WORLD-CLASS FOOD INNOVATION TOWARDS 2030

Bringing Danish Research Solutions to the Global, Sustainable Food Production

VERDENSKLASSE FØDEVAREINNOVATION FREM MOD 2030

Danske forskningsbaserede løsninger til global, bæredygtig fødevareproduktion

EXECUTIVE SUMMARY

This strategy sets out the vision of the Danish food industry and supplier relative to creating a mutual food research and innovation agenda with the ambition to ensure that the Danish food cluster[1] also by 2030 will be among the world's leading food producers.

Six key challenges that may be turned into opportunities, if mastered at a high level, have been prioritized followed by a list of key research and innovation enablers describing areas where future research and innovation activities are high in demand.

It is the intention that this strategy should serve as a catalog of knowledge, inspiration and prioritization to be used in a wide variety of contexts from the political negotiations of the national budget to the strategic considerations in companies, at research and technology organizations, universities and funding bodies.

The potential for the Danish food cluster is vast. Delivering the potential requires an ambitious goal and a common solution. With this strategy, the Danish food industry and suppliers give their joint picture of the challenges facing the cluster and the enablers within research and innovation, research infrastructure and in relation to talent and education.

The prioritized enablers within research and innovation are:

1. Sustainable production through circular economy
2. Food design – from molecular interaction to excellent eating
3. Food analytics – documenting safe foods
4. Omics technologies – from molecules to understanding
5. Foods contributing to health and well-being
6. Agile and intelligent automation
7. Connected and competitive through smart use of big data.

Investing time and money in joint research and innovation relative to these enablers will help solve the key challenges, benefitting both the society and the Danish food cluster. We invite politicians, funding bodies, industry and the research community to collaborate and in a joint effort put action behind this strategy.

1 In the following, the Danish food cluster refers to the cluster of food producers, food processors, suppliers, research and technology institutions, universities and authorities working closely together.

PREFACE

During the recent decades, the food industry and suppliers have witnessed a transformation in the choice, quality, safety and affordability of the food we all eat. However, even today we face bigger challenges; therefore, we need to think differently about food. We need to produce more food without jeopardizing the natural resources and the environment. We need to feed more people globally, many of whom want or need to eat a better diet. We need to connect better with consumers and customers around the world to better understand and meet their needs and desires. We need to tackle the explosion in non-communicable diseases and encourage healthier diets. And we need to do it all while at the same time delivering continuous improvement in food safety and premium eating experiences.

The Danish industry is ready and capable of being a strong player in a future global solution. To tackle these challenges, the cluster is facing, a number of Danish food producers and suppliers have taken the initiative, in collaboration with The Danish Food and Drink Federation (DI Fødevarer) and the Danish Agriculture & Food Council (Landbrug & Fødevarer), to develop a food research and innovation strategy, with the aim to identify common challenges that the industry anticipates in the coming years and to come up with focus areas based on pre-competitive research and innovation collaborations.

The present strategy will, if implemented, ensure that the Danish food cluster can thrive as an innovative, competitive and resilient sector, thus continuing to secure growth and jobs. Enforcing agile knowledge exchange at all levels and support world-class public research and innovation within prioritized focus areas of our industry cluster will be key to achieve this goal.

This strategy sets out the Danish food industry and suppliers' vision of creating a mutual food research and innovation agenda with the ambition to ensure that the Danish food cluster, also by 2030, will be among the world leading when it comes to producing food, ingredients, process equipment and services, and developing the industry per se.

By working together on joint opportunities, we, as a cluster, can ensure that Denmark remains a world-leading food nation. The Danish food industry and suppliers are eager to be important players in solving the global food challenges, thereby also securing future employment and prosperity in the Danish society.

Knud Vindfeldt
Chairman of the working group

A FOOD CLUSTER READY TO TAKE ON THE FUTURE

The Danish food cluster – consisting of primary producers of food, non-food and feed, the processing industry, technology providers, ingredients industry and knowledge and research institutions in the field of food – has developed into a global success that creates growth and employment throughout Denmark. As of 2015, the sector employed 190,000 people and exported for approximately 155 billion DKK accounting for 24 percent of Denmark's total export of goods [2],[3] . In fact, the food cluster exports food to more than 130 different foreign markets[4]. The food sector is therefore of great importance to the Danish society.

The cluster is characterized by a small number of big, global companies, including dairies, slaughterhouses, breweries, enzyme/ingredient companies and technology providers with very strong global market positions and, in addition, a large number of small and medium-sized food businesses[5]. The Danish food cluster produces food for many people, it develops knowledge, ingredients, equipment and solutions that are important to the global food production, and is recognized for high food safety standards, and a reliable, high quality food production carried out under organized and safe conditions[6]. Furthermore, the Danish food cluster is recognized for its efforts and investments in producing more with fewer resources and with less environmental impact. This has positioned Denmark positively in relation to delivering on the global demands for resource-efficient, sustainable production solutions and food products[7]. This will undoubtedly be a future key competitive advantage that will be critical for the "license to produce" of the Danish food industry and its many suppliers.

Stronger together

This position is based on a long tradition of close cooperation between universities, knowledge institutions, industry and authorities, and between small and medium-sized and large companies across the entire value chain from primary agriculture and fisheries to processors and producers of ingredients and foods, technology and equipment[8] – something relatively unique to Denmark. A strong interdependency exists between the parties in the food cluster with clear roles and responsibilities. These are summarized below.

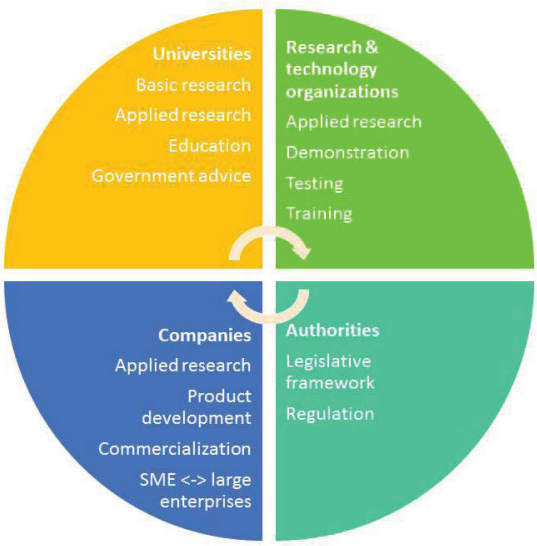

Figure: Roles and responsibilities of the partners in public-private research and innovation collaboration.

2 Landbrug & Fødevarer. Fakta om erhvervet 2016, Copenhagen, 2016.

3 Fødevareklyngens eksport rejser længere væk, DI Analyse, Copenhagen, November 2016.

4 http://um.dk/da/eksportraadet/sektorer/foedevarer%20landbrug%20og%20agroindustri (accessed 20 August 2017)

5 Vækstteam for fødevarer. Anbefalinger, Copenhagen, April 2013.

6 Styregruppen bag 'Den fælles danske fødevarefortælling'. Den fælles danske fødevarefortælling, Copenhagen, 2016.

7 Innovation in the food industry; An international benchmark study. LEI Wageningen, July 2013.

8 Vækstteam for fødevarer. Anbefalinger, Copenhagen, April 2013.

Also, our long tradition of gathering stakeholders around the table having a short distance from the minister to the director, to the agricultural organization, to the user organization, etc. is unique to Denmark and envied by other food nations. The close collaboration takes place without jeopardizing the governmental authority. The close cooperation at all levels is a competitive advantage that should be treasured and safeguarded as basis for continued success of the cluster.

A sustainable future

The world is changing rapidly these years. The UN has predicted that the food demand will rise by approx. 50 precent by 2030[9], with global population estimated to reach around 8.55 billion[10] and consumption patterns changing as people around the world move out of poverty. The population growth is stagnating in the developed countries. Future population growth will happen outside of the developed countries.

The growth in the global population and in prosperity will increase the demand for products and solutions upon which the Danish food cluster can deliver healthy and sustainably produced quality foods and technological solutions for resource-efficient food production[11].

The food industry and suppliers realize that knowledge is an essential raw material when competing on the global market. The companies invest heavily in research and innovation compared to other food nations. The total annual food research budgets amount to more than 3 billion DKK, of which the 2 billion DKK is derived from the industry[12]. However, the industry realizes that remaining competitive in the future requires continued investments (both private and public) in research and innovation with all stakeholders in the food cluster. It is becoming increasingly important to add even more knowledge to the "food", in order that Denmark also in the future accesses the first mover's advantages on new initiatives within the food universe.

For a long time, our way of envisioning the food value chain has been "linear", meaning that raw materials are used to make a product, and after its usage, any waste is disposed of. To ensure enough raw materials in the future, our food system must become circular preventing waste by making products and materials more efficiently and by reusing as much as possible.

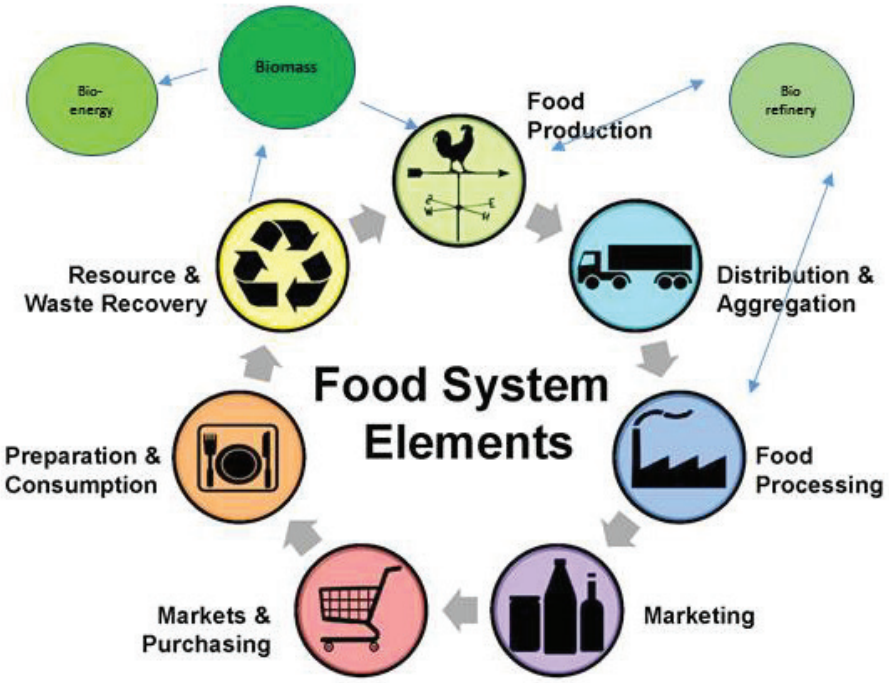

Figure: Everyone plays a role in creating a sustainable food system.

9 http://www.un.org/waterforlifedecade/food_security.shtml (accessed 20 August 2017)

10 United Nations, Department of Economic and Social Affairs, Population Division, World Population Prospects: The 2017 Revision, New York, 2017.

11 Vækstteam for Fødevarer. Anbefalinger, Copenhagen, April 2013.

12 Landbrug & Fødevarer. Fakta om erhvervet 2016, Copenhagen, 2016.

Research and innovation converted into future business opportunities

If Denmark is to maintain a competitive food cluster, a continued need exists for augmented knowledge-driven production. A strong public research sector must focus on translating public research and innovation investment into growth and development in areas such as health, sustainable and resource-efficient production as well as maintaining focus on leveraging the food sector up the value chain. Denmark should continue to position itself as an international hub where large international companies place their R&D investments. However, this requires ongoing joint investments in the existing R&D communities. Furthermore, Danish food research and innovation must be based on a strong international collaboration and focus on talent attraction and retention.

To succeed, we need to prioritize the limited research and innovation resources. Therefore, the food industry and suppliers have identified the following six key challenges that can be turned into significant business opportunities, if mastered in the right way:

- Supply of high-quality raw materials in a circular economy
- Products for the global consumer
- Food safety 2.0
- Foods for a healthier life
- Efficient and agile production
- Faster and safer to market through utilization of big data.

In the subsequent chapters, the challenges are presented. This is followed by the food industry and suppliers' view on enablers within research and innovation, infrastructure and in relation to talent and education. Investing in pre-competitive public-private R&D cooperation relative to these enablers will help solve the key challenges, and consequently result in job creation and prosperity not just for the food cluster, but also for the Danish society.

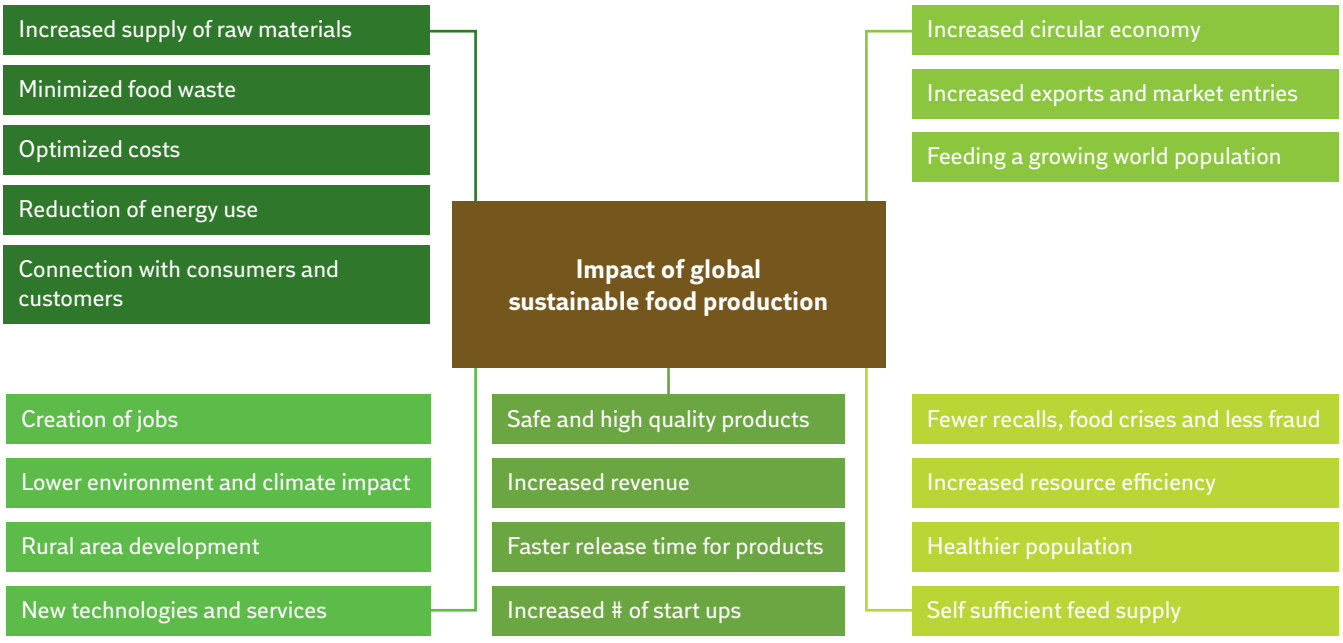

Figure: Investing in joint research and innovation in the food cluster will have a substantial impact.

The document is intended to be a strategy of knowledge, inspiration and prioritization that can be used in a wide variety of contexts from the political negotiations of the national budget to the strategic considerations in companies, knowledge institutions and funding bodies. This strategy proposes some of the research and innovation challenges raised in the FORSK2025 catalogue. The aim is to facilitate the prioritization of investment in R&D benefitting both society and the Danish food cluster.

An even bigger responsibility

As a global exporter, the companies in the Danish food cluster also have a responsibility for being part of the solution to a number of the UN Sustainable Development Goals. This strategy supports and falls in line with these challenges set out in the UN Sustainable Development Goals:

Figure: The food cluster is a global player with a global responsibility. Pre-competitive research and inno-vation in the food area provides solutions to many UN Sustainable Development Goals.

KEY CHALLENGES

KEY CHALLENGE #1

Supply of high-quality raw materials in a circular economy

Resource scarcity and higher environmental standards are here to stay. In order to feed a growing population without jeopardizing the climate and the environment, we need to produce "more with less" and ensure a higher utilization and valorization of all product streams as well as by-product streams. Furthermore, a strong emphasis on maximizing the yield and quality per unit is called for.

The initial raw material quality is essential in order to produce high-value products. Biological variation occurs and challenges efficient production lines during further processing; both in terms of amount of handling required and amount of lower value material (e.g. straw from cereal harvesting). Managing biological variation of raw materials remains important to ensure a cost efficient and viable production with minimum waste. However, biological variation is not all bad, as it provides diversity in the supply that is often sought after by the consumers.

Some raw materials and natural resources essential to agriculture – specifically fresh water and phosphate – may become scarce on the longer term. Consequently, it is key to preserve and better reuse these limited resources. Access to water is a prerequisite for food production; however, water is unevenly distributed and is expected to become even more so in the future. Food production uses 70 percent of the water resources globally, and the water resources are scarce and expensive. This induces the need to minimize use of drinking water in the industrial processes and explore the potential for reusing process water. Phosphorus is an essential nutrient for all forms of life. New knowledge-based solutions are needed in order to better recycle phosphorus from the side streams of animal and food production.

Food is part of the bio-based economy, where biomass and residues can be converted to a wide range of products and ingredients by means of modern biotechnological tools. Sustainable production and valorization of all streams are expected to be a major future competitive advantage – both nationally and on the export markets. The cluster has a long track record of valorizing waste streams through intense cooperation between all parties in the cluster. Consequently, agro, food and technology providers have good prerequisites for optimizing conversion processes such as bio-refining.

The agriculture and food industry performs well in most aspects relative to sustainable production. However, the use of imported proteins for feed remains an issue that needs to be solved – for organic as well as conventional animal production. Bio-refining of green biomass is part of the solution.

Utilization of food waste has been put on the agenda. FAO estimates that approximately 33 pecent of all food is wasted. In the developing countries, this occurs in the first part of the value chain. In the rich countries, it takes place in the last parts of the value chain, i.e. at retail and consumer levels. In Denmark alone, 700,000 tons of food is wasted. 260,000 tons is wasted in households; retailers and food service account for 227,000 tons, and the remaining has its origin in the primary production and the food industry. In the food service sector and at retailers, this loss is estimated to be approx. 2.5 billion DKK[13]. Future research and innovation efforts must address this waste issue and find solutions to how producers, processors, retailers and consumers in a joint effort can reduce food waste significantly.

13 Advisory Board for cirkulær økonomi. Anbefalinger til regeringen, Miljø- og Fødevareministeriet, Copenhagen, 2017.

KEY CHALLENGE #2

Products for the global consumer

Consumers are at the center of the food systems, and their expectations about food are multifaceted and constantly changing. Being an industry exporting to more than 130 markets worldwide makes it an ongoing challenge to fulfill the expectations of the individual, global consumers and customers.

A lack of understanding of the local consumer preferences leads to unsuccessful and costly market entries. To be successful, it is critical to capture and adapt to new market and consumer trends and foresee the needs and desires of the consumers and customers of tomorrow i.e. where they can obtain their demanded foods at any time in the right format. Solid scientific documentation and the use of big data for datamining are critical in that respect. It also involves studies to clarify what drives consumer purchasing practices, priorities (cultural, sensory), preparation methods, storage and discarding of food items. Establishing strong interactions with consumers is key in order to reduce the risk of failing when introducing new products and entering new markets.

An efficient food cluster is dependent on markets, regulatory frameworks and flexible supply chains that can respond to unforeseen contingencies and volatility leading to changes in the business practice. Understanding and reacting to risks are key. Distribution patterns, business models and communication are constantly changing in many markets making it difficult to keep market shares and exploit new market potentials. Reliability is a key driver for developing Danish food export, and new channels for communication and distribution must be taken onboard.

Many consumers are critical towards today's food production. They don't necessarily trust large-scale industrialized food production, yet value its produce as being affordable, widely available, tasty and consistent in terms of quality. They go for "clean labels" and try to avoid chemicals and additives. They are concerned about food quality, a concept which has been broadened from "what the product is and does for them" to "how and with what impact and consequences the products are brought about". Their concerns may not always be mitigated by more information, and hence other ways of creating a strong link between consumers and the producers are called for.

Around the world, retailers and the food industry are preparing for markets with added local sourcing, distributed manufacturing, increased customer interaction, diversified customer demand, multi-channel purchasing (including home-delivery), and ultimately more intimate customer relationships. At the same time, low-cost, same-day delivery services allow local companies to compete with international brands online, further supported by the emergence of online "hyper-local" advertising platforms that allow people to run such businesses in their neighborhood. These new business models could challenge the Danish export.

Exporting to consumers and customers around the world pose certain technical challenges to include retaining freshness and quality of the products and shelf life due to long transportation times. Furthermore, fluctuating and elevated temperature and humidity conditions both during transport and at the final destination challenge product quality. This is in many cases circumvented by using chilled/cold storage of products, with subsequent higher consumption of energy or by applying faster, but also more energy costly modes of transportation. Finally, developing innovative stabilization techniques, including packaging technology, may keep the quality intact.

The new generation (Millennials) rules

- Nearly half of all eating occasions take place in solitude.
- Snack occasions are nearly equal to the number of meal occasions in mature markets.
- Less than 31 percent of dinners are made from scratch and seem to decrease even further.
- Most dinners are planned less than an hour before dining and more than 50 percent of the households cook multiple meals/dishes to cater to individual preferences.

Figure: Food consumption patterns are changing, thereby affecting development of new products, technologies and services.

KEY CHALLENGE #3

Food safety 2.0

Consumers develop an irrevocable distrust in food producers when foodborne disease outbreaks occur and when food scams are revealed. Consumer awareness and concern have increased despite the fact that foodborne disease outbreaks have decreased significantly in developed countries over the last 30 years. Danish food production is characterized by reputable, high food safety standards and a strong reliability. A high, documented food safety level is vital for the ability to establish and maintain a strong position in export markets. However, this position should never be taken for granted.

Food production and human health are affected by a number of external microbial and chemical factors to include resistant microorganisms, causative viruses, and toxic chemical compounds or particles. Antibiotic resistance is, according to WHO, one of the biggest threats to human health. Using antibiotics in the primary production may lead to resistance, and consequently, application of One Health[14] thinking is required to ensure high food safety levels.

Globalization signifying increased transportation of humans, animals and consumer goods increases the risk of rapid spreading of communicable diseases. Epidemics and pandemics such as the bird flu and swine fever spread rapidly and impair food production and our ability to export products. Furthermore, it remains a challenge to reduce the outbreaks of foodborne diseases. Hence, controlling food safety becomes even more critical in a globalized world.

Increasing the resource efficiency of food processing, retailing and distribution may impact on food safety. For example, changes in food processing and handling via more energy efficient cooling systems and/or by reducing water usage in cleaning procedures should never compromise food safety. The food authorities may regulate the intake of e.g. salt and sugar indirectly through changes in taxes in order to ensure a healthier population. However, changes in composition of products may affect the hurdle technology of a given food and consequently jeopardize food safety.

Very severe cases of food fraud are seen in developing markets, often with casualties. In more mature markets, cases of e.g. polluted feed have large socio-economic effects.

Longer distribution times and changes in composition, e.g. in order to make products more healthy or match consumer needs also pose a food safety challenge. Finally, heavy regulation and customer demands in the export markets often call for clear traceability and documentation of product composition, safety and shelf life. In that context, traceability from farm to fork is required, and independent documentation is key for export products as it functions as a seal of approval.

It has become easier and faster to test products, and modern analytical instruments have very low detection levels. Furthermore, the advent of personal analytical technology enables consumers and customers to test the products, providing results that may be shared world-wide in an instant. This could potentially result in companies going out of business.

KEY CHALLENGE #4

Foods for a healthier life

Healthy nutrition is together with physical activity one of the cornerstones of a healthy lifestyle and directly related to the health costs of society.

Cardio-vascular diseases (CVD) are the number 1 cause of death globally. An estimated 17.7 million people died from CVDs in 2015, representing 31 percent of all global deaths. In 2015, nearly 0.5 million Danes suffered from CVD.

Furthermore, the number of people in the world with diabetes has risen from 108 million in 1980 to 422 million in 2014[15]. In Denmark, almost 6 percent of the population has diabetes, and the numbers are growing[16]. WHO projects that diabetes will be the seventh leading cause of death by 2030[17].

Finally, worldwide obesity has more than doubled since 1980. In 2014, more than 1.9 billion adults (39

14 One Health recognizes that the health of people is connected to the health of animals and the environment. Consequently, One Health is the collaborative effort of multiple health science professions, together with their related disciplines and institutions – working locally, nationally, and globally – to attain optimal health for people, domestic animals, wildlife, plants, and our environ-ment.

15 Colin D Mathers & Dejan Loncar. Projections of global mortality and burden of disease from 2002 to 2030. PLoS Med, 2006, 3(11):e442.

16 https://diabetes.dk/presse/diabetes-i-tal/det-nationale-diabetesregister.aspx (accessed 20 August 2017)

17 Colin D Mathers & Dejan Loncar. Projections of global mortality and burden of disease from 2002 to 2030. PLoS Med, 2006, 3(11):e442.

percent) were overweight (BMV≥ 25). Of these over 600 million (13 percent) were obese (BMI ≥ 30)[18].

These numbers are staggering, and are in most cases attributable to a mix of unhealthy diet, genetic make-up, physical inactivity, tobacco and alcohol use. Consequently, the industry has an important role to play when it comes to producing foods for a healthier life and in helping the consumers make informed choices about their food intake.

Food contributes to health at all life stages, provided that lifestyle and personal needs are taken into account. Research-based insights can be converted into tools, driving the innovations required, to enable the consumer to make informed and personalized choices in supporting a healthy lifestyle and preventing diet-related chronic diseases.

Attempts to redirect the food consumptions towards healthier choices, no matter how desirable from a societal perspective, will only succeed if the consumers are taken onboard, i.e. if the development of new products and meal solutions is closely linked to consumer engagement and preferences and builds on consumer trust.

An ever-increasing proportion of the population is getting older, and there will be a need to focus on optimal nutrition (micro and macro nutrients) that can contribute to the maintenance of well-being and health throughout life. In-depth understanding and solid documentation of health effects of foods, nutrients, ingredients, processing-related changes, etc. depending on requirements related to age, gender and genotype are therefore called for. Documentation is also crucial in the work of authorities regarding legislation and nutritional recommendations.

In recent years it has become evident that the microbiota plays a major role in our health. Consequently, it is important to better understand the relationship between food intake, the microbiota and the health status.

Finally, new studies of the mechanisms of epigenetic[19] regulation and its reversibility have resulted in the identification of novel targets that may be useful in developing new strategies for e.g. counteracting cancer, obesity and cardiovascular diseases. Consequently, considering the influence of diet or dietary components on epigenetic modifications needs to become an active instrument to combat these diseases.

It is not a trivial task to determine whether a product is healthy or not. It is not sufficient to review composition. The interaction with the product matrix and their composition, and the impact of the entire diet must also be considered.

In the past decades, the production of ingredients has become highly optimized to meet purchaser demands. Plant-based ingredients such as sugars, proteins and starches, are often highly purified, making them applicable in many different 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 ingredients.

KEY CHALLENGE #5

Efficient and agile production

Global competitors are all investing in digitalization and automation, and we need to stay on top of the automation game to remain at the leading edge. Consequently, continued development and investments in digitalization and automation technologies are required to raise productivity, increase capacity utilization and stay competitive in a global market. A potential increase in productivity related to further automation (reaching the level of automation seen in the most automated countries) is at least 7 percent for the Danish food cluster[20], stressing that even though the food sector has a relatively high level of automation there is still more to gain in terms of productivity. Moreover, being technological frontrunners in the food industry will add to the automation potential as the industry will be able to rapidly take advantage of new, groundbreaking automation and digital technologies.

New advanced technologies like intelligent robotics, machine learning, additive technologies (like 3D printing) and Internet of Things will drive a new production paradigm (Industry 4.0). This development represents a huge market potential if the in-

18 http://www.who.int/mediacentre/factsheets/fs311/en/ (accessed 20 August 2017).

19 Epigenetics relates to the study of changes in gene expression that may not result in changes in the DNA. This means that the phe-notype may change, although no changes in the genotype takes place. Epigenetic change is a regular and natural occurrence but can also be influenced by several factors including age, the environment/lifestyle, and disease state.

20 Lene Kromann, Jan Rose Skaksen and Anders Sørensen (2012). Automation og arbejdsproduktivitet – en analyse baseret på branche– og landeforskelle. Copenhagen Business School, Copenhagen.

dustry has the right tools and competences to grab the opportunities. With the right investments, the Danish food industry will be among the industries benefitting most from the digital development.

Furthermore, there is an increased focus on product differentiation through digitalization of existing products, new digital services and the development of data-driven business models. Competition focuses increasingly on the ability to create value for the customers. This leads to increased emphasis on servitization (i.e. delivering of service component when providing a product) and more intelligent products. Manufactures compete increasingly on utilization of new, embedded information and communication technology (sensors, software solutions, etc.) and on the ability to exploit data commercially. As such, packaging may act as a perfect interface between the end user and the supplier.

There is a strong need for tailored food for different population segments in the global world. This requires a more flexible production set-up with smaller production series and more items. This drives an urgent need for speed in the development of new products and processes. Furthermore, automation of many food production processes is extremely complex and challenging due to an inherent, high biological variation and the need for high product variety. Consequently, intelligent automation solutions based on newest digital technologies that can handle the biological variation of the raw materials must be developed.

Automation is an area where successful, lifelong learning programs will be critical and where tackling the man-machine interface is crucial. This calls for a concerted, interdisciplinary action, where mastering technologies such as augmented reality, deep learning and hyper flexible robotics is vital.

KEY CHALLENGE #6

Faster and safer to market through utilization of big data

Global consumers and customers demand and expect greater transparency in the future. There is no way around it. The Danish food cluster produces huge amounts of data throughout the value chain – from the raw material producer to the final consumer. This is based on a long tradition for collecting data in the primary production and due to a high level of automation. Furthermore, the Danish authorities, customers and consumers already have high demands regarding documentation of food safety. New consumer preferences, including soft parameters such as animal welfare and authenticity, can be turned into a competitive advantage by using such data.

Many companies do not utilize their pool of data to the full extent, and the potential of exchanging data along the value chain is even more important. Data can be used to gain critical insights, support and even automate decisions as well as decide on strategic business moves. Use of big data already in the product development phase can drive down the production costs[21].

Data analysis can be used to handle, organize, integrate and visualize large amounts of data to effectively extract useful information, thus creating value based on data. In addition, big data can ensure high product quality, track product defects and ensure an optimal and more sustainable production[22]. Danish agricultural technology and food technology providers are at the forefront in analysis of complex data, making it possible for the Danish food industry and suppliers to be first movers.

Trust is a key factor in consumers' everyday choices. Social media and digital channel use have democratized information and the use of data is empowering consumers and disrupting the historical reliance of manufacturers and retailers on traditional communications and marketing.

The exploitation of big data will become a key determinant of innovation and a competition factor for individual companies and the sector in the future. It is of outmost importance that Denmark is in front when it comes to the use of big data. Big data can help the food industry capture the latest trends in global markets to i.e. deliver the exact products that customers demand.

Since big data often contains sensitive information there is an increasing need to establish clear agreements or establish open and safe standards on data sharing covering data usage, security, ownership and ethics.

21 McKinsey Global Institute. Big data: The next frontier for innovation, competition, and productivity, 2011.

22 TATA Consultancy Services. The emerging big returns on big data, 2013.

INNOVATION ENABLERS

Based upon the above identified six key challenges, the industry suggests joint investments in relation to the following key enablers within (i) research and innovation, (ii) research and innovation infrastructure and (iii) talent and education to ensure future sustainability and growth of the Danish food cluster. Other enablers could be suggested. However, the following lists the ones expected to have the largest impact on the success of the food cluster.

1. Sustainable production through circular economy

A key enabler will be to identify technologies and approaches in order to valorize raw materials (including recycling of nutrients), waste and side streams to e.g. high quality foods, food and feed ingredients or fine chemicals. Using the strong Danish competences within breeding, bioprocessing (enzymes, fermentation), process (separation technology, etc.) and sensor technology, as well as process analytical technology will enable the development. Natural ingredients derived from raw materials and waste streams are, already today, key enablers that may be pursued further in the future.

Solving the supply of proteins – both for organic and conventional animal production, e.g. by applying bio-refining of green biomass, may enable a more sustainable production using locally sourced feed, which is demanded by the consumers.

Furthermore, redesigning the whole value chain to optimize use and reuse of raw materials, ingredients, energy, water and packaging will secure a more sustainable production.

Finally, development and implementation of tools to document the sustainability effects of such a redesign of the whole value chain using coherent objective measures (including life cycle assessments) will be of utmost importance.

Key outcomes

- A more sustainable production; producing more with less.
- Enhanced cascade utilization of all raw materials.
- Improved documentation of environmental impact.

2. Food design – from molecular interaction to excellent eating

Mastering food design becomes paramount in order to fulfill consumer and customer demands in a global context. When developing new sustainable and affordable foods for local markets around the world, it is vital to understand the molecular properties of the ingredients and the way they interact with other constituents in a food matrix during processing, storage and consumption. This will enable the design of new sustainable foods, healthier foods (e.g. health promoting bioactivities or fat or salt replacers), high quality products (e.g. sensory properties, texture and nutritional density), and both fresh and preserved products with extended shelf life. Furthermore, a better understanding of how processing and storage affect product characteristics can be used to optimize existing products and develop new ones.

Combining food science, material science, nanotechnology and soft condensed matter physics, and especially the corresponding use of new experimental tools – allowing characterization of molecular structures, molecular interactions, complex fluids and soft solids – will be a key enabler. Mastering formation of structure through an in-depth understanding of the interactions between raw material, ingredients, alternative processing approaches (e.g. preservation, extraction, modification, fermentation) and storage/distribution could enable creation of new product types.

Key outcomes

- Improved understanding of the impact of tailored food design.
- Development of new eating experiences.
- New technologies that can keep food products fresh for longer.

3. Food analytics – documenting safe foods

Being able to document safe foods is a key enabler in order to enter new markets and maintain a position as a reliable provider of products. Quantitative measurements of food components, food microbes, viruses, toxins and contaminants including process cont testing time, and hence the time it takes to release products for distribution, will be a competitive advantage.

Generating an understanding of the food safety risks when changing product formulations (e.g. when adding new ingredients/raw materials, reducing salt or sugar, changing pH or changing time/temperature regimes), processing technologies and packaging materials will enable us to speed up product development while ensuring high food safety levels. Predicting the changes taking place in products during transportation and shelf life and describing how raw materials and ingredients, processing and packaging affect food quality will be part of the story.

Establishing reliable track and trace systems as well as advanced testing systems to ensure product safety, guarantee product origin and reduce fraud will also ensure a strong market position. Tracking systems must be holistic and include the entire value chain from locally and internationally sourced raw materials to the end users. Finally, early warning and foresight systems and modeling to control microbial hazards and challenges will be key enablers in order to stay in business.

Key outcomes

- Improved food safety and quality.
- Advanced quantitative and qualitative analytical methods.
- Methods for risk prediction.

4. Omics technologies – from molecules to understanding

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. The application of these omics technologies in combination with powerful computing capability creates tremendous volumes of sequence data that need to be analyzed.

Thanks to the omics approach, researchers are now able to connect food components, foods, the entire diet, the individual, the health and the diseases, but this broad vision need not only the application of advanced technologies, but mainly the ability of looking at the problem with a different approach, a ”foodomics” approach. Foodomics, a key enabler for the food industry, is the comprehensive, high-throughput approach for the exploitation of food science in the light of an improvement of human nutrition. Foodomics is a new approach to food and nutrition that studies the food domain as a whole together with the nutrition domain with the end goal to optimize human health and well-being.

The omics approach may be used for a number of other applications, including further developing advanced plant and animal breeding technologies and exploring how breeding and genetics may produce better raw materials in terms of e.g. nutrient composition, eating quality, functional properties and processability.

Furthermore, omics technologies may be used to elucidate the link between product functionalities and the raw materials and ingredients utilized to produce the final product.

The microbiota is assigned a major role in our health; therefore, a key enabler for industry will be to better understand the relationship between food intake, the microbiota and the health status in order to develop new diet solutions and document existing products. Omics will be a key component in this line of research.

Key outcomes

- Decipher the ”why” through the use of omics technologies.
- Better link genetics to product functionality.
- Increased understanding of the relation between food, microbiota and health.

5. Foods contributing to health and well-being

Understanding the relationships between food and health changes throughout life and how these changes may be influenced by genotype, epigenotype, physical activity, and the microbiota will be a key enabler for the development of personalized nutrition products and diets. Understanding how diet and lifestyle affect the development of non-communicable diseases in such a way that specific strategies can be designed, developed and communicated will also pave the way for personalized nutrition.

Furthermore, documentation of health-promoting properties of raw materials and processed goods is a key enabler for industry. The area should include the full range of food supply, covering both the natural health content of our basic foods, the development of functional foods with improved and/or new, documented health effects and more specific dietary supplements with documented effects.

A key opportunity will be to combine knowledge on sensory science, food structure and nutrition with the aim of producing healthy meals that are tasty and appetizing.

Another aspect that is becoming increasingly important is how to reach consumers and customers, e.g. through logistic solutions for distribution of health diets to individualized ‘groups’ and how to connect with the user by e.g. providing scientific input to app-like solutions, which makes it possible for the consumers to find reliable and easily understandable information and the industry to gain insight into consumer needs.

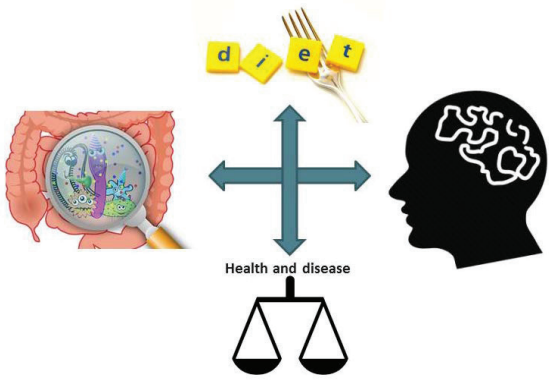

Figure: There is a direct link between what we eat, how our brain and gut functions and our health/disease status.

Key outcomes

- Evidence-based recommendations pertaining to the relation between food and health.
- Improved understanding of personalized nutrition throughout life.
- Getting the nutrition messages across.

6. Agile and intelligent automation

Diversified production is a key enabler that requires development of intelligent, highly agile and (self-learning) robotic solutions. To be successful, low-cost sensor technology for robotic control and for advanced process control will be part of the solution.

Establishing digital twin[23] models of main unit operation will facilitate and speed up process and product innovation. Integrated and intuitive man-machine-interfaces to be applied in automated production will be critical, and technologies such as augmented reality, deep learning (neural networks) and hyperflexible robotics are key to intelligent automation.

Redefining and developing packaging technology to establish an intelligent and digital link between producers and customers/end users will be a key enabler in reaching customers and consumers around the world.

23 A digital twin is a virtual model of a process, product or service. The pairing of the virtual and physical worlds allows analysis of data and monitoring of systems to head off problems before they even occur, prevent downtime, develop new opportunities and even plan for the future by using simulations.

Finally, using a minimal environmental footprint approach when redesigning or developing new processing and preservation technologies for food will save money and will be important in order to gain consumer and customer acceptance.

Key outcomes

- More agile and sustainable production.
- Hyperflexible production technologies and processes.
- Increased use of automation and intelligent robotics.

7. Connected and competitive through smart use of big data

A key enabler in terms of data analysis will be to establish a common (inter)national approach to data access and publishing of data and to create the framework for closer cooperation on sharing, retrieving, processing, storing, analyzing and visualizing data.

Another enabler will be to aggregate customer data and make them widely available to improve service level, capture cross- and up-selling opportunities and enable design-to-value (including machine learning). Data may also be used to gain an understanding of consumer preferences by correlating data from the Internet – including social media – with sales data and market intelligence to obtain insights into how to develop new products, new segments and new sales and communication channels.

Optimizing the use of Internet of Things to use real-time data from sensors and other digital technologies to track the products' journey through the entire value chain and monitor equipment is an important enabler. It permits optimization of production volume in addition to reducing waste, assembly time and production downtime. Furthermore, it helps ensure high food safety levels.

RESEARCH AND INNOVATION INFRASTRUCTURE ENABLERS

Great scientific discoveries and developments are dependent on access to advanced equipment, databases, lab facilities, pilot plants, etc. These facilities are expensive to run and consequently, it is critical that the infrastructures are shared between universities, research and technology organizations (RTOs), and industry – sometimes across borders. Availability of advanced infrastructure is also critical for the attraction and retention of scientific talents. To get the most out of the Danish investment in research and innovation infrastructure, it is critical that only complementary infrastructures are established and that there is a willingness to share and use facilities from both private and public players. Furthermore, it is important that the funding is directed to the strategic enabling technologies in order to secure a collaborative environment that supports both small and medium enterprises (SMEs) and large enterprises. A collaborative cluster covering both SMEs and large enterprises is often the prerequisite for successful innovation in an industry.

Below covers the relevant infrastructure pertaining to the strategic innovation enablers:

- Maintain and develop state-of-the-art research and innovation infrastructure in the area of primary production.
- Maintain the existing level of infrastructure at universities and RTOs to the collaborative public-private preparedness in case of animal disease outbreaks.
- Establish decentralized bio-refinery facilities to, among other things, explore production of proteins for feed and food.
- Develop existing infrastructure at companies, universities and RTO institutes to characterize quality changes of foods, i.e. changes in the raw materials based on feeding, breeding, management and processing.
- Develop existing infrastructure at companies, universities and RTO institutes to characterize changes in foods and how components interact on a molecular level. This includes upgrading of NMR facilities, imaging facilities and electron microscopy.
- Establish a food-centered beacon in relation to the ESS/MAX IV/XFEL facilities in order to get a better understanding of e.g. food structure and material science.
- Further develop existing omics platforms and strengthen the link to the food science and biotechnology area. Use omics to explore the connection between genetic make-up, foods and health.
- Develop pilot plant facilities for testing of intelligent robots, wireless communication, Internet of things, human-machine interface, etc.
- Develop pilot plant facilities for small scale food production.
- Highlight the research and innovation infrastructure around MADE – Manufacturing Academy of Denmark.
- Maintain and develop cohorts for studies since they are a key epidemiological resource from which hypotheses can be formed.
- Continue to develop the infrastructure around biobanks, animal experimental and laboratory facilities in relation to clinical research.
- Initiate the FOODHAY – Open Innovation Food and Health Laboratory – as described in the Danish Roadmap on research infrastructure will be critical to our ability to remain competitive in an area with increased focus from both consumers and customers. The research infrastructure will increase our understanding of and create unique links between raw materials, consumer food products and human health.

Illustration: Detail of equipment

TALENT AND EDUCATION ENABLERS

A key enabler in terms of talent and education is to maintain focus on educations relevant to industry needs. Public research and education must focus on the areas where companies need knowledge and skills. Directly linked to the DNA of the cluster, a number of competences are needed both in science, humanities and business; at all levels from craftsmen to highly specialized PhDs.

It is critical for the cluster that the higher educations are research-based and that a close collaboration between industry and universities exists ensuring that the candidates have the strongest scientific basis combined with a well-developed understanding of how to convert science and expertise into business opportunities and growth. At the same time, efforts must be made to challenge the very best talents – e.g. through establishment of elite programs.

For the food industry, it is crucial to recruit talented local and foreign employees. Clear career paths must be created for younger employees. Furthermore, promoting sector mobility is critical, and emphasis should be on establishing joint positions between universities and companies – both for junior and senior employees.

Finally, life-long learning initiatives and continued competence building are required to ensure state-of-the-art competences at all levels. The never ending technological changes call for continuous learning pathways and on-the-job training for employees at all levels.

The food industry is becoming increasingly aware of how to enhance internal idea development by pursuing an open innovation approach, allowing the additional exploitation of external ideas and paths to market. By opening up and encouraging external partners' insight and free access to some parts of our research we provide the first stepping stone with a larger potential.

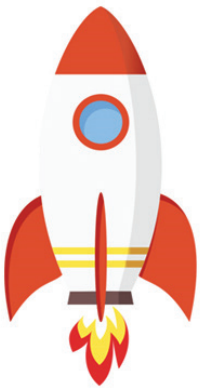

Figure: It takes many different competences to make the Danish food cluster take off. Here are some examples.

Rocket

– Agricultural science, food science and technology, engineering (sensors, software, mechanics, etc.), mathematics/statistics, physics, chemistry, biotechnology, enzymology, (micro)biology, sensory science, veterinary science, process technology, supply chain and logistics planning, material science, computing and information technology, robotics, user interface design, epidemiology, human nutrition, medics, health economics, bioeconomy, business and marketing, food cultural understanding, consumer science, innovation, cognitive science.

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