well. This will need to be coupled with research that determines what information would be suitable to engage and not just inform consumers. Much of the incoming research will be on how environmental sustainability parameters are linked to health parameters and how consumers are engaged on sustainability, when considering that choices are mostly made on price, taste and health.

The Smart Food Grid: Modular Food Production and Distribution

With the industrialization of food production, much research has been focused on developing ways to scale up processes to become more effective. However, with the increasing desire of consumers to have a customized, localized and diversified food supply available, new small-scale food production approaches that are efficient and flexible will need to be developed.

The challenge is therefore to develop techniques that can be readily modularized to allow for agility. In turn, this may require new quality and safety assessment methods for intermediates and final products, new packaging approaches, new delivery models and increased engagement of end-users as actors to finish personalization.

Expected Impact

A successful execution of this R&I target will activate a decentralized innovation ecosystem allowing for the development of completely new business models in the Food and Drink Sector. Moreover, the transformation from a mass market-oriented production system to a more decentralized, consumer-run system would do much to overcome the obvious growing gap between food solution providers and consumers.

Acceptance and understanding of the methods used in food manufacturing would grow, leading to alignment in goals of consumers and food solution providers.

Can you imagine?

The brand new flavor-of-the month ice cream in your local supermarket invented by you! It was made exclusively from local ingredients in small amounts. Friends and neighbors can share in the experience by purchasing your product form the local grocery. You profit from your invention allowing your mini-business to grow.

Can you imagine?

You have just tried a new cheese variety that was delicious. A mobile app allows you to provide the manufacturer with an immediate feedback, notifying the supermarket in your vicinity that they should keep the item in stock. Additional feedback received from other customers causes the product to be offered in a variety of serving sizes and flavors in the following week.

Can you imagine?

You have a great idea for a new food you wish to serve at your child's birthday. You shared this idea on an open platform and a small company contacted you and promised to work with your idea and deliver your wish. Freshly made food delivered to your home address based on the menu you had created for the week giving you more time to spend with your family on weekday evenings- realized by new network services.

3.1.1. Improving Insights into Consumers

Introduction and Background

During the last decades, the field of consumer science has grown and led to a better understanding of consumer and societal issues related to food and eating. Simultaneously, new technologies have become available and tools such as magnetic resonance imaging, eye-tracking and computer testing have been developed. Furthermore, it has become possible to collect and store large amounts of data easily. This volume and type of data was previously unavailable. These developments are very promising as they can make new and deeper insights possible. However, the possibilities offered by these new developments have yet to be fully exploited without compromising consumers' privacy and rights to their own data. This hampers accumulation of consumer understanding and growth of the Food and Drink Sector.

The situation in consumer science of food

At the moment, a multitude of tools and methods are being used to assess variables in the food consumer science domain. However, in most cases the tools are difficult to use in large studies and across different samples and countries. This is due to their limited practical usability and lack of harmonisation.

New influences from adjacent sciences

Additional assessment tools, for example ones that gather consumer feedback beyond self-reporting, have become available for food research through disciplines such as psychology (e.g., projective techniques, implicit measures etc.) and the social sciences, as well as from the design arena (co-creation).

New and emerging assessment technologies

New technologies (based amongst others on physiological measurements) impact on the consumer science domain. For example, automated observational tools, computerized testing, functional near infrared spectroscopy, sensors for application in food safety and human health, wireless optical and electronic tools communication modules, rapid on-site sampling method for hazards, and other non-destructive and/or high throughput technologies (in tandem with multi-sensor data analysis and integration) have become available. However, these new tools are not always fully validated and often difficult to implement in large food studies.

New developments in Big Data for consumer science and engagement

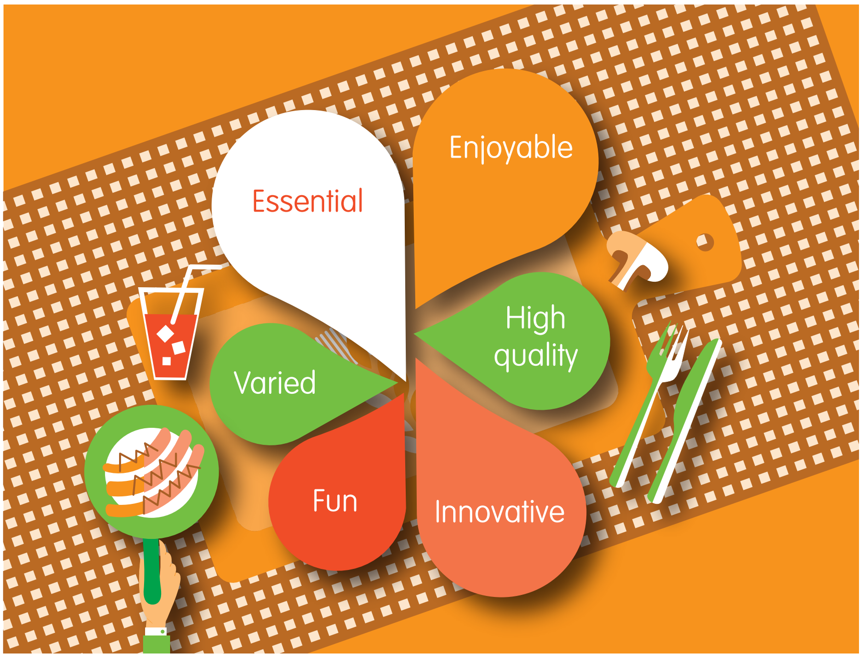
The development of Big Data analytics e.g., the process of collecting, organizing and analysing large sets of data, (both structured and unstructured data) to discover patterns and other useful information, can be applied for consumer science and engagement. This will help to better understand the information contained within the data and identify what is the most important piece of information to make decisions. A major source of such data is the social media, which opens up new interactive ways of communicating with the users. Today, there are also specific databases which contain information on consumer behaviour in the food domain. Some examples are:

1. data on consumer household panel purchases,
2. retail scanner data, and
3. loyalty card data.

These sources have only been explored to a small degree. We need to know better how to handle the large amount of data generated and how to ethically utilize such data. Sharing such data throughout the food channel is limited as GDPR (General Data Protection Regulation) and ethical issues can limit which data can be shared. The protection of data can be used for competitive advantage as well. Ethical issues need to be considered as an inherent part of the Big Data developments in general.

Thus, to enable a step-change increase in effectiveness of consumer research and consumer engagement in the food industry, five issues have to be addressed:

1. lack of harmonised tools;
2. lack of cross-linking between studies/across countries, etc.;
3. limited use of the potential of the new technologies;
4. limited use of consumer science Big Data; and
5. GDPR and ethical issues resulting from greater data intensity.



Goals and Objectives

- To make a step-change improvement in the availability and usefulness of existing and new tools and technologies in foods consumer science.
- To develop standard approaches for developing and analysing Big Data in the consumer science field.
- To explore and develop synergies between new assessment tools and analysis of Big Data in the consumer science field.
- To develop platforms that enable sharing of data and information throughout the food channel and between different studies and countries in order to allow insights to be exploited effectively by industry, consumers and policy makers, taking due considerations of potential ethical issues.

Rationale and Significance

The relatively short history of consumer science in the food domain may explain the delay in the improvement of tools and the adoption of new assessment technologies. It may also explain the delay in the exploitation of the mass of data on consumer behaviour which has become available through both purposefully collected data (i.e. scanner data, loyalty-card data etc.) as well as through more incidental consumer data (i.e. social media).

Reducing the delay can provide a step-change improvement in the level of consumer insight and consumer engagement. It will be beneficial for small and large food industries, as they will have faster, better and more comprehensive insight in consumer needs. It will also be beneficial to consumers and society in general, as it can facilitate consumer engagement in the food industry.

Potential Approaches

- Improve and harmonise a selection of key consumer science assessment tools for the food domain. Establish standards for developing and analysing consumer science databases and Big Data. Finally, investigate possible emerging opportunities resulting from these new standards, databases and analysis tools.
- The developments in this field will generate opportunities for creating much better consumer insight and engagement which can help to identify opportunities for developing new products, new delivery means and other new services.
- Skills and competences in using and analysing new tools, new databases and new analysis techniques are necessary. Furthermore, as the insight generation becomes faster and more comprehensive, implementation of the insights will require specialized skills.
- Tools and methods of data-collection may not always fit all groups in the population. For example, computer testing with infants and toddlers requires special tools. As this proposal intends to be inclusive for all, it is suggested that special populations are defined and addressed separately. Examples are differentiation based on age, income and gender.

Expected Results and Key Performance Indicators

- A selection of harmonised consumer science tools in order to generate more effective consumer insights leading to higher success rates of new product launches and closer alignment with consumer and societal needs
- Development of important new tools based on (new) technologies in adjacent fields.
- Innovative and standardized approaches to collecting, managing and analysing Big Data which will enable deeper consumer insight and sharing of data.
- Improved possibilities to pool data from different studies and sources in order to conduct more powerful analyses and to avoid duplication of efforts.
- Increased speed and effectiveness of consumer insight generation, resulting in more effective product and service development.
- Improved consumer engagement.
- Evidence-based recommendations for education programs increasing the skill and competence set needed to apply existing and new tools and Big Data in the food industry.

3.1.2. Food and Me: Making Food an Activity

Introduction and Background

The level of mutual understanding between food chain operators and the consumer is generally poor. Over the past hundred years, the industrialization of food production, the development of infrastructure, the dismantling of barriers to trade and the ensuing globalization of food markets have resulted in unprecedented efficiency gains. However, these very developments have also led to a state of affairs in which consumers and food producers have little contact with, or understanding of, each other. This has contributed to the difficulty for food producers to read consumer preferences correctly and has resulted in high failure rates of new product launches. From the consumers' side, the lack of understanding of how the food chain operates contributes to a lack of trust. This continues to be an issue even though it has long been identified as such.

The low level of alignment between consumers and the industry is a major barrier to making the industry contribute to solving some of the major societal problems related to food consumption. These include promoting healthy eating, more sustainable food production, and food and nutrition security. Realigning consumers and the food chain requires engaging consumers because they play an active role in bringing about tomorrow's food production. The European food industry faces a challenge to move from developing products and services for consumers, to one in which they develop these with consumers.

The high failure rate of new product launches mentioned above results in a waste of resources. Additionally, it may result in lower levels of consumer wellbeing, if failed products and services could contribute positively to health. It implies that attempts to bring healthier and/or more sustainably produced products to the market often fail because of a lack of consumer acceptance. Thus, production and processing have to focus on food products that are acceptable by consumers. Many consumers are critical and distrust large scale industrialized food production. Revival of local production and short supply chains offer an alternative to consumers who seek transparency in production. At the

Goals and Objectives

The overall objective is to realign consumers and the food chain by exploring and implementing new forms of two-way communication between consumers and food producers. This overall objective is achieved through:

- Developing, testing and implementing new forms (the "how") of how consumers can be integrated to new product development and innovation processes using both online platforms and various onsite approaches to better respond to consumer needs and engage consumers as co-creators.
- Developing a better understanding of trends in consumer preferences by analysing data that are routinely generated by transactions, on social media, and in consumer panels, exploiting new techniques for mining of Big Data.
- Developing new business models for collecting and analysing consumer data, for providing information to consumers, and for disseminating consumer insights, especially to SMEs.

same time, changes in communication technology and the way that media is accessed and used provides a unique opportunity for re-establishing closer contact between consumers and food producers regardless of location or scale of the production.

Rationale and Significance

The current developments in information and communication technology (ICT) and changes in people's media habits provide a fertile environment for realigning consumers with the food chain and for getting the best out of global, industrial and localized food production.

The Food and Drink Sector has thus far been slow in exploiting the new possibilities these developments offer. Consumers have questions, inquiries, complaints, and are willing to interact with participants in the food chain provided they perceive that such interactions will have positive consequences.
However, these developments also lead to the consumers being overloaded with information that they feel is not relevant for them. This perhaps even further diminishes the intended alignment. Engaging the consumer will require the development of new forms of interaction that limit information streams to what is relevant to the individual. Also needed is a two-way communication that takes place when and where the consumer wants and needs it. Establishing new forms of communication between consumers and the food industry will benefit all parties by enhancing transparency and encouraging co-creation.

Consumers will get information when they need it, will profit from products better aligned to their preferences and will feel empowered in bringing about changes in the food supply.

Food producers will be more successful with new product launches and will regain consumer trust allowing their invaluable contributions to healthier eating and a more sustainable food production to have the desired impact.

Potential Approaches

- On the basis of a better understanding of consumer information seeking and media habits, develop new solutions for two-way communication in the shop (e.g. smartphone-based devices), in the kitchen (e.g. integrating information and communication technologies into kitchen appliances), at the dinner table and on the go; developing data mining techniques for analysing massive data streams generated by consumer actions to generate insights into consumer preferences
- Develop business models for the generation, provision and analysis of data from and to consumers, and for the dissemination of consumer insights based on this to small and large companies at all stages in the food chain.
- Train those working in new product development in food companies to apply methods that allow consumer participation in the processes to develop new products and better use of consumer insights based on these new sources of evidence in the new product development process.
- Train consumers in the use of tailored information during shopping, meal preparation and consumption.

Key Performance Indicators

- New flexible forms of communication between consumers and food chain participants in the form of social media platforms, app-based solutions, and integrated solutions in the kitchen.
- New data streams both to and from consumers that can be used to generate insights into consumer preferences and their developments.
- Business start-ups that deal with the generation and analysis of consumer data and with the dissemination of results to food chain participants.
- New sources of consumer insights that both large and small food producers can exploit in the new product development process.
- New tools for product development
- Increased success rate in new product launches, especially for healthier products and products based on more sustainable production methods.

3.1.3. Food Inventors: New Food Production and Delivery Models to Provide Better Access

Introduction and Background

How people access and consume food is changing constantly. Food consumption in the home through meals made from ingredients bought in stores is declining and the purchase of ready meals and pre-prepared meal solutions is growing. Out-of-home consumption is increasing through restaurants, cafes and work canteens, and new concepts allow on the move consumption and snacking via vending machines, mobile and pop-up catering facilities. The take-away and home-delivery services provide possibilities for new business models. At the same time, some food production is becoming more localized. This shortens supply chains, as consumers use farm shops and engage in local and in-home production themselves. This is often made possible, or at least potentiated, by having current information and communication technology approaches embedded in them.

These complementary trends increase the diversity in the ways that consumers access, prepare, produce and consume food.

Consumers traditionally access food largely through a supply-driven, gatekeeper-managed, linear delivery model. The manufacturer makes a product; the retailer or foodservice provider determines availability and consumers select from the choices offered. Through their gatekeeping characteristics, traditional production and channel delivery models influence consumer behaviour and consumer understanding of food. Changes in consumer demands and expectations at the point of purchase or consumption, and in the origin of and degree of food preparation required have, however, stimulated changes to this approach. In traditional channel models, retailers and foodservice providers respond by marketing food solutions for "now, today, tomorrow", "food on the go" or "food for later". They use on-line purchasing and home delivery or collection models and new store formats and venues with a blurring of solutions (e.g., food to go in supermarkets) and an emphasis on experience.

New consumer-led channel models are on the rise. Some involve home production or localized micro-processing of some food categories (e.g., vegetable gardens, bread making, home brewing/ baking) and local buying hubs by-passing traditional channels with consumer to consumer rather than business to consumer relationships have emerged. This reflects a different type of engagement and involvement with food, characterizing consumers as co-producers or co-processors.

Such new combinations of food production and delivery models (use of mobile applications, local distributors, combination of local availability/healthy parameters) have potentially large yet currently unknown implications for consumers, food companies and policy makers. Early evidence of the effects of COVID19 related restrictions has shown a very rapid expansion of technology driven delivery models linking customers and providers and other innovations such as at-home restaurant experiences from the foodservice and restaurant industries. This indicates that change can occur in this area very rapidly indeed.

Goals and Objectives

The overall goal is to identify the impacts of the new dynamics and diversity in food production and delivery models in terms of:

1. consumer perceptions (trust and satisfaction with the food system) and consumption behaviours (consumption patterns from a health, sustainability and waste perspective);
2. business potential (for innovation and new business models);
3. the economics of the food system (in terms of job creation), and
4. policy (in terms of food and nutrition security, food safety, and competitiveness).

These goals will be achieved through the following objectives:

- Identifying and describing in detail the diversity and key features of new production and delivery models across Europe.
- Identifying the challenges of traditional channel business models and understanding the characteristics and operations of new business models for consumer access to food.
- Describing and quantifying the economic and innovation opportunities provided by new channel models. Of particular interest will be job creation in

- food production (technology), food logistics (including e-commerce), and supporting services (for food access and food/meal preparation).
- Assessing the implications for consumers of these changes in terms of their involvement and behaviour from diet and nutrition, food security and waste perspectives.
- Identifying the societally relevant potential impacts on public health, sustainability of food providing systems, food security and food waste/sustainability.

Rationale and Significance

The new approaches to production and delivery channels redefine the roles and responsibilities of consumers, delivery agents and producers. They also have implications for supporting technologies, flows of information and materials and, ultimately, innovation and job creation within the food system.

The traditional channels need to be analysed in terms of the options presented by the growing food to go - out of home and on-line shopping markets. For example, as online shopping and home delivery models evolve, do consumers purchase less healthy food, do they perform less home cooking and meal preparation, and does this result in more waste from longer fragmented supply chains? Likewise, the question arises whether there are opportunities for behaviour change.

For the new channel models, the potential for scaling-up of these approaches needs to be established. There are many small-scale examples of such models, and those models that prove successful in an economic ecosystem would be expected to spread. This makes it imperative to understand their functioning and their potential impact on the food system. The limits to the spread of home and localized production and processing are unclear, certainly in terms of what food products and processes are suited for these approaches and whether they could succeed in different societal groups. There are potential market opportunities for material and services serving this type of production model, such as in-home technologies like 3D printing, raw materials for home production, support services and information, and a possible re-configuration of kitchens and other elements of the home.

Potential Approaches

- Research: map, demonstrate and assess the impact of the emerging options in localized production and of different food supply systems on the role and responsibilities of participants in the food chain in different consumer contexts (national versus regional; urban versus rural; young versus elderly).
- Innovation: construct a range of exemplary business models for new production and delivery models to act as catalyst for innovation and new commercial opportunities.
- Education: develop information and communication mechanisms to increase awareness and understanding of the innovation and business opportunities these new models represent.

Key Performance Indicators

- Credible inventory of consumer acceptance, trust and satisfaction and consumption behaviour impacts (health, safety, sustainability and waste) of the new and increasingly diverse production and delivery models.
- A map of the economic opportunities that the new production models represent, including, but not limited to, home appliances, ingredient and raw material supply and service solutions.
- Proposed sustainable business models for new-channel configurations allowing consumer or community driven food provision.
- Specific, critical issues of public interest or risk for consumers identified for these new approaches, including those in areas such as public health, food security and food waste issues.

3.1.4. Footprinting of Food: Consumer Engagement in Sustainability

Introduction and Background

Food products are sometimes labelled with different kinds of indicators, many of which are related to specific aspects of sustainability, e.g, fair trade, food authenticity, animal welfare, food miles, carbon and water footprint.

The lack of a clear definition and proof of impact in combination with the use of own indicators been started by many retailers and manufacturers, which are considered to be subjective, has led to much consumer confusion and, in the end, to disbelief and distrust. It does not make sense to create yet more indicators, however it is important to engage the consumers themselves. For optimal engagement they should decide which information should be aggregated into personalized reports on food products, which would allow the individualization of sustainability data without causing information overflow.

Nowadays the Big Data revolution enables quick combination and correlation of massive amounts of data, even when much of it is unstructured. At the same time, the emergence of more and more sophisticated, self-learning artificial intelligence systems enables us to not only collect, but also to interpret information. The first tools that enable structured reports created by artificial intelligence to be obtained are already available (Fig. 5).

Solutions should be developed that would enable the consumer to actively conduct a query (e.g. using a scan of a product with a cell phone camera) so that exactly the information relevant to that particular consumer is reported back. Depending on the wishes of the consumer, this could be concentrated around animal welfare, dietary requirements, carbon footprint, origin, sensory profile and/or other aspects that will be included in the report. This can be done by utilizing new analytical approaches in the area of Big Data, and includes an active involvement of both producers and consumers.

Although there are intellectual property, competitiveness and ethical issues to be considered, this will greatly increase the transparency of the total food chain and is expected to build and foster consumer trust in the full chain.

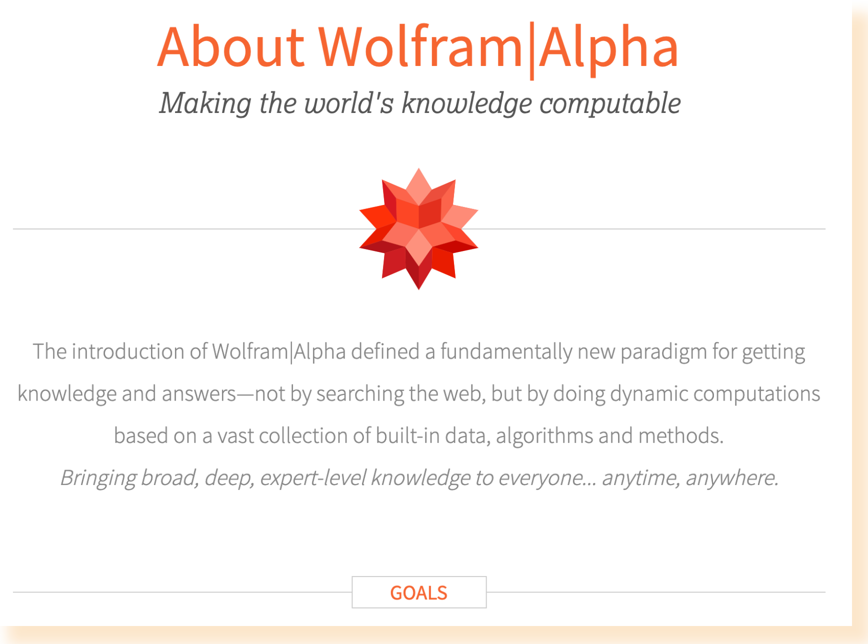


Figure 5. An example of a query compilation system based on artificial intelligence is Wolfram Alpha; in specific, non-open-source areas, even stronger examples are available (e.g., in the area of the assessment of medical information).

Goals and Objectives

Solutions will be developed that allow consumers to actively query for a set of related agri-food information as well as related nutritional parameters on a specific product that they individually look for and find important. To accomplish this:

- Data on the production, conversion and nutritional profile of foodstuffs needs to be made available and continuously updated, since product lifecycles are often quite short. Data anonymization and data security strategies, as well as competition issues need to be considered. This requires collective action by producers, retailers and many other participants. Ideally, such action would be coordinated by an EU-wide organization. Special consideration should be given to ensuring that SMEs will have a system available that does not significantly add to costs and that does not put unnecessary reporting burdens on them.
- Research will need to clarify what consumers would like to know and at what level of specificity/detail (e.g., single information or a holistic assessment), and how to actively engage consumers. Furthermore, consumer research will be needed to optimize the interface, presentation, and to avoid information overload.
- Search and reporting solutions based on the use of these data should be developed. These might make use of existing technologies (e.g., Google, Watson, etc.) or not.

Rationale and Significance

The current overabundance of sustainability indicators has led to confusion and distrust by consumers. More passive labels would only add to this, and are not the solution.

With the consumer actively involved in obtaining data, and having active influence on both content and presentation of the results of an individual query, it is expected that people will become more involved and will have a greater trust in the total agri-food production. In addition, such a system will provide two-way information exchange. The types of queries, and the requested forms and combinations of the results will yield a wealth of information to the participants in the chain (producers, retailers, catering trade, etc.). A well-functioning system will require that major players provide access to their data, whereas the anonymized information coming back from individual consumers will provide better insights into their motivations and wishes.

Potential Approaches

- Creating an open source system based on open information. One can start either from the data end or from the consumer one. If one starts from the consumer end, one may develop a system which collects data from the internet, and then compiles this, using artificial intelligence, into a coherent report to the consumer, who then would use an app to access it while walking in the supermarket, or while web shopping.
- Starting with a concerted action on data access. One may also start with a consortium with relevant stakeholders that agrees to make data on production and sustainability available for the platform. From this, a query and compilation system can be built that gives consumers and others access to the data and the analyses.

Key Performance Indicators

- A practical information system for personalized consumer queries in the area of food sustainability and health
- Coverage of the consumer population by such system.
- Coverage of the relevant agri-food chain players.
- Number of new data-centric agri-food businesses.
- A measurable increase in the trust level in the agri-food system.

3.1.5. The Smart Food Grid: Modular Food Production and Distribution

Introduction and Background

For a long time, the development of the food chain was driven by scale, i.e., from primary production at large farms over large production units to large distributors and retailers. There is now a demand for mass customization rather than mass production. Some consumers wish small-scale customized food production closer to them. Proximity of production and consumption can reduce food waste and increase the utilization of side streams but requires existing food processes to adopt the use of new raw materials and shorter food chains. Modularization at various stages of the food value chain will give the opportunity for new business models and will contribute to social, economic and environmental sustainability.

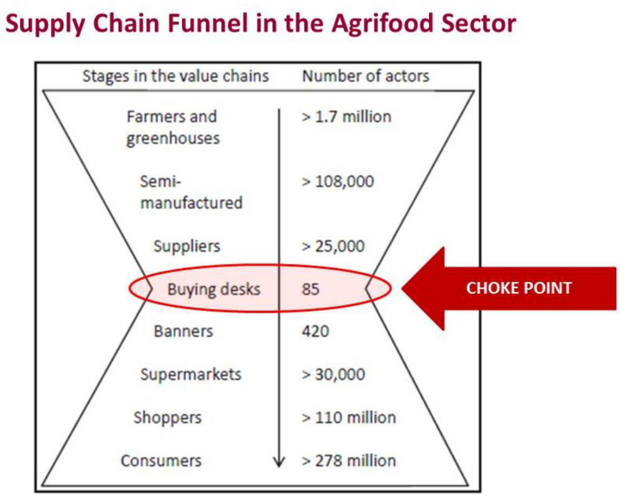
Food production and retail sales have become centralized due to economies of scale. This has made the consumer a recipient of products made, sometimes, far away. Retail sales and food delivery are under pressure to change mainly due to digitalization and demand for personalization and customization. There is a need for flexible processes that are agile and enable fast adaptation to changes in consumer demand. Food supply chains are in many instances, at least to a certain degree, global, and may therefore be impacted by regulations. Modularization may also be a very valid approach to convert packaging systems from passive ones to processing aids. Typically, packages act to protect products from external influences (e.g., mechanical stresses, oxidation, microbial spoilage) after manufacturing. In addition, they are crucial for communicating information about the content of a package to users.

However, one could foresee that, as processing moves from large scale operations serving mass markets to smaller ones, these could also become vehicles to transform materials to food products, e.g., by fostering and controlling fermentation or by catalysing enzymatic reactions. This is not a completely new approach. Indeed, household containers have in some cultures been used for a long time to generate foods (e.g., the production of Kimchi or table olives in refrigerators using glass jars). If one takes this through to a new level, a completely new and decentralized way of producing foods could be developed. In the particular case of Europe, the food supply chain has a converging-diverging shape (Fig. 6). It is controlled by the distribution sector (buying desk), because of its enormous concentration. The weaker players are especially the small farmers and producers on the one side, and the consumers on the other.

Modularization will not only affect food processing, but also the food supply chain, and will enable the creation of new distribution businesses that contribute to the sustainability and diversity of the system.

Recent publications have shown how research in concepts such as Horizontal Cooperation, Pooling and Physical Internet, might increase efficiency at the same time as reducing emissions.* Nevertheless, modularization faces some drawbacks such as the loss of advantages of economies of scale.

Figure. 6. Double funnel market structure of food supply chain in Europe (2012).



* Mangina, E., Narasimhan, P. K., Saffari, M., & Vlachos, I. (2020). Data analytics for sustainable global supply chains. Journal of Cleaner Production 255, 120300.

Goals and Objectives

- Adapt food processing to small-scale production and to increase its efficiency. This will be done by adding value, creating new intermediate products and by using digital technologies for process control systems.
- Adapt packaging to modularization and vice versa.
- Adapt the logistics channel to modularization and to modularize the logistic channel itself.
- Develop or adapt ability tools (introducing blockchain technologies) appropriate for the modularization process which assist in safety assessment and in delivering a quality label for the product.
- Involve end-users as actors in the process, allowing for culinary diversity and personalization of high-quality products with desired sensory properties.

Rationale and Significance

The approach needed will stimulate clustering of intermediate products of small or medium producers to operative networks and create new service structures. It will create new value chains and new business models. It will also create or reinforce new distribution models that will assist in increasing the competitiveness of modularized production. Modularization may disrupt existing value chains and create demand for new products, ingredients and intermediate products, and allow new concepts for pre-processed ingredients. It will also enable more local food production and diversify the food culture.

Potential Approaches

Enabling technologies include the internet of things as a source of information but also the internet as a way to supply products. Cloud computing will enable remote operations and systems control, as well as allow traceability implemented with blockchain technologies. It will involve the development of small mobile processing plants, and new models of logistics and advanced data analytics that fit to modular systems. Definition and standardization of intermediate products will be important elements of the development.

Moreover, the systematic conversion of packages from passive protection systems to active processing aids will be executed following the development of the necessary scientific and technological means.

Key Performance Indicators

- Reconfigured distribution channels and delivery modes (family and small businesses).
- Degree of food sovereignty - self-sufficiency.
- Reduced the carbon fingerprint.
- Sustained biodiversity of local ecosystems.
- Improved sustainability of local farms (rural areas) and local operations.
- Enhanced process efficiency.
- End-user acceptance of new productions and distribution modules.

3.2 R&I Target 2

Providing the Basis for a More Personalized and Customised Food Supply

Aim

In the future society, every citizen will have access not only to sufficient and affordable food, but will have exactly the 'right' food for him or her in terms of his/her preferences and physiological and psychological needs. Diverse choices will be available that make eating a cultural and social experience while simultaneously maintaining one's health and agility in various life stages. Our food will communicate these benefits to us via electronic means allowing us to be informed about it at all times.

R&I Target 2 is about achieving this goal by fostering developments in laboratory science approaches and in the social sciences to permit the understanding of both of why and how consumers choose and eat food as well as how food interacts with our bodies after it is ingested.

This deeper understanding will provide the basis for the design of intrinsically healthy foods that fit into the myriads of lifestyles in modern society. In order to develop these foods, one first must know in detail both the ways in which food is valued and what food actually does inside us after it is eaten.

For this, six key areas have been identified that deserve priority:

1. conducting research to better understand how food appreciation can be modulated to achieve maximal satisfaction;
2. methodologies that will add detail to our description of the effects of diet and lifestyle on non-communicable diseases;
3. developing new ways of enabling food to communicate with us and inform us about itself to allow for personalization;
4. understanding what happens to various foods after they have been ingested, especially in terms of
5. impact on our gut microbiota; and finally
6. how this translates in terms of reducing the development of non-communicable diseases.

Implementation

How food fits into our lives

The Food I Love, Appreciation of Diversity in Food and Eating

In the European context, food appreciation, how it is moulded by culture, and how it modulates how food is consumed and the consequences thereof in terms of health, wellbeing and sustainability, will be investigated.

(Tr)Eat Me, Dietary Approaches for the Prevention of Non-Communicable Diseases

State of the art methodologies from epidemiology, medical and analytical approaches and social sciences will be used to greatly accelerate and add detail to our description of the effects of diet and lifestyle on non-communicable diseases.

Packaging 4.0; Intelligent and Communicating Packages

Active and intelligent packaging will be developed by taking advantage of new knowledge of materials (including nanotechnology insights) and the possibilities that new generation connectivity brings.

What food does inside us

In Silico Food Design; Understanding Food Digestion

A multifaceted approach will be used to unravel the mechanisms of micronutrient digestion from complex food matrices. Experimental cell biology and human intervention studies will be accompanied by modelling approaches and this mechanism directed research will itself be complemented by epidemiological, Big-Data driven work on existing and newly generated information.

The Ecology Inside Us:Food Meets Gut Microbiome

Basic research on functional aspects of the intestinal microbiome will create the basis for establishing how specific foods affect human physiology via the microbiome.

Foods for Tomorrow: New Concepts and Technologies to Assure Consumer Health and Wellbeing

The last action item in this target is an overarching initiative in the form of a forerunner project. It will take the concepts of alternative food sources and upgrading of secondary product streams to a new level of ambition. In this initiative, the design of sourcing, processing and nutrient characterization will target consumer acceptance as a key end point.

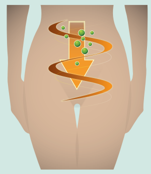
Expected Impact

A successful execution of this research and innovation target will lead to a societal strategy that ensures that consumers not only can eat the food needed to live life to the fullest extent, but also have the means to do so.

The work to be executed here will bring forward key insights into how the individual interacts with food. It will provide new knowledge which industry can use in the design of new intrinsically healthy and desirable products that fit into specific lifestyles and provide well-being to consumers. It will describe in detail the effects of diet and lifestyle on the development of Non Communicable Diseases (NCDs) in such a way that specific strategies can be designed, developed and communicated in order to attain positive changes. It will enable an understanding of how micronutrients and bioactive elements are made available to their target tissues in the human body. It will define approaches potentiating bioavailability through technological innovations. It will take the knowledge of the effects of foods on the human microbiome to a level that can be employed in positively affecting health via food and diet, and bring a new generation of ingredients and foods from alternative sources that are both sustainably sourced and welcomed by the consumer.

Can you imagine?

Our gut contains a larger number of microorganisms than there are cells in our body! And they can be modulated by the food we eat! Foods digested during meals contain ingredients and microorganisms that impact gut microbial and health. And you will feel good if your microbial is happy! As Hippocrates said: let the food be your medicine and medicine be your food!



Can you imagine?

You always wanted to know exactly where the fruit in your favorite multivitamin juice was from and whether it was from fair-trade sources. Scanning a bar code on the back of your juice package allows you to access this information. From previous scans, the system has learned that you are also watching your vitamin and mineral intake, and informs you automatically how a glass contributes to your daily levels.

Can you imagine?

You have this app which helps you make the right food choices. It measures how much you move, how much you rest. When you take pictures of what you eat, and what you want to eat, it will give you advice on staying healthy… in a friendly way. 'Please, no more of this today. Let's eat that tomorrow', or 'Why don't you have an apple and some yoghurt – we could do with some calcium', or 'great choice, that will give us vitamins we still need today' – allowing you to stay healthy while enjoying food.

3.2.1. The Food I Love: Appreciation of Diversity in Food and Eating

Introduction and Background

Food consumption is central to human life, not only in terms of nutritional needs (survival), but also in terms of social (relationships, local communities), emotional (well-being, life satisfaction), enjoyment (indulgence, sensory pleasure), and identity-related (values, food culture, authenticity) needs. With food (still) available in abundance, and food safety levels largely secured, food may easily be taken for granted in the European community.

Despite increasing similarities across Europe, consumer appreciation in terms of the perceived value and satisfaction from food and eating shows intriguing and valuable, yet poorly understood, differentiation. What (individual) consumers value and have concerns about may relate to any part of the food value chain and system, including primary production, processing and manufacturing, distribution, purchase, preparation, consumption and even its disposal. Lack of understanding of the diversity in what different consumers value in food and eating across Europe leads to suboptimal decisions, as it focuses on a heterogeneous average rather than catering for the diversity and the individual needs.

Enhancing food appreciation at the individual and sub-group level increases consumer satisfaction and wellbeing, allows business value creation and capture as well as policy level interventions (e.g., education and regulation).

The term food appreciation has different meanings in different parts of Europe, which differ between ethnic groups, (regions within) countries, age cohorts, socio-economic groups, education levels and even identity-based groups. Food appreciation changes over time as a result of new provisions in the marketplace, as well as from education.

Hence, it is important to track developments in food appreciation over time, in different groups and as a causal result of interventions (e.g., education). Understanding food appreciation will allow better alignment of its supply with the diversity in valuation by European consumers. This will bring economic value in terms of willingness to pay and reduced food waste.

Many economic sectors, including primary production, food processing and manufacturing, food distribution (both retail and e-commerce) and food provisioning [including (institutional) catering] will benefit from this, as will also peripheral industries (e.g. information and communication technology services). Of course, in addition to the economic benefits the consumer satisfaction will increase.

Goals and Objectives

The goal is to better understand and quantify the diversity in what European consumers value about food and eating as a basis for the European Food System to realize the full potential of the economic, social and sustainability value of Europe's food culture. The European food culture should be understood as the traditions and culinary evolutions within the regions and countries of Europe, but also through the insertion of ethnical foods from immigrants which have merged in Europe, creating in some cases even local evolutions of food traditions.

This is achieved through the following objectives:

- Identify the meaning and content of European consumers' food appreciation and its determinants from the whole food system perspective, including primary production, processing, purchase and consumption and food disposal.
- Map the geographic diversity in food appreciation across Europe, with focus on similarities as well as diversity across different countries, regions, socio-economic groups, food-related lifestyles and value structures.
- Identify the social diversity in food appreciation across different European consumer segments, and the diversity in: (1) current food and meal type choices (e.g. high versus low level of processing); (2) patterns in current consumption practices (e.g. what the implications for health, sustainability, authenticity and wastefulness in current practices are); (3) level of satisfaction and wellbeing; and (iv) willingness to pay.
- Identify the untapped potential for new products, new delivery models, and associated services (technology and information and communication technology) to create value and increase consumer trust.

Rationale and Significance

Better consumer appreciation of food and eating has value in the economic sense (higher willingness to pay), in a social sense (higher satisfaction and social capital around food and eating), and in a sustainability sense (less food waste and higher recognition of health and sustainability).

Insight into the heterogeneity of consumer appreciation, while at the same time also appreciating the similarities, may give us more diversified and better customer-aligned food provisioning across Europe. This will benefit both SMEs targeting specific niches and large manufacturing industries catering for larger groups. Aligning the diversity in supply with the identified diversity in food appreciation will:

1. increase consumer satisfaction and commitment;
2. extract larger value from the product supply (willingness to pay); and
3. increase cross-selling of new products and services (innovation and job creation) to further support food appreciation and increase trust.

Potential Approaches

Research: conceptually and empirically unravel the concept of food appreciation, its scope (e.g., acceptance of high versus low levels of technology in food production and processing, authenticity, social value from commensal eating occasions, sheer enjoyment, individual values, identities and predispositions), its origins (e.g., history and food culture) and its consequences (in terms of health, sustainability and wastefulness of consumption practices, consumer wellbeing and quality of life).

Innovation: identify and empirically validate the untapped potential for new options for products, delivery and services that add value to segments of consumers and thereby further support consumer appreciation of the food system.

Education: extract evidence-based recommendations for education programs for better understanding and recognition of diversity in food appreciation within European culture.

Key Performance Indicators

- Insight into the similarities and diversity across Europe in what consumers value in food and eating behaviour (mapping diversity in of food appreciation).
- Assessment of the impacts of food appreciation on current food consumption practices in terms of consumers' health, sustainability, trust and food waste.
- Identification of the economic potential of product and service innovation to better answer the diversity in consumer satisfaction at an individual or group level.
- Identification of the opportunities for better food and eating appreciation in out-of-home situations, including institutional environments, and its impact on health and wellbeing.
- Evidence-based recommendations for education programs to increase understanding and recognition of diversity in food appreciation within European culture.

3.2.2. (Tr)Eat Me: Dietary Approaches for the Prevention of Non-Communicable Diseases

Introduction and Background

Working methods and the age structure of the population in Europe have significantly changed over the last decades. This has led to a significant reduction in energy intake in the diet and, especially in the aging population, to a substantially higher need for optimal nutrition supplying a full set of micronutrients rather than calories. It is recognized that the role of nutrition is crucial for health and directly related to the health cost of society. There is a need for tailored nutrition depending on requirements related to age, gender and genotype. Furthermore, the microbiome has an impact on health, which is currently being increasingly investigated.

Epidemiological associations between the intakes of nutrients, foods or food categories, and dietary patterns with health outcomes are frequently not supported by results of randomized controlled trials. In addition, many non-communicable diet-related metabolic diseases share common comorbidities, involve multiple organ systems, and are multifactorial. For example, type 2 diabetes is not only related to cardiovascular disease, but also to cognitive impairment, mood disorders, and sarcopenia.

Such common comorbidities indicate shared underlying causes and pathways such as low-grade inflammation, impaired glucose and lipid metabolism, impaired vascular function, ectopic fat deposition, intestinal dysbiosis and environmental stressors. Common underlying causes and pathways may also mean that there are shared solutions.

These considerations urge the need for targeted hypothesis driven long-term intervention studies, not solely focusing on accepted biomarkers, but also on functional intermediate endpoints or even hard endpoints.

Goals and Objectives

- Identify and validate new dietary approaches to prevent NCDs and their co-related comorbidities, and to improve health in specific population groups or individuals, thereby progressing towards (semi)-personalized nutrition.
- Target shared mechanisms and pathways by dietary approaches to prevent NCDs and their co-related comorbidities.
- Identify and provide mechanistic underpinning for dietary approaches and develop behaviour change models to prevent NCDs and their co-related comorbidities and to improve health.
- Develop and validate new innovative, multidisciplinary approaches to predict dietary responsiveness.

Rationale and Significance

Dietary and lifestyle intervention strategies specially designed for specific population groups, e.g., the elderly and children, and their validation in well-powered intervention studies will support cost-effective strategies to reduce the socio-economic burden of NCDs.
This will also improve competitiveness of the European food industry by generating sound evidence of the benefits of healthy foods and dietary habits.

Potential Approaches

- Carry out hypothesis driven long-term studies to target shared mechanisms for preventing multiple (comorbidities related to) NCDs by dietary approaches.
- Improve predictive approaches (e.g., challenge tests, isotope labelled substrates, multi-omics profiles, 3D in vitro models) and biomarker profiles as well as algorithms to link these to responsiveness to dietary interventions.
- Develop and implement up-to-date approaches (for example individual feedback based on habits and preferences) to optimize compliance for effective life-style changes to prevent multiple (comorbidities related to) NCDs across Europe.
- Develop digital technologies (apps using computer vision and deep-learning based image analysis, wearables, web-based, etc.) to promote healthier lifestyles among individuals across Europe.
- Develop novel intervention strategies and adherence to healthier lifestyles by the use of digital technologies (apps using computer vision and deep-learning based image analysis, wearables, web-based, etc.).
- Encourage the development, validation and routine use of new and emerging potential biomarkers to support a healthy nutritional status and behaviour (e.g., apps, saliva, and dried blood spot testing).
- Determine what measures motivate people to incorporate such novel intervention strategies with long-term health consequences in current decision-making processes with respect to food.

Key Performance Indicators

- Availability of new, well-accepted and effective, sustainable dietary approaches to prevent NCDs and their related comorbidities.
- Availability of behaviour change models to prevent NCDs and their related comorbidities.
- Availability of an efficient integrated toolbox for identifying the most promising foods to be tested in specific population groups.

3.2.3. Packaging 4.0: Intelligent and Communicating Packages

Introduction and Background

Industry 4.0 denotes the concept of a manufacturing system with full integration of cyber and physical technologies, wherein machines and devices communicate with each other, as well as with users. In the context of a rapidly evolving digital world, one can envision packages providing an interface to implement an Industry 4.0 concept in the food systems arena.

The proposed action item involves the exploration of technologies that go beyond classical active and intelligent packaging approaches and allow full leveraging of digital connectivity.

Due to the Covid19 pandemic and recent trends, there is an increase of online shopping and thus an increase of last-mile distribution (retailer to consumer). This affects also packaging i.e., the volume of packaging and the way it is managed, produced, distributed, recycled etc. Investigating the impact of last-mile logistics on sustainable packaging systems could also lead to novel food packaging. In addition, there are new solutions to packaging, such as edible packaging, which could be further explored by future research taking a holistic view. Finally, another R&I pathway could be to connect the packaging systems with the home environment.

Goals and Objectives

The overall goal is to develop a new functionality that engages the consumer with the product in a new way. Information will be provided by the producer about the product and its condition but, potentially, also by the consumer. It will be processed, and an adequate reaction will be executed.

Potential Approaches

- Affordable, cheap and scalable digital technologies and new digital interfaces that can enhance consumers' engagement with the packaging & raise awareness about its sustainability and nutrition story, allowing more detailed information than that on the package. This should interact with the digital technologies developed (in 3.2.2) to promote healthier lifestyles among individuals across Europe to achieve a holistic approach to healthier and sustainable food choices.
- Intelligent solutions at different interfaces in the product packaging value chain.
- Intelligent packaging solutions that can transform the product offering to the consumer.
- Packaging that communicates actively with manufacturing and distribution systems and can register data to monitor quality in real time.
- Packaging that allows extended interaction in the home environment, such as the current concept of smart houses, that can control the home environment to provide additional information to the consumer (e.g., reducing food waste).
- Packaging that registers consumer preferences/habits at home/on the shelf. The information will be stored in a cloud database and used for benchmarking strategies.
- Ethical issues related to data storage and use need to be explored.

Key Performance Indicators

- Technologies which are relevant and directly applicable to business end use.
- Technology must be quickly and easily accessible, and its application by the consumer intuitive and acceptable.
- Technology must be affordable and deployable on a large scale.
- Technology must be compatible with packaging materials and formats and should be food application safe.
- Technology must be compatible with recycling packaging.
- Tools to measure packaging performance in terms of, shelf life, protection, durability, recyclability.

3.2.4. *In Silico* Food Design: Understanding Food Digestion

Introduction and Background

Many of the NCDs in our society are related to an unbalanced diet. Increased intake of specific ingredients should lead to better health and quality of life. However, simply adding health promoting ingredients often does not work as the food matrix plays a key role in making specific ingredients available for our digestive system.

Until now, the specific mechanisms that play a role during food digestion have not been well understood. Digestion is massively complex and involves (bio-)chemical and microbiological phenomena while the gastro-intestinal tract impacts on the properties of the food that is digested. In addition, digestion is affected by very complex control and feedback physiological mechanisms. Understanding digestive processes will enable us to understand how we can incorporate ingredients so that they will be taken up efficiently and, indeed, will have the desired health effects. This may then be done by incorporation in a matrix, by encapsulation, by complexation, or whatever mechanism is most effective for the desired bioavailability. Current in silico models can semi-quantitatively predict the fate of macronutrients (Fig. 7).

Moreover, the fate of specific functional micronutrients cannot be predicted at present. This then gives true functionality to functional foods: not only is the addition of healthy ingredients important, but also the structural incorporation in the matrix which is optimized towards achieving the right metabolic effect. In other words, here, the design of products is inverted. You start from the desired metabolic effect, and from this, the product is designed.

In addition, personalised foods require that food formulation and other aspects such as shape and size would be process variables that can be changed from one instance of the food product to the other, while satisfying microbiological safety and quality constraints. It is impossible to ensure this by experimental means because the infinite number of combinations of variables. One solution is to apply predictive models of the food process in a computer aided engineering approach, also called digital twinning.

Goals and Objectives

- Enhanced functionality by matrix effects, encapsulation and/or synergistic effects will allow development of new ingredient functionalities. This will require a concerted action to understand and model the digestive tract in order to generate structure-function relationships that allow for reliable prediction and design of matrix effects on the digestion of micronutrients.
- Understanding the fate of food matrices and the digestion of individual micronutrients in the gastro-intestinal tract and capturing it in an in silico open-source model. This will be the result of a concerted effort concentrating on a specific aspect of the food matrix or part of the digestive tract.
- Ensure that enhanced bioavailability is turned into products that consumers will find transparent and trustworthy.

Rationale and Significance

The actual health effects of functional ingredients are the basis of any functional food. They greatly depend on the matrix in which they are embedded and on the direct environment and shape of the ingredients being studied. For example, the type and form of complexation/chelation of iron is of great importance to its bioavailability. In addition, the matrix in which it is embedded is also important. The same holds for many other micronutrients. Increased understanding in this area will provide major opportunities for functional foods and facilitate the acquisition of evidence for measuring and claiming health effects. While in many cases it is daunting to model a complex system in silico, such models will very quickly lead to the blank spots where more research is needed. At the same time, they will serve as a platform connecting the different work pieces done by different partners over Europe. The new possibilities offered by Data Analytics and Big Data approaches will certainly be of great help in such efforts.

Potential Approaches

- Creating a concerted effort for studying micronutrient digestion. Non-invasive techniques (e.g., use of ultrasound, magnetic resonance imaging, sensors-in-pills, and stable isotope methods and monitoring plasma levels), invasive techniques (with animal models), and in vitro techniques will be combined into a large-scale, Europe wide program that unites many different partners to form a concerted effort for studying the fate of micronutrients in the digestive tract.
- Understanding the interaction between complexation/chelation/encapsulation and matrix effects to benefit the bioavailability of micronutrients. Here, a 'design' approach will be followed. The direct form of micronutrients will be changed through encapsulation and/or complexation/chelation, and the effects and cross-effects between micronutrient form and overall matrix will be studied.
- Mechanistic in silico modelling. The above open-source modelling system will guide research towards parts that are still not understood and crucial for understanding bioavailability. Different approaches are possible, but it is important that they lead to mechanistic understanding.
- Data analytics approaches derived from Big data will be used for in silico metabolic modelling. These may not only be based on existing databases but may also be combined with cohorts that are monitored using modern methods such as the use of wearables.
- Computer aided engineering approach (digital twins). This can be used in combination with sensor networks and Big Data analysis tools to control the process in real time.

Key Performance Indicators

- Increased understanding of micronutrient functionality. This may lead to a new generation of ingredients capable of better addressing malnutrition (e.g. hidden hunger).
- Outcome of in silico modelling. This can reduce costs by limiting the extent of intervention studies. It may also reduce the number of animal studies required, thereby addressing animal welfare issues.
- Executed Big Data. These will lead to new insights with respect to synergistic or antagonistic actions of ingredients.

3.2.5. The Ecology Inside Us: Food Meets Gut Microbiome

Introduction and Background

Nutrition and diet are essential for health and well-being. Ingested foods and drinks are "processed" in the gut. The gut serves two essential functions: a digestive one (digestion of foods and transfer of nutrients to the host) and a barrier one (protecting the host from invading microorganisms, toxic compounds and allergens). The gut is a complex ecosystem that remains at homeostasis in healthy subjects thanks to a constant crosstalk between key players: the microbiome, the epithelial barrier, the associated innate and adaptive immune systems and the enteric nervous system (Fig. 9). The gut ecosystem is also connected to the brain by a bidirectional exchange of signals via what is designated as the gut-brain axis. It is increasingly recognized that the gut-brain axis is influenced by the microbiome, which is then referred to as the gut-brain-microbiome axis. Disturbances of this ecosystem (such as a "leaky" gut barrier or changes in microbiota diversity) have been increasingly associated with several non-communicable diseases including diabetes, sarcopenia, cardiovascular diseases, allergies and autoimmune disorders, as well as psychological co-morbidities such as depression and anxiety.

The gut ecosystem is shaped by the genetic background of the host but is also largely influenced by environmental conditions, including diet and living conditions. In terms of prevention of non-communicable diseases, the influence of the maternal health and nutrition on the long-term health or risk of disease development is receiving increasing attention. At present, there is a focus on metabolic and immune imprinting, but this is progressively extended to mood and cognitive functions. It thus links physiological and psychological responses to food intake. It is recognized that there might be long term effects already initiated in utero during pregnancy.

However, the gut microbiota - food axis does not only play an important role in the early years. There is an urgent need to acquire additional knowledge of the aging digestive tract (e.g., aging of the digestive system per se and its absorption capacity) and the interaction between immuno-senescence and cognitive decline, nutritional needs, and lifestyle. Specific dietary and nutritional recommendations for aging people are basically lacking and should be established taking better characterized physiological needs into account, thereby realizing that lifestyle and psycho-social environment may play a critical role in healthy aging.

To maximize economic and consumer benefits of a microbiome-optimized nutrition, an integrated research approach of the gut ecosystem and a better understanding of the role of food and nutrition in the gradient from health to disease during different periods of life is needed. In doing so, it is necessary to take food structure and function and food microbiota into consideration, while examining key partners such as the gut microbiome, immune system and digestion/tolerance to foods and their effects beyond the gut. It further becomes increasingly critical to provide consumers with a more comprehensive and fact-based view of the potential risks and benefits of food constituents and processed foods via their impact on the gut ecosystem.

This approach is strongly connected to the assessment of potential health benefits of new food materials, novel processing approaches and to consumer research.

Goals and Objectives

The goal of this action is to gain a comprehensive and holistic understanding of the central gut-brain-microbiome axis in order to develop new functional foods or nutritional recommendations that lead to established or highly resilient gut and overall health. To that purpose, research should be conducted to:

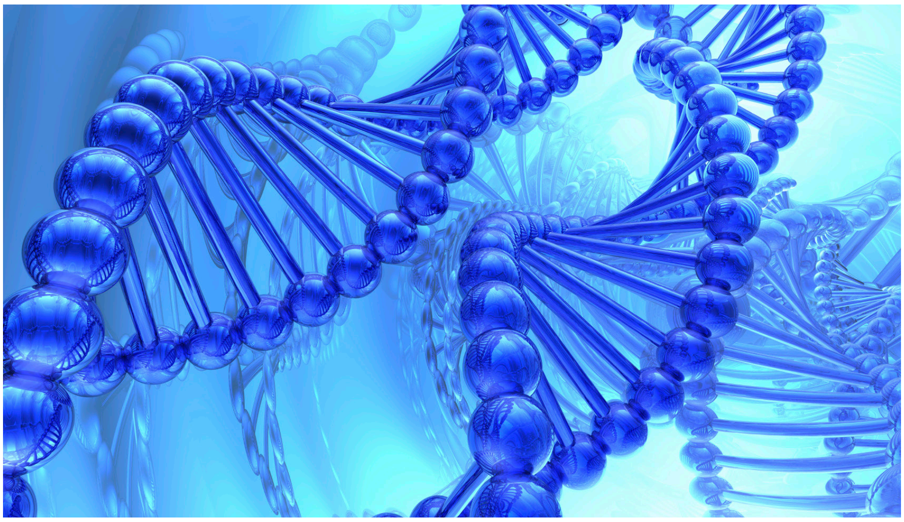
- Gain a better understanding of the impact of variation in microbiome function (rather than solely composition) and go beyond descriptive correlation studies to establish where this can be targeted by diet to achieve meaningful benefits.
- Clarify the cause-consequence relationships in the data described to date to generate working hypotheses that can be tested in well-designed human intervention studies.
- Establish to what extent NCDs can be reduced/prevented by nutritional interventions that impact on the microbiota, the gut barrier, the immune system and/or the enteric nervous system.
- Create awareness that one health benefit should not be obtained at the expense of another health benefit by conducting integrative studies on the different physiological effects induced by foods or food constituents.

Rationale and Significance

The intestinal microbiome is currently, and rightly so, receiving much attention from the scientific community - whether in academia or industry - but also increasingly from consumers and governmental and non-governmental organizations. However, current expectations for applications derived from microbiome research are based mainly on association studies. The cause-effect relationship of the current observations remains largely unexplored, which may lead to partial, or even wrong, conclusions. This may in turn lead to embarking on human interventions studies with limited chances of success.

The issue of whether meaningful effects on human health-related outcomes can be feasibly and sustainably derived from targeting the microbiome through dietary interventions needs to be further investigated.

The absence of such research may perpetuate unjustified emphasis on the microbiome as a route for nutrition intervention on the one hand, and jeopardize the possibility to design the appropriate health promoting foods on the other. Such a possibility relies on an improved understanding of the impact of foods/food components (including their microbiota) on the host gut ecosystem and could truly impact on the prevalence and treatment of NCDs.



Potential Approaches

- To develop ecological and functional approaches to studying the intestinal microbiome and move from description to function (including metaproteomics, metagenomics, metabolomics) with a strong emphasis on evidence of realistic diet-inducible effects in human systems.
- To perform mechanistic studies (preclinical) with foods/food constituents, raw materials, processed foods, functional ingredients and their related microbial ecology, on the different components of the gut ecosystem in order to clarify whether, for example, the observed changes in microbiota composition are a cause or a consequence of the correlated modulation of a health parameter, and judge the potential effect sizes that might be derived from dietary interventions.
- Based on sound and educated hypotheses, test food components/ processed foods/nutritional ingredients in small proof-of-principle human trials with well-defined primary outcomes (i.e., 'go / no-go' criteria). Develop the right "models" to support this research step.
- To generate new hypotheses by integrating multiple physiological readouts as exploratory measures in these studies and linking them to microbiome composition/function by using a systems biology approach.
- To test specific ingredients or matrix or processing effects to determine whether structure-function relationships can be established for health effects of diet acting via the microbiome.
- To characterize the ageing gut ecosystem in order to generate scientific underpinning for potential interventions and developing specific nutritional recommendations.
- To understand the role of the gut-brain axis and its interaction on behaviour and well-being, influencing decision making processes with respect to foods.

Key Performance Indicators

- Provision of a convincing description of the microbiota function, its impact on health parameters and cause-effect mechanisms proposed or elucidated to underpin meaningful health effects for dietary interventions acting via microbiota.
- Development of a methodology to align preclinical research with small human intervention studies in order to 'validate' preclinical assays.
- Building of coherent cases and performing sound experimental studies that address the impact of food structure, function and microbiota on the different components of the gut ecosystem.
- Identification of characteristics of the gut ecosystem (e.g. key microbiota consortia) that can be used to stratify subjects especially for the small scale human studies.
- Meaningful estimates of the health impact of dietary interventions that act via modulation of the microbiota.

3.2.6. *Forerunner Project* Foods for Tomorrow: New Concepts and Technologies to Assure Consumer Health and Wellbeing

Introduction and Background

Foods for tomorrow have several requirements. On the one hand, there is an urgent need for food produced with a more favourable carbon footprint and improved productivity to balance out the climate change induced reduction of farmland. On the other hand, food is required which supplies optimal nutrition depending on age, gender and genotype. Producing food in the current way cannot supply a population of 9 billion people without increasing the average temperature by an additional 1-2 °C. In addition to the carbon footprint, one already notes the effects of climate change, resulting in the loss of farmland and/or the increased need for water and pesticide use.

New approaches for sourcing, processing and manufacturing, and delivery systems for foods and food ingredients are constantly on the rise. These may be specifically intended to add or enhance nutrition and health benefits, to improve the nutrition status and/or be for cost savings or reduced environmental impact. In addition, they may also target global challenges such as the increase in the world's population, the decrease in land for food production (e.g., desertification) and climate change. The desire for more alternative or efficient and sustainable food supply systems drives the interest in alternative raw materials, improved processing (with regard to resource inputs and losses), and efficient (re-use) of un-utilized side-streams. All of these may have beneficial or adverse effects on the presence, retention, behaviour and functionality of nutrients and other health-relevant components. Nutrition goes far beyond the need to just supply calories. The economic and consumer benefits of future innovation will be supported by research ensuring that the nutritional impact of newly introduced materials and treatments are understood and managed, and that new opportunities to improve the nutritional quality of foods are identified and exploited. At the end of the day, food has to be delicious and enjoyable; it not only nurtures the body, but the soul, as well. Europe provides a wide variety of foods. The trend of localization of food within a global society providing local tastes, textures and flavours and ensuring a safe and sustainable supply will be crucial.

Goals and Objectives

Assess and maximize the potential health benefits of future foods and food materials as related to new processing methods in order to:

- Characterize the nutritional value of new or alternative nutrient sources.
- Develop new manufacturing approaches intended to help retain or enhance nutritional qualities with acceptable sensory properties (e.g. non-destructive technologies to monitor quality and/or safety).
- Improve prediction of potential nutritional implications of alternative sourcing and processing methods (e.g. implemented to improve sustainability and affordability).
- Increase the value of under-utilised side streams by characterizing and validating nutritionally beneficial components.
- Ensure that new food processing approaches will be viewed as transparent and trustworthy by consumers.
- Develop scientifically sound methods for assessing the broad sustainability performance in a systems perspective.
- Ensure the acceptability and actual use/ingestion of new concepts and technologies.

Rationale and Significance

Innovations in sourcing, processing, manufacturing and delivery of foods and food ingredients offer a wide range of benefits to agriculture, the food industry, individual consumers, and society in general. The ability to successfully exploit these new approaches to deliver improved taste, texture and health attributes with reduced costs and environmental impact will be crucial to maintaining a globally competitive and sustainable food industry, while contributing to improved health and wellbeing in Europe and giving answers to global challenges related to climate changes and a growing population.

The consumer's role in the supply chain has been identified as crucial in improving healthy choices and achieving sustainability goals, with the acknowledgement of the trade-offs between 'prosocial' versus 'proself' drivers of sustainable and health related attitudes.

Potential Approaches

- Identify potential sources of food, novel food with added health functionality, e.g. from under-utilised side streams and by-products.
- Evaluate current and new food sourcing and processing approaches.
- Develop alternative processing approaches, e.g. extraction, modification, fermentation, and processing aids, e.g. enzymes, to enhance the design/production and consumer acceptance of desired nutritional functionalities, e.g. those resulting from specific dietary fibres, new protein sources, nutrient-dense foods, less-energy dense foods, reduce the risk of food intolerance and allergies, etc.
- Improved understanding of societal acceptance and demand for new food sources for a healthier and more sustainable food chain. Barriers to and opportunities of the use of new food sources will be explored.
- Characterize the nutritional and sensory attributes of future foods/ingredients/raw materials derived from alternative food, protein and ingredient sources (e.g. algae, insects), extraction/isolation and production methods, or global regions (i.e. not traditional to Europe).
- Assess and develop/validate improved predictive models for effects of (new) processing methods on retention and transformation of nutrients, and impact on the digestion and bioavailability of micronutrients and macronutrients, and physiological effects.
- Utilize the already available data sources by applying adequate models and archiving methods.
- Analyse the effects of the systems' sustainability induced by novel raw materials and processing, thereby considering the dynamics in the supply chain.

Key Performance Indicators

- Standardized approaches and methodologies to characterize nutritional attributes of outcomes / raw material / foods generated by using new food sources and new processing.
- Validated improved predictive models for effects of (new) processing methods on the retention and transformation of nutrients, and impact on the digestion and bioavailability of micronutrients and macronutrients, and physiological effects.
- Consumer acceptance of new and alternative food sources including the valorisation of under-utilised side streams.
- Validated methods for evaluating the environmental implications of effects of large-scale changes in the supply chain.
- Advances in knowledge of new dietary approaches and promising foods that can be implemented by consumers on a daily basis as part of a sustainable diet.

3.3 R&I Target 3

Developing a More Flexible, Dynamic and Sustainable Food System

Aim

In our future society, good and healthy food should be available to everyone, while making sure that our Earth can remain healthy and even recover from current strains on the environment. To do this, we need to make much more effective use of all that we have, and we need to do it the right way to provide healthy, safe and wholesome foods, and not deplete any specific resource.

R&I target 3 is about achieving this goal by combining the exploration and use of new sources for our food and making sure that our future foods are as safe and healthy as they currently are, or even better.

For this, six key areas have been defined that deserve priority:

1. integrated food safety over the whole chain;
2. better understanding of the nature and role of both the internal food matrix structure;
3. the package, which ensures the integrity of the food product, should become much more environmentally benign and open to closure of the cycle of raw materials;
4. the quest for alternative raw materials for making good foods;
5. new ways of approaching key aspects of exposure assessment in the risk assessment process; and
6. less refined, more natural food ingredients to be used in minimal or gentle processing.

Implementation

Getting It Right: Integrated Food Safety as a Unique Selling Point

In any future scenario, the safety of our food should never be compromised. Safe, reliable food is essential for ensuring a healthy diet, avoiding the adverse effects of any food- borne illnesses, but also to ensure consumer trust. Already, European foods are often preferred in other areas, because of the virtual guarantee of their safety. In the future, with the trend towards milder processing and the use of a diversified portfolio of raw materials, as well as an aging population that will become more vulnerable to food-borne complications, the assurance of overall safety, integrity and wholesomeness is essential. Therefore, a programme will be created that aims at the assurance of integrated food safety and food quality over the whole food system.

This programme will take into account the implications of the emergence of new raw materials, new and milder processing methods, and new business models (e.g. having many smaller producers selling to individual consumers through the internet).

The Matrix Matters: Food Structure for Better Health

In our quest for healthier foods, industries and Academia have mostly looked towards the metabolic role of individual ingredients or even molecules. However, there is overwhelming evidence that this metabolic role strongly depends not only on the composition of our food, but perhaps even more strongly on the exact structure of the food. Some micronutrients are ineffective when added to, but very effective when naturally present in our food.

The reverse is also true: even macronutrient availability is strongly dependent on the structure in which it is consumed. This is even more the case in more vulnerable consumer groups: infants, elderly people, and people suffering from a disease. In some cases, over-nutrition leading to overweight and obesity is directly related to insufficient recognition of the importance of the food matrix, and the satiety that well-structured food provides.

The result is that a significant step can be made towards the healthiness of our foods, but also towards the efficiency with which we use our resources to feed ourselves, the latter being by better understanding and using the matrix of our food. The challenge is therefore to investigate the exact structure and fate of food during digestion. This is to make sure our food delivers good availability of micronutrients, provides adequate satiety to prevent over-intake, and reduces or even eliminates the occurrence of adverse effects.

Coming Full Circle: Towards Sustainable Packaging Systems

An essential part of the overall structure of a food product is its package. It provides integrity by making sure that the consumer gets what the label indicates. It also provides safety and stability by avoiding contamination, and enhancing the shelf life (by e.g., modification of the atmosphere in the package), and it contributes to the decision of the consumer to purchase that particular product due to the information on the package.

Unfortunately, food packaging contributes significantly to the world's environmental problems. The most often used material is non-biodegradable plastics, which can be incinerated but may also end up in the environment and contribute to the 'plastic soup' in the oceans. Other parts may be of metal. Since these are also discarded, all efforts to produce these materials are ultimately wasted. Thus, a programme should be initiated that will develop novel packaging solutions for the distribution and use of food products that are safe and significantly increase the environmental performance of the food systems. While this may be through further developing existing materials, it should certainly work towards more bio-based packaging concepts.

New ways and means should be explored to increase the circularity, which include recycling as well as reuse. This will not only include packaging concepts for existing types of products but will also consider packaging of new types of product creation and distribution, such as through 3D printing, in-store manufacturing and drone air delivery. In addition to this, significant work will be done to better understand and quantify the fate of packaging materials, in direct relation to their primary role and performance as packaging materials.

It's All Food: Alternative Food Sources

We are used to preparing our foods from plants – seeds, roots and tubers, leaves – and animals – mostly pork, poultry, beef and fish but, in fact, many more. Great foods are made from these resources, and these will continue to be major raw materials. However, to feed the world, we cannot only rely on these sources. We will need to diversify and explore other sources of good foods. Fortunately, Nature provides many more food sources. We may consider sources that are positioned earlier in the natural food chain, such as micro-organisms, algae, seaweeds, fungi, but also terrestrial non-chordate phyla such as molluscs and insects, as well as sources much later in the food chain, such as un-utilised side streams. Fermentation may be used to convert these streams into high-quality sources that can then be used either for cattle feed, or directly as human food. By doing this, the capacity for providing sufficient quality food will be greatly enhanced, while at the same time the footprint in terms of carbon, energy, water, land use or any other indicator will be significantly reduced.

Check It: Next Generation Strategies for Food Safety Assessment

The capacity to assess the risk that a food-borne hazard of any type presents to the consumer is fundamental and the basis for taking intervention measures across the food system. In the case of chemical hazards, the variety of potentially toxic residues detectable in food is continuously increasing. In recent years, toxicology and the assessment of chemical safety in humans has undergone a paradigm shift in approach due to the rapid advances in science (e.g., the chemical mixtures) and technology and the emergence of Big Data (e.g., the European Chemicals Agency, ECHA, (Quantitative) Structure-Activity Relationship (QSAR) models). As a consequence, new strategies are needed to meet the societal demands on reducing animal tests on human foods, for the safety assessment of food matrices and ingredients. In addition, microbial hazards constantly challenge the safety of the modern food chain. New threats appear from known hazards in unexpected situations, and organisms previously unrecognized as hazards reveal themselves to be pathogenic. Many of the factors that change the landscape of chemical risk assessment also alter the possibilities for undertaking risk assessments on microbial hazards.

Simply Natural: Towards Less Refined, More Natural Food Ingredients

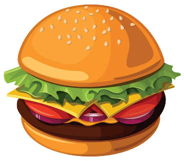
In the past decades, the production of ingredients has become highly optimized. Plant-based ingredients are often highly purified, which makes them universally applicable in many products. There is, however, an opposing consumer pull for new, less refined ingredients. In addition, fractionation and purification approaches also contribute to environmental impacts of the food system. However, while many less refined ingredients have excellent properties, they often differ from those of highly refined ingredients. Innovation in the use of less refined ingredients to allow manufacture (i.e., formulation and processing) of healthy, tasty and attractive products for consumers is therefore needed.

Expected Impact

A successful execution of this research and innovation target will lead to a world in which there is less stress on our environment by spreading the use of Nature over many more sources, and one in which European food is recognised as being completely reliable. This trust may make people open to trying out new products and products made from new raw materials. Be the prime trusted region in the world for innovative, sustainable, tasty and healthy food!

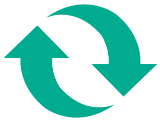
Can you imagine?

The drink you bought today: made from seaweed, healthy from its PUFAs, and the cartoon is made from sugar beet pulp! If you discard it, the carton actually re-fertlises the soil. Many people collect them to use them in their garden…



Can you imagine?

A new premium burger, made with fermentation from side stream from lupine, and it tastes great! In fact, it is also quite healthy. And it's European, so we know it's good.



Can you imagine?

You just looked for a recipe for your 3D food printer on your tablet. A bonus is that the packaging of the ingredients is an ingredient by itself- no waste! And since it comes from the EU, you know it's safe, so you're happy to try it out.

3.3.1. Getting It Right: Integrated Food Safety as a Unique Selling Point

Introduction and Background

Biology has seen a revolution with the introduction of cutting-edge technologies in the field of "Omics". The ability to rapidly and relatively cheaply decipher entire genome sequences, complemented by the ability to map the metagenome of microorganisms, holds the promise of significant advances in our understanding of microbial ecologies. Microbiologists can now uncover in great detail functional metabolic networks in their entirety – not only in single species of microorganisms, but indeed in entire communities.

The application of these "omics" technologies in combination with powerful computing capability creates tremendous volumes of sequence data that need to be analysed. Relevant composition and environmental data are also constantly generated across the food chain in the context of current quality and safety management schemes. New and unforeseen levels of data will be available as a result of more direct interaction with consumers who will have food products that communicate through intelligent interfaces included, for example, in packaging systems and mobile devices. Altogether, these and other data sources could generate a seamless picture of the micro-ecology across the entire food system, enhancing food safety and quality. The implementation of Big Data to food safety, however, requires data to be rapidly analysed and cross-correlated in order to translate it into useful and relevant biological insights, which could then be applied to develop effective interventions or control strategies.

Within the food safety and quality area, there is great potential for the generation and utilization of Big Data to obtain new biological insights for e.g., estimation of Burden of Disease and risk benefit analyses. Food safety and quality systems are based on a sound scientific base of risk assessment of both microbiological and chemical (toxicological) contaminants. More reliable risk assessments lead to better approaches to mitigation and/or elimination of risks.

Consumer demand for safe and stable foods has not truly changed. In fact, the high quality and safety standards of the European food supply are a characteristic that provides a substantial competitive advantage. However, there is now a pressing need to develop foods that are more gently processed to retain key organoleptic and functional (e.g., health-enhancing and nutritional) properties, and foods that have been sourced and processed sustainably. From a microbiologic point of view, this means a shift towards a combinatorial or hurdle approach to preservation. This is a holistic approach covering the entire farm to table continuum.

Microbiome techniques and approaches enhanced by data characterizing the various microenvironments will allow a much more detailed understanding of microbial behaviour and identification of metabolic and regulatory networks in communities that could reveal potential targets for control. This is critical to a hurdle approach where the microorganisms and their environments (the food matrix, processing, storage and distribution environments) are key elements to determining the efficacy of the preservation approach. Such modern data-driven concepts would also create the basis for scenario studies that could support foresight exercises to anticipate new risks.

Advances in genomics and epigenetics have allowed toxicology and the assessment of chemical safety in humans to move away from whole-animal deterministic approaches to one requiring understanding mechanisms of toxicity and human relevance. Considering the potential impact of Big Data and its translation into biologically relevant insights, the value of a research program in this area becomes obvious.

Goals and Objectives

To advance this field, a number of different objectives should be systematically pursued:

- Exploit the potential of Big Data in tandem with analytics to develop deep insights into microbiological and chemical (toxicological) contaminants and their behaviour across the food system for risk assessment, control and foresight purposes
- Apply omics technologies through Big Data to
  - Increase traceability;
  - identify potential targets for preservation;
  - develop enhanced predictive models on growth and survival;
  - develop next-generation risk assessment and mitigation protocols to assure food safety & stability; and
  - develop rapid, unambiguous, relevant and non-destructive identification methods for microbiological contaminants to reduce or contain the impact of incidents. This could be done via small and user-friendly analytical devices, with a rapid readout and low cost, that would speed the real time decision making.
- Develop a science and technology infrastructure (networked and coordinated information technology and microbiology capabilities and skills) that will position the European food industry as the leader in the use and implementation of data analytics as applied to food safety and quality. There is a need of a new type of researchers that are skilled in both microbiology and bioinformatics in order really apply Big Data to its fullest.

Potential Approaches

- Fund compelling strategic research programs that use omics technologies in combination with a more deliberate exploitation of big data analytics.
- Develop a strategic information technology microbiology ecosystem (looking outside the box) through collaborations with companies and institutions that have the 'new' skills and resources necessary. Partners will include enterprises, research institutes and universities having both the scientific computing expertise to help generate and interpret the data and the ability to generate and collect 'omics', chemical safety, and consumer data.
- Participate in and influence appropriate consortia that will drive progress and standardization, e.g., the COMPARE Consortium on Genome Sequencing of infectious pathogens or the Global sewage surveillance project where sewage from major cities around the world have been collected to detect, control, prevent and predict human infectious diseases recently also in regard to COVID-19.
- Establish a 'Virtual Centre for the Food Microbiome and Foodomics'. Such a virtual centre will boost progress in all fields of food related research with the attendant reduction of costs that such collaborative initiatives offer.

Key Performance Indicators

- A decrease in the incidence of food-borne diseases.
- A measurable decrease in food waste (or a measurable efficiency increase of the food system due to less food being lost due to microbial spoilage), and an increased use of side streams.
- An increase in the availability of 'more gently' processed food products.
- Availability of new reliable, predictive models to forecast risk areas and hazard points.

3.3.2. The Matrix Matters: Food Structuring for Better Health

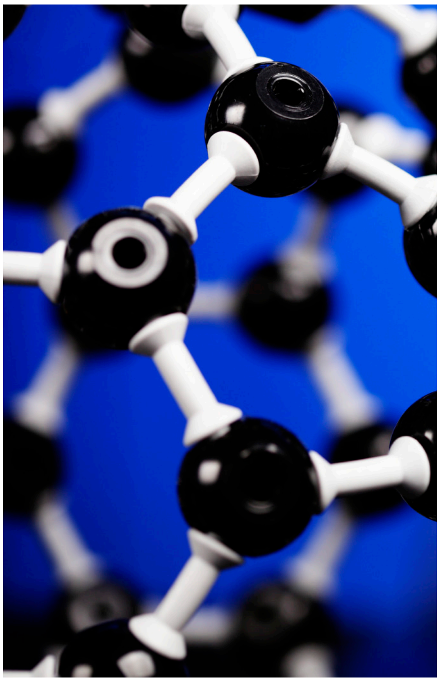
Introduction and Background

Many NCDs that plague our world are related to poor diet. A first point of concern is the global obesity epidemic, where excessive caloric intake is often coupled to (selective) under-nutrition. However, even when the caloric intake is appropriate, nutritional profiles are rarely optimal. In addition, the Western world is faced with an aging population. This poses major and often specific challenges to foods and the raw materials they consist of. On top of these food-derived aspects, which already challenge the European health care budgets, there is also a growing consumer awareness of the possible role of food as a direct source of health.

In a more technical sense, these challenges can be understood as a lack of intake and/or (bio) availability of key nutrients, suboptimal profiles of fats, carbohydrates (including fibres), proteins, as well as the over-abundance of high caloric/low satiety foods in general. More balanced diets generally can lead to better health and higher quality of life. In this context, increasing recognition is being given to the role of the food matrix and its interdependency with factors such as bioavailability, gut microbiota and the health beneficial bioactive substances themselves.

Simply adding beneficial ingredients is often insufficient, due to the key role the food matrix plays in making specific ingredients either available or unavailable (the latter in the case of caloric control) to our digestive system. Primary processing can play a key role to include natural bio-active molecules into matrices tailored for the concomitant final food products.

A deliberate creation of food structures that maintain the nutritional function of ingredients will ensure that uptake is more efficient, and that the ingredients will indeed have the desired health effects. This may be done by incorporation in specific matrix phases and substructures, by encapsulation with e.g., electrospraying, by complexation/chelation, by fermentation or by other approaches that render the components more bioavailable. Here, primary and final food processing can play a key role in making nutrients more or less available, thus enabling a better match between food and metabolic needs.



Goals and Objectives

New bioactive compounds (by utilization of underutilised side streams) providing enhanced health functionalities will be developed. Creating such functionalities will be intimately linked to an optimal integration in the (raw material) carrier matrix during processing. The following four objectives will be addressed:

- Food structures for optimal satiety and nutrient uptake will be developed. Based on a fundamental understanding of the disassembly of food matrices in the digestive tract, optimal structures for enhanced satiety and nutrient uptake will be developed and scaled-up.
- New technological approaches to better design matrix structures and compositions for the explicit goal of a health benefit optimization will be developed.
- Food matrices and encapsulation techniques that feature the appropriate interaction with individual micronutrients will be developed to optimize aspects like bioavailability. Conversely, the uptake of substances that are detrimental will be minimized.
- The generation of health-adverse co-products created during processing will be reduced.

Rationale and Significance

The actual health effects of functional ingredients greatly depend on the matrix in which they are embedded. For example, both the type and form of complexation/chelation of iron, on the one hand, and the matrix in which it is embedded on the other hand, are of great importance to its bioavailability.

The same holds for many other micronutrients. Generating a basic understanding of the molecular mechanisms/interactions of food matrices in the digestive tract is of vital importance. Building on such understanding, iterative developmental steps will support the successful development of innovative bioactive compounds.

Potential Approaches

Scientific Approach

This action will create hierarchically organized multiphase food structures that facilitate the physiological action of various functional ingredients, in particular in terms of novel processing and self-assembly concepts. A proof of principle at the bench-top/pilot plant scale is intended. At the same time, new analytical and data processing capabilities may have to be developed which are aimed at characterizing and optimizing such structures, compounds and processes. This work is also expected to deliver samples of health beneficial substances in appropriate matrices with good sensory quality for studying and optimizing bioavailability to the human metabolism.

Industrial Approach

Ingredient suppliers will be active players in the development of new structuring and processing approaches to create functional and acceptable food matrices. A close collaboration with both the primary producers and product manufacturers is needed to make this structure-based health approach economically viable. Scale-up expertise in processing, an understanding of economic and regulatory viability, and a demonstration of in-product feasibility and performance are needed.

Key Performance Indicators

- Number of processes and structuring technologies created or optimized (scale-up to at least pilot plant level).
- Number of raw materials and raw material clusters used.
- Changes in key nutritional and sensory indicators as a result of food matrix design (e.g. bioavailability, satiety).

Impact

- Consumer perceived health benefits due to reduced negative impact of primary processing, optimized bioavailability and enhanced health active substances.
- Consumer preferred food options enabling a lower caloric intake, thus facilitating a healthier lifestyle.
- Increased pool of skilled and knowledgeable European food processing engineers.
- Europe as a food brand: revenues from export of food products and technologies.

3.3.3. Coming Full Circle: Towards Sustainable Packaging Systems

Introduction and Background

The primary role of food packaging is to contain products and to avoid damage resulting from transportation and storage. It also ensures microbiological food safety and is a barrier against access by unwanted substances that can degrade the product (oxygen, chemical migrants), and against loss of elements like aroma or moisture. Packaging typically also contains a lot of information relevant to the consumer (such as ingredients, nutrition, and content of potential allergenic compounds, shelf life, handling and preparation) and the supply chain players. At the same time, packaging is often perceived as generating unnecessary waste and polluting the environment. However, efforts to optimize packaging can be detrimental to the environment, particularly if they fail to properly protect the product and thereby generate more food loss and waste. Therefore, packaging solutions must be looked at as part of the food supply system and their effectiveness must be measured in this holistic context. Consumption patterns and distribution channels are changing dramatically due to increasing numbers of single and small households, the increasing demand for healthy, fresh and sustainable foods, increased online shopping and the use of other new channels. As a consequence, packaging solutions must be adapted to new trends in order to yield the best performance in protecting food with minimal use of resources.

Furthermore, one of the biggest challenges for the plastic industry is the transition from fossil-based materials to a bio-based industry. Some parameters that are not well understood by citizens is that bio-based materials can be of two types: (1) Feedstock to produce the exact same material obtained using fossil-based materials or (2) unique polymers with its own structural properties. Regardless of the structure attainable by the bio-based material, they can be either non-biodegradable or biodegradable in the same fashion as fossil-based materials.

About 60% of the overall bio-plastics is used on packaging material, which in turn is mostly used for food packaging (or packaging used within the food system). However, there is limited information on the differences, identity and performance of bio-based polymers in comparison with their fossil-based counterparts. There are big challenges ahead: The scaling up of bio-based materials has become more expensive than fossil-based industry due to the systemic refinement of petrol oil and maximisation of the efficiency to the process. Bio-based materials have to account for factors such as water use, fertilisers, pesticides, competition with actual landmass used for food and feed, forestry practices, carbon emissions to the environment, and recycling costs.

At the endpoint of plastics life, chemical recycling arises as one of the most feasible technologies for plastic recycling, being complementary to mechanical recycling. It allows the recycling of composites and layered materials, which otherwise cannot be recycled by conventional mechanical methods. The development of chemical recycling still requires further research to fully achieve working scale, from a market, regulatory and infrastructure perspective, as well as real indicators of impact from the environmental (carbon emissions), economic (sustainability) and social (performance). The plastic business often requires multiple stakeholders in a global framework. To achieve a truly circular economy an effort has to be done from policy makers, industry and consumers to develop new business models and product designs that are included in a systemic approach.

Goals and Objectives

The overall goal is to develop novel packaging solutions for the distribution and use of food products that increase the environmental performance of the food systems (life cycle analysis). In this research action, new ways and means to increase the circularity, i.e. to increase recycle or reuse opportunities, will be developed.

Currently, there are technological, economical, and regulatory hurdles that need to be addressed simultaneously to decrease the loss of packaging materials into waste streams. Consumer acceptance of reuse solutions and options should be studied to assure that the new technical solutions will not fail in the market because they are ultimately rejected.

Potential Approaches

- Develop technologies to better collect, valorise and/or recycle packaging materials at end of their lifecycle (e.g., close-loop recycling technologies, mechanical recycling, up-cycling, down-cycling, chemical recycling).
- Research is needed on bio-based materials. Particularly on the environmental impact and its use in specific applications. Standardisation of the applications, realistic business cases, functional parameters and legislation applied are some of the areas of interest.
- Generate packaging concepts that can reduce food waste after first opening (e.g., by enabling complete emptying, or by better protecting leftovers in the original package to increase secondary shelf-life by optimizing and enhancing re-closing functions).
- Develop packaging materials, technologies and concepts with the right functionality and delivering superior environmental performance in the total lifecycle. Approaches are needed that generate materials of which less is needed and that last longer. Examples include nanomaterials, composites, and down-gauging films.
- Measuring the combined societal impact of proposed solutions (i.e., considering health, environmental and economic impact, as well as consumer acceptability implications) of proposed solutions to identify optimal innovations in different settings.
- Innovation is needed on the application of transport and logistics of food items without compromising food safety. The reduction of plastics on this area requires innovation inputs on design of logistics, design of packaging and design of sustainable business models to achieve full potential.
- Gaining acceptability and trust: Increase consumer trust using education schemes, better labelling and standardised policy regulation at European level.
- Develop new multidimensional tools and methods that allow for package optimization considering packaging performance in terms of, e.g., shelf life, protection, thermo-mechanical stability, processability.
- Standardisation, harmonisation and alignment are needed at global, but also at European level to achieve full efficiency on the investment and research efforts on recycling technologies. This action requires a systemic, multi-level, and multi-actor approach to achieve full potential.

Key Performance Indicators

- Reduced food losses and waste.
- Reduced leakage of packaging into environment.
- Reduced packaging-driven environmental impact.
- Improved recyclability of material and infrastructure.
- Decreased proportion of packaging materials not re-cycled or valorised.
- Increase use of biodegradable materials for food packaging use, maintaining sustainability on the making.

3.3.4. It's All Food: Alternative Food Sources

Introduction and Background

The availability of food from environmentally sustainable sources is a pre-requisite for feeding a growing population and preserving resources. One way to obtain more food is to make better use of the diversity that Nature offers. New raw materials and processes to convert them into food products/ ingredients need to be identified. A key challenge for future food security is meeting the demand for sustainable sourcing of the main food building blocks being proteins of non-animal origin, (healthy) lipids and (healthy) carbohydrates (e.g., dietary fibre).

A general observation is that the current agri-food chain is biased towards the higher levels of the food pyramid: in the human diet there is a relatively strong emphasis on fish and meat. Especially for the latter large quantities of feed from plant origin are required thus greatly amplifying the ultimate ecological impact. Instead, we could also harvest the resources that are near to or at the bottom of the food chain, either marine or terrestrial. In the sea, algae, seaweed, and krill are present in abundance and with careful management a significant harvest could be realized. We can also make better use of the terrestrial non-chordate phyla (insects, molluscs) which typically grow very quickly, and efficiently metabolize their plant food into animal biomass. In addition, we can harvest these not from 'wild' stocks but rather cultivate them in terrestrial or marine farms, which, if carefully managed, allows for concentrated growth and controlled quality while limiting environmental footprint.

A third source of food remains also relatively untapped, i.e., food grown directly from waste, manufactured through direct use of side streams or by-catches from the sea. Our society and industries produce very large quantities of side streams which are now either discarded, burned, or sometimes partially re-used, composted, and combusted. However, we can also convert the organic parts into food, for example, by fermentation using novel fungi, food-grade bacteria and yeasts, and further refining. In a world with ever larger metropolises, it would be attractive to re-use wastes to grow food that is also used in the same metropolises, thus mitigating the logistics and the depletion of the surrounding countryside. Aside from growth practices, biotechnological and enzyme approaches can be used to convert non-food materials into food. Overall, the various approaches could alleviate raw material shortages that are already occurring thereby increasing food security across Europe. Obviously, when using lower grade effluent streams rigorous measures should be in place to prevent challenges from a safety or quality perspective.

Goals and Objectives

We strive here to reduce the overall environmental impact and the reliance on imports, and to improve the quality of foods by introducing a host of new raw materials for the production of food.

- Finding ways to process lower organisms (microorganisms, algae, insects, molluscs, and krill) efficiently into high-quality food ingredients. This requires overcoming a number of important technical, health and cultural (e.g., under what conditions will consumers consider and even choose food made from these lower organisms and how can we make sure they do not pose any health risk to consumers, incl. new allergies) hurdles.
- Finding ways to efficiently grow micro-organisms (fungi, bacteria, archaea, yeasts, etc.) on waste and harvest those for production of food ingredients.
- Finding ways to overcome cultural hurdles that may inhibit adoption of use of alternative raw materials in food products.
- Finding new ways to utilize process side streams and valorise them by further processing (purification, fermentation, enzyme, or physicochemical catalysis). This makes the best possible use of the complete starting raw material. The efficient removal of unwanted components sometimes concentrated in side streams, as well as safety and regulatory considerations incl. allergenicity assessments, will be important points to address.
- In order to use the ingredients derived from new raw material sources, it is imperative to develop an in-depth multi-scale understanding of their functionality, sensory attributes, and nutritional quality and how to tailor their functionality for use in complex foods. This includes multi-scale understanding of ingredient functionality (gelling, foaming, emulsification etc.), the study of interactions (molecular) between different ingredients and assessing the eating quality of the final applications. Here bioinformatics can be a useful tool.

Rationale and Significance

The use of lower organisms and waste or underutilized side-streams as raw materials to produce new food is more efficient than the use of higher organisms, such as our current C5/C6 plant sources, and mammal and avian species for food. The use of lower organisms can be a big step in increasing the efficiency of food production. Additionally, the composition of these organisms may be attractive from a nutritional perspective. Insects have an excellent protein composition, while sea organisms contain oils and other nutritionally important components.

Using waste and underutilized side-streams as a raw material may not only help in the production of food but also in reducing the total amount of waste created in urban environments. It may also shift food production partly into the cities and bring food production closer to the individual consumer (who could even become a local producer). It thus may help create a different type of society.

Potential Approaches

Industrial Approach

Usage of new raw materials will only be successful if there is a market for them. However, a market can only be developed when the supply is guaranteed. This system lock-in can only be broken by a concerted action of ingredient suppliers and food producers. Therefore, a consortium will be built around exploring a limited number of possible new raw materials to further refine them into food ingredients.

Innovative Approach

While many potential raw materials have an interesting chemical composition, new processes will need to be developed to recover value components in the most effective way. Due to the involved processes and raw materials, the resulting ingredients will likely be novel and will therefore need a thorough characterization in order to evaluate their potential as food ingredients and ensure that they can be approved. In the recent years, for example, precision fermentation has been proved to be an enabler of new sources of animal protein and of fungi and algae refinement.

Scientific Approach

The identification and mapping of new raw materials is a key element. A thorough understanding of possible raw material sources, their composition, nutritional quality, availability and allergenicity must be built including risk-benefit analyses. New fractionation and/or enrichment or elimination processes will need to be developed. This will help to focus on the most promising materials and allow a more targeted approach. Moreover, as consumers may not always accept new raw materials as source of their food, consumer research is needed to understand what influences acceptance by consumers of new raw materials and production processes.

Key Performance Indicators

- Creation of intellectual property and new businesses.
- Number of viable new raw materials identified.
- Economic feasibility demonstrated.
- Consumer acceptance of new raw materials and production processes has been assessed.

Impact

- Percentage of foods consumed derived from/containing new ingredients.
- Growth in employment, e.g. new jobs created in cultivating, harvesting new raw materials.
- Lower dependence on raw material imports into the European community.
- New consumer food experiences.

3.3.5. Check It: Next Generation Strategies for Food Safety Assessment

Background and Rationale

The capacity to assess the risk that a food-borne hazard of any type presents to the consumer is fundamental to those charged with overseeing the food chain. Risk is the basis for taking intervention measures and applying resources across the food system. In the case of chemical hazards, the variety of potentially toxic residues detectable in food is continuously increasing because of industrial development, new agricultural practices, environmental pollution, rapidly evolving analytical procedures, and climate change. In recent years, toxicology, and the assessment of chemical safety in humans has undergone a paradigm shift in approach. We have moved away from a science based solely on whole-animal deterministic approaches to one based on understanding the underlying mechanisms of toxicity and relevance to human metabolism e.g., cocktail effect predictions. Factors contributing to this shift include rapid advances in science (particularly in genomics and epigenetics), advances in technology (e.g., analytical, computational toxicology, systems biology, bioinformatics) and the emergence of Big Data. The scientific value of data generated with animal tests is under discussion while, at the same time, society is demanding the transition to non-animal assessment methods like e.g., QSAR models.

This new "toxicology in the 21st Century" approach was heralded by the US National Research Council (NRC) in 2007, and the OECD has subsequently provided guidance on developing and assessment of adverse outcome pathways. As a consequence, new strategies are needed to meet the societal demands on reducing animal tests on human foods, for the safety assessment of food matrices and ingredients.

A main human health risk related to novel foods, is the risk of introducing new food allergies, either as de novo sensitisation to the novel proteins (development of new allergies) or via cross-reactions to known food and respiratory allergens (eliciting reactions in already allergic individuals). While this aspect of new and sustainable

Goals and Objectives

The overarching goal is to develop an integrated strategy for food safety assessment adopting a 'from farm to fork' approach which includes monitoring strategies for the safety of food throughout the food chain. It will include the comprehensive assessment of food safety, quality, and traceability as a whole.

- An open and transparent culture of food will be created. It will guarantee safety amongst all stakeholders and confidence in consumers.
- Sustainability will be addressed within the context of food safety.
- Approaches to assess the combined health, environmental and socio-economic impact of foods and food systems, including of dietary shifts, will be developed. The assessment of health impacts will cover nutritional and food safety aspects (microbiological and chemical), to ensure that the risks and benefits of consumption of different foods are considered. The estimated impacts will be used to compare and prioritize proposed solutions.
- A platform trusted by the food industry and consumers for the safety assurance of food will be built without the need for animal testing. Doing so will deepen the insight in the underlying mechanisms and phenomena.
- Genomic approaches will be exploited to drive microbial safety assessments to new levels based on deeper and more strain-specific knowledge of human-microbe interaction and a fuller understanding of the micro-ecologies of the food chain.
- New detection methods with shortened analysis time for potential hazards, critical control points (and monitoring).
- Developing practices to eliminate or reduce the risk of these hazards occurring.

food products has received very limited public attention, the actual problems, and unmet needs, are significant. As no specific properties are recognised for being predictive of allergenicity, methodology may be based on a weight-of-evidence approach, which includes knowledge of the source of the proteins, sequence homology to known allergens, susceptibility to enzymatic digestion, specific IgE binding in selected patient groups as well as cell-based and in vivo analyses.

Microbial risk assessment, whilst not as mature as that applied to chemical hazards, is still the scientific basis of the governance of modern microbial food safety. Microbial hazards constantly challenge the safety of the modern food chain. New threats appear from known hazards in unexpected situations, and organisms previously unrecognized as hazards reveal themselves to be pathogenic.

Many of the factors that change the landscape of chemical risk assessment also alter the possibilities for undertaking risk assessments on microbial hazards. This is certainly so for genomic, systems biology and bioinformatics developments. Parallel to the possibilities in toxicology, the incredible discrimination that these approaches permit, when applied to the interactions between the microbe and the human (pathogenicity and dose-response), opens up the possibility of greatly reducing the high level of uncertainty caused by the current "taxonomical" approach of attributing pathogenicity to all organisms that share a name. This approach, in addition, would reduce food waste which could be a relevant key performance indicator.

The application of these approaches to microbes in a food environment (or an environment's metagenome), together with the constant gathering and analysis of microbiologically relevant compositional and environmental data which happens as a matter of course in the modern food chain, will generate a seamless picture of the micro-ecology of the food chain. This will permit new ways of approaching key aspects of exposure assessment in the risk assessment process.

Potential Approaches

- All parties work together to assure the practical implementation of the new methods and procedures that will be developed.
- Detailed research into the way consumers perceive risk and food safety. Integration of the findings in the new methods and procedures. Involvement and engagement of consumers in methods and procedures.
- New and better methods to assess chemical safety especially in complex food matrices. Flexibility and innovation are required to deal with new challenges such as the allergenic potential of new ingredients such as new and modified proteins. This may include miniaturization of analytical systems (labs-on-a-chip), reduction of sample preparation for fast screening methods, and new analytical methods to detect and characterize nanomaterials.
- Bringing together all of the chemical safety-directed approaches to develop a roadmap of research with the explicit objective of reducing and eventually replacing animal testing by the use of QSAR models.
- Working with the full complexity of data (and subsequently models) - analytical, food chain, consumer and public health generated - in an overall integrated approach to safety assessment.
- Big Data enables the safety of the food in the marketplace to be monitored using post-launch monitoring approaches. Combination with machine learning methods will allow leaps in our understanding of causes of a breach of safety.

Key Performance Indicators

- Quicker, less expensive routes for the assurance of food safety.
- A better understanding of human metabolic pathways and interactions that will allow the prediction of the safety of a food or new components by using in silico models.
- New methods that will enable the minimization or even elimination of animal testing without compromising on food safety.
- Integrated strategies in foodomics, including advanced analytical techniques like risk-benefit analyses and bioinformatics which will integrate food safety assessment into a better overall understanding of nutrition.
- More precise methods for the microbiological safety assessment of foods based on the real risk presented by an organism and not only its wider taxonomic status.
- Reducing food waste without compromising on food safety by risk driven food microbiology diagnostics.
- Transparency will increase consumer trust in the food value chain.

3.3.6. Simply Natural: Towards Less Refined, More Natural Food Ingredients

Introduction and Background

In the past decades, the production of ingredients has become highly optimized to meet purchaser demands. Plant-based ingredients such as sugars, proteins, starches, and many other ingredients, are often highly purified, which makes them universally applicable in many products. There is, however, an opposing consumer pull for natural ingredients due to perceived beneficial effects on health. Concerns about "E numbers" and an overall drive towards increased transparency of the food system have created demand for new, less refined (i.e., more "clean label") ingredients. In addition, fractionation and purification approaches also contribute to environmental impacts of the food system, having an effect on the sustainable use of raw materials, energy, and water. However, while many less refined ingredients have excellent properties, they often differ from those of highly refined ingredients. Innovation in the use of less refined ingredients to allow manufacture of healthy, tasty, and attractive products for consumers is therefore needed. These may include food tailored for specific consumer groups and conventional products, but they may also be ingredients that facilitate the production of very new products (e.g., components that allow foods to be 3D-printed).

Modern insight into the properties and structure of the raw materials enables development of a new generation of food ingredients by tailored fractionation of the raw material into classes, which are not pure isolates, but which consist of mixtures of structures and components with very good functionalities, both in a technical and in a nutritional sense. In addition, increased understanding of complex raw material matrices will enable development of smarter processes with an integral approach to use raw materials more holistically. This is in opposition to the conventional approach, which divides the raw materials into main streams used for products and side streams being discarded or used for something else (Fig.7).

For example, an impure plant protein fraction obtained by concentrated wet fractionation is superior to a pure isolate in emulsion stabilization and pH robustness. Extracting complete oil bodies with a mild aqueous extraction yields a vegetable oil that is well protected by its natural membrane, giving it a chemical stability of several months. With it, stable emulsion products can be manufactured without the need of any stabilizer. Using such types of new, more complex structured and composed functional ingredients may give opportunities for more "clean label" products, with less need for additives having E-numbers. As a side benefit, this could minimize risks for the increasing group of consumers that are subject to food allergies.

Production methods tailored to employ the minimally necessary level of processing may offer improvements in environmental sustainability as well as in production costs, since raw materials do not have to be completely broken down and then built back up to form complex foods. At the same time, this will enable products that are less refined to be manufactured, because a significant portion of the ingredients contain fibre and other components. Such products may have superior properties in terms of stability, since biological systems designed to protect the raw materials from degradation may still be intact.

Goals and Objectives

This action aims at developing new methods to fractionate food raw materials into functional ingredient classes, without striving for purity at a molecular level. The goal is thus to explore the naturally occurring nutritional and functional properties using minimal or gentle processing. To accomplish this, projects will be carried out:

- To understand how consumers view 'naturalness' and how its perception is linked to characteristics of food origin and processing.
- To understand how the benefits of minimally processed ingredients can be communicated to consumers in a convincing way.
- To develop new methods to prepare minimally processed, highly functional ingredients with only a fraction of the resources needed in conventional ingredient refining and with reduced use of additives and processing aids. Method development will be linked to understanding the impact of using less refined ingredients on the taste and appearance of the food products

and may include in situ generation of flavours by fermentation. Recent developments in sensory research will be integrated.

- To exemplify how raw material matrix understanding, combined with an integral approach to smart processing, enables full exploitation of raw materials with overall higher value creation.
- To explore and understand the nature of the interactions in semi-refined ingredients which give rise to their specific properties. Understanding from a molecular to a supramolecular level is needed to identify the decisive parameters for optimal functionality and nutritional value of these ingredients for incorporation into food products.
- To define crop characteristics for optimal processing, thus selecting new cultivars with improved profiles suited for new fractionation methods with respect to separation efficiency or yield.
- To develop scaled down processing solutions to enable more local ingredient sourcing away from global mass production ("glocalization"). Such provenance will be at the heart of establishing naturalness credentials and will build consumer trust through a radically transparent agri-supply chain. Using simple fractionation, e.g., dry separation, one can already separate part of the raw material (e.g., the husks and bran) on the farm, leave valuable soil nutrients on the farm, and only transport the nutritionally valuable part to processing plants, thus lessening soil depletion, and reducing the need for transportation and lessening the production of waste.
  To explore food safety aspects of novel processing methodologies, including safety assessment of new processing chains (microbial, allergen and anti-nutritional components) and traceability for local down-scaled processing (semi-refined ingredients).
- To decrease declaration short lists by developing functionally complementary single origin ingredients.
- To explore and understand the attitude of consumers to products made from functional fractions without E-numbers and to find the best way of answering the call of the consumer for cleaner-labelled food and consumer demands for food produced in an environmentally sustainable way.

Rationale and Significance

The European food and drink industry can take a giant leap.
Production costs can be significantly lowered, products can contribute to health (thus mitigating diet related non-communicable diseases), and the industry can implement a more viable path to food production using a knowledge-based approach to food ingredient classes. The value is not so much in the fraction or the class as such, but mostly in understanding how we should apply it to food products, and how to relate these new properties into products that the consumer wishes to purchase and consume.

Thus, this radical, yet realistic action will have far-reaching consequences. It will give the European food industry a significant competitive advantage, while offering a long-term approach towards improving our health, reducing energy and water consumption, and reducing waste and carbon emissions.

Potential Approaches

Industrial Approach

Production of new types of ingredients will only be successful if there is a market for them. However, a market can only be developed when the supply is guaranteed, and its application is accepted in the marketplace. This system lock-in can only be broken by a concerted action of readily adaptable/agile ingredient producers, together with some major food producers.

A consortium of small, medium, and large-scale enterprises will be built around exploitation and demonstration of the feasibility of a limited number of less refined ingredients to create an open market for these types of ingredients. When transforming the agri-supply chain, care will be taken to address the requirements of more localized production.

Innovative Approach

Functionality is a major driver for developing food ingredients that meet market demands. Understanding why and how impure fractions with preserved natural components contribute to better functionality and health beneficial effects will redefine the market for tailored and sustainable food ingredients.

The innovation approach will consist of an adaptation of biology-inspired processes supporting the consumer demand for naturalness, thus using, for example, naturally occurring enzyme cascade systems and naturally occurring sources of microorganisms for fermentation.

The perception of product quality and of naturalness and its acceptance will then be studied with consumers or through test markets.

Scientific Approach

Research has to be conducted to uncover the reasons for consumers' perception, appreciation and acceptance of the naturalness of less refined ingredients. This can give direction to the development of specific solutions. The reason for new properties and functionalities exhibited by less refined ingredients is not fully understood.

This requires significant research efforts, ranging from fundamental to applied, in which colloidal and nanoscale approaches will yield insights into structure - function relationships of biological systems at the relevant size ranges. The action will require an interdisciplinary approach spanning:

- understanding the nature of raw materials from molecular to macroscopic scales;
- the stability of ingredients once removed from the raw materials;
- design of optimal fractionation procedures not only during standard food process operations, but also during primary processing;
- potential reconstitution needs; interaction of the new ingredient classes in food matrices; and
- economic factors.

This will allow the food and drink industry, as purchasers of the new food ingredients, to assess viability. Additional research will then be needed to prove safety and benefits of new ingredients in humans.

Moreover, research will be required to understand consumer preferences for products with fewer E-numbers and more natural ingredients, based on product sensory perception, physiology and social and cultural contexts.

Key Performance Indicators

- Alternative sustainable and biological (natural) processes for producing processed raw materials with equal and/or improved functionalities when compared to their currently available fractionated forms.
- Approval of the above raw materials for use in foods.
- Market releases of raw material structures that allow the creation of new food properties.

Impacts

- A new class of more natural food ingredients which will support the development of potentially health-promoting food based on preservation of natural functionalities and improved possibilities for individualized food and will have a potentially positive impact on public health systems.
- An increased integration of primary producers in the food production chain which will increase the livelihood opportunities of farmers by increasing the value of crops.
- A renewed focus on the functionality derived from many diverging raw material structures will shift agricultural practices towards an increased valuation of crop biodiversity rather than just yield.
- Support for new job creation and job retention in rural areas will be achieved through down-scaling of processing methods, which will be of particular importance to Eastern Europe, fostering an increased modernization of agri-food chain production methods.
- Consumer trust in the agri-food-industry through generation of a more transparent food system with minimally processed food ingredients and more cleanly labelled food.
- A more sustainable use of raw materials, energy and water, thus positively impacting the environmental effects of food production.

4. Appendix 1 Related Initiatives in the European Research Area

The success of the execution of SRIA of the ETP 'Food for Life' relies on an effective collaboration with other partners of the European Research Area, coming from sectors such as ICT, manufacturing, energy, transport, nanotechnology, water, agriculture, etc. and with the relevant funding structures. Below is a non-exhaustive list of related initiatives and groups the ETP 'Food for Life' is keen to cooperate with to accomplish the proposed objectives.

4.1. EU R&I Framework Programmes

Horizon 2020 was the biggest EU R&I framework programme to date with nearly €80 billion of funding available over 7 years (2014 to 2020) implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing Europe's global competitiveness. By coupling research and innovation, Horizon 2020 put the focus on excellent science, industrial leadership and tackling societal challenges.

Building on the success of Horizon 2020, the new EU R&I Framework Programme, Horizon Europe, will run from 2021 to 2027. With a proposed budget of €80.9 billion, Horizon Europe aims to strengthen the EU's scientific and technological base, boost Europe's innovation capacity, competitiveness and jobs, and provide evidence for other EU policy areas and programmes.

4.2. EIT's Knowledge and Innovation Communities (KICs)

The European Institute of Technology (EIT) integrates all three sides of the 'knowledge triangle', i.e., higher education, research and business, in Knowledge and Innovation Communities (KICs), fostering the entire innovation chain – including training and education programmes, reinforcing the journey from research to the market, innovation projects and business incubators. Its goals are, among others, creation of new businesses and new jobs, and the promotion of new skills and entrepreneurial talent in the economy.

There are currently eight Innovation Communities, and each focuses on a different societal challenge: climate, digitalisation, food, health, sustainable energy, manufacturing, raw materials, and urban mobility. EIT Food is working to make the food system more sustainable, healthy and trusted, by building an inclusive and innovative community where the consumer is actively involved. EIT Food's six strategic objectives are:

1. Overcome low consumer trust;
2. Create consumer-valued food for healthier nutrition;
3. Build a consumer-centric connected food system;
4. Enhance sustainability through resource stewardship;
5. Educate to engage, innovate and advance; and
6. Catalyse food entrepreneurship and innovation

4.3. European Innovation Partnerships (EIPs)

EIPs promote technology transfer to increase the impact of actions funded under Horizon 2020 by linking them to a broader strategy.

The EIP on 'Agricultural Productivity and Sustainability' (EIP-AGRI, launched in February 2012) aims to foster a competitive and sustainable agriculture and forestry sector that 'achieves more from less', contributing to ensuring a steady supply of food, feed and biomaterials, and a sustainable management of the natural resources. For achieving this goal, the EIP-AGRI builds bridges between research and practitioners.

4.4. Scientific Committee for Agricultural Research

The Standing Committee on Agricultural Research (SCAR) was established in 1974 and re-launched in 2005. It is a source of advice on European agricultural and wider bioeconomy research, along with being a major catalyst for the coordination of national research programmes. SCAR currently represents 37 different countries, the members being ministries (or other organizations such as research councils) from all EU Member States, with Candidate and Associated Countries as observers. The SCAR Strategic Working Group in Food Systems provides strategic advice and orientation to support the EU R&I policy framework. For this purpose, SCAR FS SWG has set up 5 objectives:

1. Monitoring food systems outcome in light of governance and future proofing;
2. Increasing diversity among food systems;
3. 'Food Environment' drivers and outcomes;
4. Zero waste from food systems; and
5. Knowledge management.

4.5. Smart Specialisation Platform for Agri-Food

The Smart Specialisation Platform for Agri-Food (S3P Agri-Food) established at EU level aims to accelerate the development of joint investment projects in the EU by encouraging and supporting interregional cooperation in thematic areas based on smart specialisation priorities defined by regional and national government linked to agriculture and food. Through the S3P Agri-Food, EU regions and Member States are able to implement more efficiently their smart specialisation strategies, and regional stakeholders benefit from the new cooperation opportunities with partners from other regions.

The key objective of the S3P Agri-Food is to orchestrate and support the efforts of EU regions committed to work together for developing a pipeline of investment projects connected to specific thematic areas of smart specialisation priorities through interregional cooperation.

4.6. FACCE-JPI (Agriculture, Food Security and Climate Change)

FACCE-JPI gathers Member States committed to ensuring sustainable food production under climate change while at the same time protecting the environment and natural resources. The actions funded are targeted to achieve a sustainable food security under climate change and an environmentally sustainable growth and intensification of agricultural systems under current and future resource availability.

It also aims at assessing and reducing trade-offs between food production, biodiversity and ecosystem services, adapting to climate change throughout the whole food chain and mitigating greenhouse gas.

4.7. JPI HDHDL (Healthy Diet for a Healthy Life)

JPI HDHL brings together 25 countries that collaborate together to align their research strategies in the area of nutrition and health. It is focused on ensuring that the healthy choice is the easy choice for consumers, on developing high-quality, healthy, safe and sustainable food products and on preventing diet-related, chronic diseases and increasing the quality of life. JPI HDHL focuses on the consumption side of the food chain while FACCE-JPI's main focus is on the production side. Nevertheless, both initiatives have a common interest in the impact of climate change on providing a sustainable food supply that has the nutritional requirements to ensure a healthy population.

Besides FACCE and HDHL, the current list of JPIs includes: JPND (Neurodegenerative Diseases), JPI CH (Cultural Heritage), JPI-MYBL (More Years Better Lives), JPIAMR (Antimicrobial Resistance), Water JPI (Water Challenges for a Changing World), JPI Oceans (Healthy and Productive Oceans), JPI Climate (Connecting Climate Knowledge for Europe) and JPI UE (Urban Europe).

4.8. ERA-Nets

ERA-Nets are designed to support public-public partnerships in their preparation and coordination of joint activities as well as European Union topping-up of a trans-national call for proposals in the area of research and/or innovation projects, resulting in grants to third parties. Some examples of ongoing ERA-Nets are:

- SUSFOOD 2– Sustainable Food Production and Consumption
- SusAn – Sustainable Animal Production
- BiodivERsA – Consolidating the European Research Area on biodiversity and ecosystem services.
- CORE Organic (under prep.) – Organic farming
- LEAP-AGRI (under prep.) – EU-Africa food nutrition security
- MarTERA (under prep.) – Blue Growth
- PhotonicSensing – Photonics

For a complete list of past ERA-Nets in the Bioeconomy, please refer to the ERA-LEARN 2020 platform at http://era-platform.eu/

4.9. European Technology Platforms (ETPs)

Industry-led stakeholder fora that define medium to long-term research and innovation agendas and roadmaps for action at EU and national level, ultimately enhancing European competitiveness. They are organisations independent from the European Commission, although the Commission participates in their events as an observer. Some Member States have established national technology platforms to mirror ETPs: some to build capability and enable their research communities to influence and participate in European activities, others to align their activities with the shared strategic vision. There are ETPs placed in the areas of bio-based economy, energy, environment, ICT, production and processes and transport. Some examples are: Food for Life, Plants for the Future, TP Organics, Aquaculture, Fisheries among others.

4.10. Joint Undertakings (JUs) or Joint Technology Initiatives (JTIs)

Joint Technology Initiatives are long-term Public-Private Partnerships managed within dedicated structures based on Article 187 TFEU. Members of the Joint Undertaking include the European Commission, a not-for-profit industry-led association and Member/ Associated States. Small and medium-sized enterprises (SMEs), research organisations (including universities) and corporate members are all welcome to join the industrial associations.

JTIs support co-operative research across Europe in fields of key importance for industrial research, where there are clearly identified common technological and economic objectives. A JTI implements a common Strategic Research Agenda, jointly defined by its members, and organise their award funding for projects on the basis of open calls.

The current JTIs are Innovative Medicines 2, Fuel Cells and Hydrogen 2, Clean Sky 2, Bio-based Industries; Electronic Components and Systems for European Leadership and Shift2Rail. A related type of initiative is the Single European Sky ATM Research 2020.

The Joint Undertaking on Bio-based Industries (BBI) is a public-private partnership aiming at increasing investment in the development of a sustainable bio-based industry sector in Europe. It focuses on feedstock, biorefineries and markets, products and policies.

4.11. Contractual Public-Private Partnerships (cPPPs)

In the cPPPs the contractual arrangement specifies an indicative 7-year EU funding, and the budget is only committed on an annual basis. The Commission is responsible for implementing the programme, which is governed under the rules of the EU R&I Framework Programme: Interested organisations form consortia and submit proposals in response to call topics announced annually by the Commission. Following an independent evaluation, a project is assigned a percentage of funding from the European Union with the rest of the funding and resources coming from the members of the project consortium. To date, ten cPPPs are in place – some already dating back to 2008 (Factories of the Future, Energy-efficient buildings, European Green Vehicles) whilst others have been set up later when Horizon 2020 started in 2014 (Sustainable Process Industry, Photonics, Robotics, High Performance Computing, 5G Infrastructure, Big Data Value and Cybersecurity). Almost all cPPPs were sitting in the LEIT (Leadership in Enabling and Industrial Technologies) pillar of Horizon 2020, such as:

- **SPIRE (Sustainable Process Industries through Resource and Energy Efficiency)** is dedicated to innovation in resource and energy efficiency and enabled by the process industries. Its objective is to develop the enabling technologies and solutions along the value chain, required to reach long term sustainability for Europe in terms of global competitiveness, ecology and employment. More specifically, SPIRE is addressing three fundamental European challenges: create growth and increase competitiveness, rejuvenate the European process industry and reduce resource and energy inefficiency and the environmental impact of industrial activities.
- **FoF (Factories of the Future**) aims at enabling a more sustainable and a more competitive European industry by supporting European manufacturing enterprises in strengthening their technological base.

4.12. European Partnerships in Horizon Europe

The Horizon Europe proposal lays down the conditions and principles for establishing European Partnerships. There are 3 types:

1. Co-programmed European Partnerships: These are partnerships between the Commission and private and/or public partners, based on memoranda of understanding and/or contractual arrangements.
2. Co-funded European Partnerships using a programme co-fund action: Partnerships involving EU countries, with research funders and other public authorities at the core of the consortium.
3. Institutionalised European Partnerships: These are partnerships that require legislative proposals from the Commission and are based on a Council Regulation (Article 187) or a Decision by the European Parliament and Council (Article 185). They are implemented by dedicated structures created for that purpose.

The identification of European Partnerships will be an integral part of Horizon Europe's strategic planning process. The portfolio of European Partnerships includes 49 candidates collected across 5 areas: health; digital, industry and space; climate, energy and mobility; food, bioeconomy, natural resources, agriculture and environment; and cross-theme partnerships.

From the list of candidates, the one with special relevance to the work of the ETP 'Food for Life' is the European Partnership for Safe and Sustainable Food Systems for People, Planet and Climate. This partnership will underpin the needed transition to sustainable food systems, provide solutions to the Farm to Fork strategy by connecting national, regional and European research and innovation programmes and food systems actors. The partnership aims at foster alignment, boost investment, and increase the societal relevance, impact, uptake and visibility of research and innovation and strengthen EU leadership in tackling food system transformation. Other partnerships with will also directly or indirectly connect with the work of the ETP 'Food for Life' are the one on accelerating farming systems transition and those for a Circular bio-based Europe and for Chemicals Risk Assessment.

4.13. Missions in Horizon Europe

European R&I missions are an integral part of Horizon Europe. Missions aim to deliver solutions to societal challenges within a certain timeframe and budget. The areas where the first batch of missions will be rolled out have been announced: cancer; adaptation to climate change; healthy oceans, seas coastal and inland waters; climate-neutral and smart cities; and soil health.

At the end of June 2020, the Board of each mission produced an interim report proposing concrete targets and timelines for possible missions. Although food is touched upon on several of these reports, we strongly believe that a food system-themed 'mission' is essential to make real progress towards the EU Green Deal's ambition.

5. Appendix 2

From the first publication of the Strategic Research and Innovation Agenda of the ETP 'Food for Life' in 2016, further collaborations have been carried out with other stakeholder representatives. Of specific interest are the Joint Strategic priorities for research and innovation with Copa-Cogeca's Working Party on Research & Innovation and ETP "Food for Life", published in 2019; and the joint policy brief 'Translating the Green Deal into Practice: Research and innovation opportunities for sustainable food systems', performed jointly with TP Organics and the ETP 'Plants for the Future' in 2020. Both documents have been included here as a further development of the ETP 'Food for Life' Strategic Research and Innovation Agenda.

5.1. Copa-Cogeca's Working Party on Research & Innovation and ETP 'Food for Life' (October 2019)

Joint strategic priorities for research and innovation

1. **Climate change mitigation and adaptation**: this is a key priority that has a huge impact on the future of the agricultural sector and the availability of food, feed and other products and services that are critical for a sustainable society. Research and innovation should address both mitigation and adaptation and take into account the whole agri-food sector, including consumers. For example, solutions are needed for a more climate-smart and robust agri-food sector focused on water and energy efficiency, with innovative technologies, digital tools and plant and animal breeding techniques that provide the sector with the means to tackle climate change and its effects. Only with a more integrated approach can we meet our international commitments, EU targets and take consumers with us as we stand up to face this challenge.

2. **Circular bioeconomy**: improving resource efficiency through the application of circular and bio-based approaches is key for the EU agri-food sector. This will enhance the environmental and economic sustainability of the entire agri-food sector and create new business and employment opportunities. A crucial element that needs to be addressed is mobilising all actors across the agri-food sector, including consumers, to prevent losses/waste and an improved use of residues, by-products and co-products.

3. **Vital rural areas for a dynamic society**: Reversing depopulation of rural areas and creating the conditions for generational renewal are of crucial importance both for the EU agri-food sector and for the Union in a wider sense. If we want rural areas

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to be more connected as well as fair, sustainable and competitive value chains, it is essential that we enhance the sustainability of existing businesses and promote new business models, which needs to be supported by education and training, infrastructures and services. This will help the EU preserve its diversity of traditions in food, diets and landscapes and ensure that it can continue to produce the food it needs.

4. **Co-creation and co-development of ideas and approaches across the agri-food chain**: new tools and models are needed to enable more successful innovations and a better connection between the consumer and farming and agri-food practices. This will help build more trust and appreciation (mutual understanding) across the whole value chain.

5. **The development and uptake of new technologies by the agri-food sector must be addressed by future research and calls for innovation**. Examples include new breeding techniques, digitization, satellite and sensor technologies as well as artificial intelligence. New technologies and their adoption and use will have a positive impact on the agri-food sector's contribution to the SDGs and to food safety and security. An accelerated uptake of digital technologies will help enhance transparency and trust within the agri-food sector, including consumers, and will enhance its sustainability and competitiveness. Transforming the sector into a connected one will help improve logistics (e.g., prevent losses of fresh produce) and promote collaboration with other sectors like the bio-based industry.

5.2. TP Organics, the ETP 'Plants for the Future' and the ETP 'Food for Life' (July 2020)

Translating the Green Deal into Practice: Research and innovation opportunities for sustainable food systems

The European Green Deal and the Farm to Fork strategy therein, announced by the European Commission, aim to transform the agri-food sector and arrive at a carbon-neutral, circular, resilient, and resource-efficient food system, restoring biodiversity and promoting sustainable and healthy diets to citizens. Such transition will heavily affect the EU as the agri-food sector provides the highest number of jobs in Europe . To progress on these goals, research and innovation (R&I) is needed to minimise unfavourable trade-offs and to develop, implement and scale-up workable solutions. The Green Deal offers the opportunity for companies to take the lead in the transition to more sustainable practices which - with the right support - can lead to a thriving bioeconomy within planetary boundaries. By well-chosen R&I investments, Horizon Europe can contribute to making these opportunities come true.

The European Technological Platforms (ETPs) 'Plants for the Future', 'Food for Life' and TP 'Organics' have jointly developed R&I policy recommendations to address several of the most pressing challenges for food systems. The recommendations focus on primary production and consumption, and. They are the outcome of a dedicated expert workshop to discuss priorities common to the three ETPs . This executive summary will be followed by a more exhaustive report.

As the entire agri-value chain has an important role to play in the transition, the ETPs propose that in another track R&I opportunities are being mapped out that are critical to bridge primary production and consumption.

Challenges in sustainable food systems

Climate change

Agriculture and food production are both a main cause and victim of climate change. Farmers are increasingly suffering from the effects of climate change in terms of global warming and weather volatility. The rise in temperature is increasing the migration of pests and disease from south to north, while heat waves and irregularities in water supply have become frequent in Southern Europe and have also start to occur in Northern Europe. To secure sustainable production of crops and livestock the agri-food sector needs to invest in R&I to both adapt and mitigate the effects of climate change.

Biodiversity loss

Agriculture through land use change and practices is a main contributor to biodiversity loss. Failure to act now will cause further losses of agricultural biodiversity and natural biodiversity. This will negatively impact the overall ecosystem, as well as society when it comes to food diversity, choice, affordability and a healthy environment. All actors in the food system and especially farmers need to be enabled to adopt more diverse crops and agroecological practices to maintain the natural balance of ecosystems and to produce in a sustainable fashion. A special focus on below-ground biodiversity is needed, since soils are key to maintain the resilience of agriculture production.

Consumers competence

Consumer choice is a primary driver for demand at farm and industry level and shifts in consumer choice bring change in the entire food system. However, effective market incentives for healthy and sustainable individual food choices are currently missing. To reduce the environmental impact of food production, diets should be promoted that are composed of diverse, healthy and nutritious sustainably produced ingredients and that ensure culturally accepted, joyful consumption. To achieve this, consumers should be aware and trustful of the overall food system and its co-benefits, supported by a holistic regulatory framework.

Malnutrition

Food plays a central role when health is considered as a state of physical, mental and social well-being. A consumption lifestyle driven by unhealthy diets is at the basis of malnutrition. Malnutrition relates to a lack or overconsumption of calories in a diet and to an inadequate consumption of essential nutrients. It ultimately contributes to the rise in non-communicable diseases. To fight malnutrition, better consumer knowledge needs to be developed to successfully promote a shift towards a healthy diet and lifestyle.

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R&I recommendations

An environmental performance toolbox

To adapt to climate change and to maintain or even to improve crop yield and quality, farmers need access to state-of-the-art tools and knowledge regarding available crop varieties and livestock breeds, including their performance in various environmental conditions. R&I is needed to catalogue and improve crop and livestock performance by testing, across the EU27, the effects of diverse combinations of livestock and crops with diverse and mixed cropping systems. This should be done on a multi-year, multi-cropping scale, in combination with sustainable and mixed agricultural practices, and should include information regarding farm outputs, such as carbon sequestration, landscape maintenance and/or rehabilitation, and biodiversity.

These data would need to be brought together into an environmental performance toolbox and be made accessible to farmers and other stakeholders such as breeders, advisors, food business operators, retailers, policy makers and researchers. Farmers could select from the toolbox the optimal combination of crop varieties; livestock breeds and agricultural practices to fit their conditions and needs in the most sustainable way possible. It is anticipated that decision support systems will be needed to enable the best use of the toolbox, and that switching to more sustainable practices will require financial support to mitigate business risks.

The environmental toolbox is expected to optimise farm productivity and contribute to climate change adaptation and mitigation by promoting a wider use of more environmentally friendly crop varieties and livestock breeds and management thereof, and of appropriate processing practices.

Smartly reducing pesticide use

For many farmers pesticides are currently essential to maintain crop yield and quality and to profitably operate the farm. At the same time, pesticides have a negative impact on biodiversity, on the ecosystem and on human health. There is therefore a push to reduce the use and risk of pesticides. R&I is needed to

1. investigate pest and disease resistance in plant genetic resources and how to accelerate genetic resistance using breeding techniques;
2. improve and broaden farm management practices, such as crop rotation, intercropping, tillage, use of functional biodiversity, biological control, use of natural predators, use of microbiome, pre-treatment of seeds and precision farming;
3. develop and optimise new digital monitoring technologies, such as disease/pest detection sensors to enable preventive measures; and
4. identify and develop environmentally friendly pesticides.

To successfully reduce the use of pesticides it will be critical to consider the specific needs of the different sectors, e.g., arable crops, horticulture, etc. Experimental real-life labs and demo-farms need to be set up to demonstrate feasibility and to provide training to farmers. For the highest impact, solutions will need to be tailored to the needs of individual regions/farms.

Improving consumer knowledge and choice regarding healthy and sustainable diets

The purpose of increasing the competence of consumers regarding healthy and sustainable diets is to enable an increased demand for diets meeting such criteria. Such demand would create a market pull enabling value chain players to respond and to set up tailored production channels across the food system. R&I is needed to 1) understand the drivers and barriers for consumer choice associated to healthy, diverse and sustainable diets, and 2 determine how to promote best consumer education and awareness on the foregoing. Many options exist (e.g., school education, social media, focus groups) and the best practices will vary depending on criteria such as age, ethnicity, financial means etc. Information should be tailored as much as possible to the target groups. R&I is furthermore needed to 3) install harmonized and effective communication with citizens and consumers across Member States, including labelling, advertising and food products co-creation. For this, R&I is needed to 4) advance traceability and transparency regarding the sustainability and health impact of food products throughout the value chain.

Short food supply chains offer here an excellent entry point to connect consumers with producers, thereby increasing consumers' food competence, while increasing transparency of the value chain. This R&I action should be supported by a timely harmonisation of standards and of Member State policies regarding healthy diets to promote a concerted multi-actor value chain approach addressing a growing consumer preference for healthy and sustainably produced food.

Diversified farming systems for diverse diets

A broad dietary diversity is a cornerstone of a healthy lifestyle in which disease is prevented rather than cured. The taste, nutritious value, health, sustainability and diversity of diets is to a great extent determined early in the production value chain at the farm by the choice of crops and livestock, and the associated farming practices.

By broadening the diversity at the farm level, the variety of healthy, sustainable diets offered to consumers can be extended and tailored, and thereby lead to higher adoption. R&I recommendations include

1. exploring and improving alternative protein sources, including plant-based protein;
2. improving livestock breeding and management (including feed characteristics) for mixed farming systems with a lower environmental impact;
3. developing new varieties of existing crops, reintroducing and domesticating niche and heirloom crops, and developing and introducing new or underutilised crops; and
4. developing and scaling up new crop rotations and new intercropping techniques, to diversify the number and types of crops grown on one farm or in one region.

Promoting diversified farming systems for diverse diets, human health and resilient production is a joint responsibility of policy makers and actors in many areas: agriculture, health, education, environment and R&I services. A multi-actor approach is needed to avoid fragmentation and develop a resilient food system built on diet diversity.

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