ACADEMIC EXCELLENCE AND IMPACT WITHIN FOOD RESEARCH

Seen from University of Copenhagen and The Technical University of Denmark

June 2018

Published by:
National Food Institute
Technical University of Denmark
Kemitorvet
DK - 2800 Lyngby

and

University of Copenhagen
Nørregade 10, PO Box 2177
DK - 1017 Copenhagen K

Layout and graphic: Susanne Carlsson, National Food Institute, DTU
Print: STEP
ISBN: 978-87-93565-22-7

Author Group

Christine Nellemann (cne@food.dtu.dk), Institute Director,
National Food Institute, Technical University of Denmark

Anna Haldrup (anna.haldrup@food.ku.dk),
Head of Department, Food Science, University of Copenhagen

Arne Astrup (ast@nexs.ku.dk), Head of Department,
Nutrition, Exercise and Sports, University of Copenhagen

Svend Christensen (svc@plen.ku.dk), Head of Department,
Plant and Environmental Sciences, University of Copenhagen

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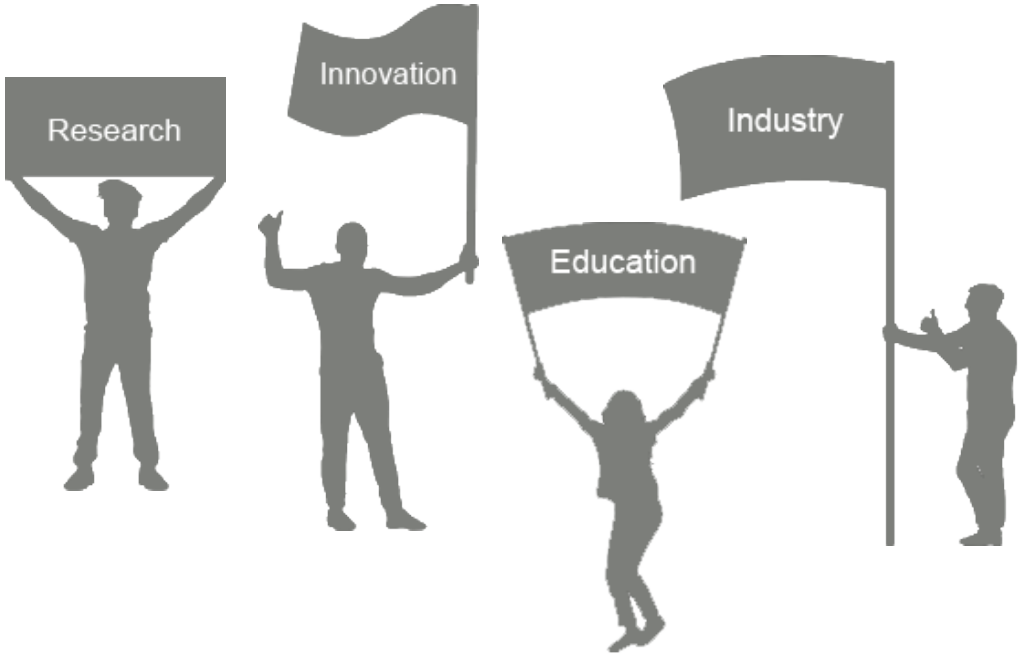
A strong team is made up of many players



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INTRODUCTION

With the purpose of following up on the 2017 Danish food industry strategy: WORLD-CLASS FOOD INNOVATION TOWARDS 2030, the University of Copenhagen (UCPH) and Technical University of Denmark (DTU) present their complementary and collaborating excellence areas under the headlines of the prioritized key innovation enablers in the strategy.

We hereby map and describe the excellences, impact and the potential seen from the academic point of view. We found it important to show the major areas, the international impact as well as the outreach to industries and students. The examples shared are areas of exceptional excellence from the Technical University of Denmark and University of Copenhagen.

The key enablers and their short descriptions are from the industry strategy mentioned above.

In total, 523 scientists (including postdocs and PhDs) at DTU and UCPH work specifically with food science.

Indeed, valuable research collaborations and impact are derived from participation of colleagues from other departments across both universities, from general science, medicine (human and veterinary), physics, chemistry, biology, food and resource economics, computing, engineering as well as from robotics to nanotechnologies. These collaborations bring food science to its innovative edge on a global scale.

However, the main focus of this document is the perspective of food research from the Technical University of Denmark (National Food Institute) and the University of Copenhagen (Department of Food Science, Department of Nutrition, Exercise and Sports and Department of Plant and Environmental Sciences).

The National Food Institute, Technical University of Denmark, conducts research in sustainable and value-adding solutions in the area of food and health for the benefit of society and industry. The institute makes a difference by producing knowledge and technical solutions that prevent disease and promote health, making it possible to feed a growing population and develop sustainable food production.

As a mark of excellence, the National Food Institute hosts four EU reference laboratories within the areas of food chemistry and microbiological food safety. In addition, the institute hosts a WHO Collaborating Centre, also within microbiological food safety. The institute combines research results into risk assessments, provided for the benefit of authorities and industry collaborators, national as well as international. In 2017, an international panel evaluated the research-based scientific advice provided by the institute and rated all areas as being of international quality and with a realized or potential international footprint.

The Department of Food Science (FOOD), UCPH, conducts research in sustainable food production, secure food supply, food

and health, and the challenges within energy and the environment, having impact for consumers and industry and contributing to growth, employment and solutions to global challenges. The department is organized in four research sections covering the chain from raw materials to processing and food consumption. The vision is that Department of Food Science is internationally recognized for excellence in food research and education.

The Department of Nutrition, Exercise and Sports (NEXS), UCPH, conducts research in food, nutrition and physical activity in relation to health. NEXS has facilities that ensure that studies are conducted according to the highest international standards.

The Department of Plant and Environmental Sciences (PLEN), UCPH, conducts research on plants, animals, soil and microorganisms – from molecules through organisms to populations and anthropogenic ecosystems. The vision is to maintain and develop a position as one of the principle centers for plant biology based on excellent basic and applied research.

The education programs from the universities offer and provide strong vocational and internationally recognized skills, preparing future employees to work with food production, food safety, food quality and food processing technology. The appendix addresses issues related to education and the programs offered by both universities and others as well as collaboration within food educations.

The universities work closely with ingredient companies, dairies, breweries, and many others to establish a synergy where the research is focused on solving industrial needs while adding value and providing innovation to the industry.

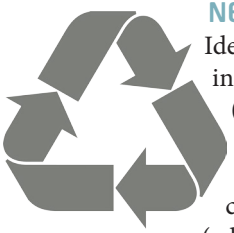
Areas of exceptional excellence are the only ones presented here. The groups described under each Mapping of Competences reflect specific research areas from UCPH and research groups at DTU. The universities complement each other with our individual strengths as we hope shows from these short descriptions.

Collaboration with Industry (2016)

Organization	Publications (co-author)	Student Projects	Research Projects
DTU FOOD	57 out of 229 (25%)	41 out of 71 (58%) Prof.B, MSc*	42 out of 93 (45%)
UCPH FOOD	45 out of 167 (27%)	41 out of 82 (50%) MSc	90 out of 100 (90%)
UCPH NEXS	41 out of 241 (17%)	Limited	26 out of 71 (37%)
UCPH PLEN	40 out of 363 (11%)	20 out of 86 (23%) MSc	81 out of 271 (30%)

*Professional Bachelor, Masters of Science

#1 SUSTAINABLE PRODUCTION THROUGH CIRCULAR ECONOMY



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Identifying technologies and approaches in order to valorize raw materials (including recycling of nutrients), waste and side streams to e.g. high-quality bio-based products (food, feed, chemicals, materials) and bio-energy (advanced and conventional bio-fuels), matching both the consumers and productions needs and demands. 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. Ensuring a steady supply of safe, high-quality raw materials, fitting the various productions and matching consumer and customer needs remain a prerequisite. 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.

MAPPING OF COMPETENCES

Exploration of side streams, byproducts, waste streams in several food production areas has been developing in the Danish research arena for several years. Collaboration between the Danish universities and Danish as well as international industries has grown dramatically.

There are several research areas of excellence provided below from both DTU and UCPH. There are some that complement each other, and some that are unique to each university. Further exploration of partnering between the universities and industry can open more opportunities and development for both research and industry.

Research and technologies developed at both universities focus on improving sustainability and contribute to a circular economy, where waste streams are valorized to produce value-added food and feed components. By increasing utilization and developing processes for industries where by-products are added back into the product value-chain, the research aims to reduce the environmental impact, improve sustainability and foster innovation by creating novel products and methods.

Microbial Biotechnology and Biorefining

DTU improves quality, efficiency, and sustainability in brewery and dairy processes. The research focuses on the sustainable production of food and feed ingredients, biochemicals and biofuels, using adapted/engineered microorganisms, which can utilize various industrial side streams or by-products from industries such as dairies, breweries, food producers. With state-of-the-art microfluidic technology, adapted and selected bacteria are super producers of various industrially important chemicals and amino acids. Research is focused on developing tomorrow's sustainable protein sources via biorefining, such as proteins from grass as well as microbial protein production.

Food Production Engineering

DTU encompasses the mechanistic understanding of the interactions between food processing and raw materials, as well as mathematical modelling and monitoring of food production processes at all levels, from unit operations to complex systems, including microbiological characteristics of products. One example is the development of mathematical models for quality characteristics of various foods during cooking in industrial ovens. This helps suppliers and equipment producers minimize the consumption of energy and to maintain the desired quality, texture, and sterility.

Bioactives - Analysis and Application

DTU works together with the seafood industry on the utilisation of side streams (head, bones, tails, livers) from the fish industry for the production of high-quality fish oil and fish protein for food and feed as well as extraction of bioactive compounds from seaweed and microalgae.

Food Microbiology and Hygiene

Resource optimization, such as development of strategies for safe reuse of water, improved hygiene and control of food-related microorganisms and knowledge of the epidemiology of food and waterborne pathogens are focus areas at DTU. Tools have been created and knowledge developed that improve safety, quality, and traceability in food production.

Microbes, Health and Allergy

DTU has several previous and ongoing activities related to the exploration of industrial bi-streams as food ingredients with a health-promoting effect on the intestinal microbiota (prebiotic fibers). Different approaches are applied for screening on the effects of specific indigestible carbohydrates.

Compositional Analysis and Bioprocessing

Focus is on understanding the biochemistry of raw materials for developing new processing technologies, with specific expertise within bio-extraction, fractionation, purification and sustainable processing on a pilot scale. This includes developing gentle processing technologies for natural plant-based food ingredients, and furthering sustainable use of side streams from the food industry.

Food Fermentation and Starter Cultures

The long-standing focus is on food fermentation and starter culture functionality in order to optimize the use of microorganisms for transforming raw materials into delicious food and beverage products and also to reduce food waste. The research covers a wide range of fermentation processes, microorganisms, and product types, nationally and internationally. Many years collaboration with Western Africa has given huge knowledge on food fermentation as conservation method. A deep understanding of the microorganisms, their characteristics and interactions provides a basis for new developments in starter cultures and supports fermentation-based processing from artisanal level to the large, industrial food and beverage producers.
This research area also supports Enablers #2 and #4.

Process Analytical Technology and On-line Process Monitoring

Focus is on new fast food quality control systems, how to detect food authenticity, how to avoid food fraud and how to optimize full-scale food production using advanced on-line or at-line spectroscopic sensors, advanced multivariate data analysis (chemometrics) and process control. The ultimate aim of using these methods is to reduce the environmental footprint of food manufacturing by optimal use of raw materials, ingredients and water in the food production and to produce high quality and safe food.
This research area also supports Enabler #3.

Climate and Food Security

The group researches and develops improved process- and system-level understanding of crop biosystems and food systems including sustainable food, feed and bioenergy production, global food production, climate and agronomy.

Horticultural Science and Biotechnology

A focus area is fruit production and wine making; the enological potential of main cultivars as well as a selection of robust historical local varieties are tested. In addition, the research explores the impact of pre-fermentation techniques including cryoconcentration of juice on sensory and analytical wine quality. In organic production, emphasis is on development of strategies for prevention of diseases.

Molecular Plant Breeding

The research group carries out interdisciplinary research that combines molecular genetics, genomics and biotechnology with classical breeding of crop plants. Examples are: Improving carrots for production of natural food colorants. Exploring existing genetic variation for health-promoting starch like resistant starch and beta-glucans or change fatty acid composition. Removing anti-nutritional factors by conventional breeding, mutations and new breeding techniques. Optimize ligno-cellulose polymer composition to facilitate biofuel and bio-based development of high value product to support bioeconomy.

Soil Fertility

A focus area here is processing and valorizing of food industry side/waste-streams, e.g. abattoir effluents, digestates, extraction residuals and other biowastes, into bio-based fertilizers and soil amendment products. R&D includes technologies for recovery and enhancement of nutrient content and plant availability (e.g. concentration, separation, decomposition, acidification, drying, pelletizing), in order to enhance recycling opportunities in primary agricultural/horticultural production. Future opportunities include synergies in biorefinery processes between recovery of energy and secondary raw materials, including nutrients and organic matter for fertilizers.

Natural Ingredients (covering the research groups Cell Wall Biology and Bioengineering; Cyanogenic Glucosides, Vanillin, Steviosides and Carmine; Triterpenoids; and Starch)

Functionalized vegetable protein and carbohydrate dietary fiber are essential to provide ample quantity and quality for future food demands. This is addressed by identification and engineering of functionalities into plant biomass, heterologous expression, and by the use of underutilized waste production lines. Plant protein could be a good replacement for animal protein and research is ongoing to remove the toxic compounds to utilize the protein from lupin. In depth knowledge of polysaccharides leads to new bio-based materials, bioplastics and health-promoting polysaccharides.

High-value products for food production are an example of another area of expertise. This includes the transfer of metabolic pathways to yeast to produce natural colors, sweeteners and flavors. Other approaches include utilization of natural-occurring variation for the production of natural color pigments.

Supply of Proteins (covering the research groups Alkaloids and Chemical Ecology; Insect Pathology and Biological Control; and Tropical Crops together with research center DynaMo)

The protein supply challenge is addressed by identification of new or alternative protein sources such as niche crops (quinoa, amaranth, lupin, faba bean, pea and lentil) and insects as sources for protein, by breeding for better yield and quality or by pathway bioengineering to remove toxic compounds (rape seed and lupin).

Environmental Chemistry

Water research is strongly coupled to water use, water-use efficiency, water balances, water quality and water cleaning along the track from primary production and manufacturing operations during different steps of the value chain terminating with wastewater treatment and/or reuse. Water research is strongly coupled with research on contaminant and nutrient loads (N, P), and recapture and recycling of the latter, e.g. via filters, traps and converters at different parts of the production cycle. UCPH has high-end competences on chemical analysis and toxicological valuation of water as well as innovative approaches to water reuse and nutrient recycling.

ALCOWHEY

Researchers from DTU have developed a patented technology that uses lactic acid bacteria to efficiently convert lactose in the whey into ethanol. Ethanol is the type of alcohol that is found in spirits.
The researchers have formed the company Alcowhey, which aims to help smaller dairies use the patented technology to create more value from the whey they produce. The dairies can then sell the ethanol to distillers, who can use it in the production of spirits.

PROTEIN2FOOD

At UCPH, PLEN (Tropical Crops) and FOOD (Compositional Analysis and Bioprocessing) are both participating within the large EU project PROTEIN2FOOD (coordinated by PLEN), with 19 partners under Horizon2020, fully entitled "Development of high quality food protein through sustainable production and processing", 2015-2019. The aim is to replace meat by vegetable protein for food, and reduce European import of soybean.

REDUCE INDUSTRIAL WATER USE

Both UCPH Food and DTU participate in the large initiatives to reduce the food industrial water footprint by investigating the possibilities to reuse process water: the research project REWARD (Reuse of water in the food and bioprocessing industries) and the partnership DRIP (Danish partnership for resource and water efficient industrial food production). Here, novel technological ideas, safety management, monitoring, etc. are further developed and proposed.

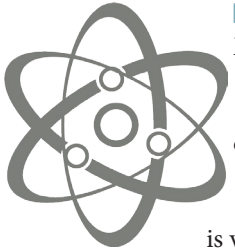
IMPACT FOR KEY OUTCOMES

A circular economy is based on concepts such as a cascading use of bio-resources and thus optimizing the production and use of raw materials, of closing the loop so any bio-resource is re-used, valorisation of possible valuable substances that can be isolated from by-products or side streams, or by using the by-products or side streams as a fuel for bioengineering new valuable substances.

Competences at UCPH and DTU can specifically deliver the following impacts:

- A sustainable and resiliant primary production of high quality food and feed
- Efficient use of side-streams that can be collected and valorized for new food/feed elements or for ingredients has been achieved.
- Natural ingredients developed that can replace artificial additives to food/feed.
- New protein sources developed and their production has been up-scaled.
- New processing technologies developed that can optimize the use of raw materials throughout the production chain or enhance the consumers' experience.
- Methods developed for safe recycling and re-use of side-streams of biomaterials and processing water.

#2 FOOD DESIGN - FROM MOLECULAR INTERACTION TO EXCELLENT EATING



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Mastering food design becomes paramount in order to fulfil 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.

MAPPING OF COMPETENCES

The universities research different aspects of food design, from the oxidation stability of foods, to nano-microstructured ingredients. They also delve into the sensory characterization of foods and behavioral consumer intervention studies. The research aims to improve shelf-life stability, sensory quality and health effects of the produced foods, as well as develop new milk-derived ingredients and non-thermal processing of foods.

DTU

Bioactives—Analysis and Application

DTU contributes to increasing the population's intake of healthy foods by improving eating quality and the oxidation stability of food products. DTU uses knowledge about the biological activity of vitamins and the underlying mechanisms for lipid oxidation in foods as well as developing new strategies for optimizing the durability and eating quality of vitamins and fats in foods.

Nano-Bioscience

Development of functional nano-microstructured ingredients utilizing natural polysaccharides, proteins and lipids is a focus area with bottom-up approaches to assemble individual molecules to complex hierarchical nano-microstructures (namely fibers, particles, capsules, membranes, gels, emulsions, hybrids). The properties of these

nano-microstructure ingredients can be tailored towards specific industrial needs, e.g., as encapsulation and delivery systems of bioactives, as carriers to enhance the bioavailability of nutrients through biological barriers, and as texture and organoleptic property modifiers for the development of innovative functional health-food products.

Molecular Food Science

Focus is on understanding the chemistry and physics governing food functionality based on kinetic and mechanistic research of the molecular interactions in the food matrix. Of specific expertise is controlling and tailoring functionality of food ingredients through processing, modification and storage with regard to product stability, rheology, texture, appearance and quality, bioactive compounds and nutritional value. Furthermore, delivery of bioactive compounds in colloidal formulations is investigated.

Food Proteins

Focus is on understanding fundamental complex chemical interactions between food components during processing and storage and to implement this knowledge in rational and healthy food design, with improved shelf-life stability, sensory quality and health effects of the produced foods. Of special interest is the inhibition and control of protein modifications induced by processing conditions, which strongly influence the functionality, metabolism and effects of these bioactive compounds.This research area also supports Enabler #5.

Dairy Processing and Technology

Focus is on exploring emerging technologies for production of new dairy food products and milk-derived ingredients, advancing the field of dairy technology and investigating how dairy processing technologies and storage effect molecular stability to tailor shell-life and functionality of the food products. The technologies are explored and developed from lab scale to pilot-plant scale.

Meat Technology

Focus is to explore technologies that lead to an increase value in the value chain, in the processing stage and through the development of new products. Better utilization of raw materials from the slaughter industry through enzymatic processing for new functional ingredients involving proteomics and metabolomics methods. The processes are followed from lab scale to pilot-plant scale.
This research area also supports Enabler #4.

Functional Design

Focus is on exploring new innovative applications of ingredients and processing methods/techniques including non-thermal processing of foods, in order to develop healthier and more sustainable food products, ensuring the bioaccessibility and bioavailability of nutrients and

optimal use of bioresources. This includes exploration of possibilities within 3D printing of foods. The research addresses innovation along the whole food production chain (i.e. processing, chemical-physical changes, nutritive and appetitive value, waste reduction and utilizing local resources).

Food Exploration and Innovation

Focus is on exploring often local raw materials (e.g. seafood, insects, and plant-based foods), and small-scale processing operations (fermentation, drying, maceration, etc.) for future food preparations, closely interacting with high-end culinary environments to stimulate curiosity and creativity in food research and gastronomy.

Flavor Characterization

Focus is on characterization of isolated food volatile and non-volatile taste components using analytical techniques and methods in order to understand the formation of flavor and determine key (off) flavor compounds in food and beverages. The instrumental product quality is closely correlated with sensory properties and consumer preferences in a food design focus.

Sensory Perception and Acceptance

Focus is on sensory characterization of foods in an end-user or consumer perspective using trained sensory panels for testing sensory perception and consumer preferences, combined with emotional responses to foods by electrophysiological methods. The research addresses cross-cultural food acceptance, food in immersive contexts and food emotions, and relates to formation of flavor, visual appeal and textural properties – i.e. the multisensory perception of food.
This research area also supports Enabler #5.

Biochemical Engineering

Work carried out in this research group aims to overcome an important hurdle in the industrial exploitation of many natural products, the difficulty to explore the available chemical diversity and to obtain a consistent supply of compounds with desirable properties. Extraction of compounds from their natural sources is laborious and often inefficient, while their chemical synthesis and modification can be difficult because of their structural complexity.

FOODLAB

Foodlab at DTU Skylab will provide new and unique opportunities for students to develop and validate concept ideas into prototypes within the food area. It is a unique platform to test ideas in close cooperation with fellow students, businesses, educators and researchers.

Foodlab is intended as a "playground" for entrepreneurial, imaginative students working with food and technology. The footprint of Foodlab is approximately 300m2 hosting an experimental kitchen, a fermentation facility, open working space and meeting rooms.

Skylab is proud of its 133 startups and pre-startup-projects, 300 prototypes developed and more than 75,000 visitors (2016 totals).

FUTURE CONSUMER LAB

Future Consumer Lab at FOOD UCPH is placing consumers at the center of food science and nutrition behavior. The lab combines different units: Gastro Lab for exploring food designs; Flavor Lab for analysing food flavor/off-flavor compositions; Sensory Lab for characterizing sensory quality of foods and meals as well as measuring consumer acceptance, preferences and attitudes; Simulation Lab for immersive food experiences (3D Virtual Reality and other sensations) for evaluating food preferences, choices and appetite; Physiology Lab with an electrophysiology setup combined with olfactometry for measuring, e.g., food emotions (EEG/EDA) and post-ingestive feelings (EGG); and Observation Lab with the Observer XT for studying food consumption and meal choices. Future Consumer Lab adds to the Gastronomic Science Lab as a platform for creating innovative new food solutions.

IMPACT FOR KEY OUTCOMES

As the Danish food industry targets high-value markets, the ability to create foods with functionalities or quality parameters that appeal to consumer segments willing to pay for particular attributes becomes critical. Food design is based on the condition of paramount importance that world-class food innovation is keeping up with consumer trends and preferences and able to tailor foods according to value trends.

Competences at UCPH and DTU can specifically deliver the following impacts:

- Healthier foods have been developed that contain reduced fat, salt and artificial additives.
- New decision support systems optimized processing and storage conditions for sustainable foods.
- The key molecular interactions that impact the tailoring of foods has been mapped and described.
- Applicable data systems for tracing quality along the value chain have been developed.
- Real-time methods for tracing the authenticity of raw food materials have been developed.
- Technologies developed to track and identify consumer preferences.

#3 FOOD ANALYTICS - ENSURING AND DOCUMENTING SAFE FOODS

NEED

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 contaminants, are key to this. Developing online/at-line measurements for early assessment and developing rapid methods that can reduce the testing time, and hence, the time it takes to release products for distribution, will be a competitive advantage.

MAPPING OF COMPETENCES

Through tools, models and knowledge that can be used to improve safety, quality, and traceability in food production, authorities and industry can benefit from collaborating with the universities and develop specific pilot projects. In addition, the development of a new paradigm for the human-relevant risk assessment of chemicals, including residual chemicals in foods, is key to understanding the biological effects of these compounds.

DTU

Nutrition and Health Promotion

The Danish National Survey of Diet and Physical Activity makes it possible to quantify eating patterns in different subgroups of the population, thereby providing the basis for calculating risks and benefits and documenting safe foods within the whole diet. In addition, the on-going work on compiling the best data on content of nutrients in foods for the database published on Frida.fooddata.dk enables us to convert information on diet intake to information on nutritional intake. These data provide the basis for modelling 'what if' scenarios at population level related to safety and health promotion and for the industry in producing nutrition declarations.

Analytical Food Chemistry

DTU strives to contribute to food trust and transparency by developing the future food control, to discover emerging risk in production as well as from new food ingredients - documenting quality and revealing fraud - and to understand the biological effects of chemicals in food. Our goal is to contribute with the data needed for a healthy choice. This goal is reached by exploiting high-performance mass spectrometry

to develop both robust and accredited quantitative methods and untargeted screening analysis for trace-level analysis of food and biological samples. The platform serves as the foundation for our National and three European reference laboratories.

Genomic Epidemiology

DTU enables secure sharing of data, as well as real-time analyses of next-generation sequencing data. In addition, we have competences in designing optimal sampling strategies for detection and control.

Food Microbiology and Hygiene

DTU develops and uses new and innovative methods for the rapid detection, typing, quantification, as well as the prediction of the growth and survival of microbes and viruses in food and water. New mathematical models and software are developed for risk assessment and HACCP-based own control programs, as well as the improved development, processing, and distribution of food products. Results from research projects lead to resource optimization and development of strategies for safe reuse of water, improved hygiene and control of food-related microorganisms and knowledge of the epidemiology of food- and waterborne pathogens.

Nano-Bioscience

DTU studies occurrence and biological/technological fate of trace elements (both essential minerals and toxic metals) and engineered nanoparticles in food and feed materials and their production lines. The studies are done by the use of state-of-the-art analytical infrastructure, e.g. inductively coupled plasma mass spectrometry.

Molecular and Reproduction Toxicology

DTU conducts research on how environmental chemicals can affect early life development and cause diseases. The group has particular focus on the toxic effects (for example of endocrine-disrupting chemicals) that occur during fetal development. The research output is primarily related to male reproduction, but also includes female reproduction as well as the effects on thyroid hormones, which can lead to brain dysfunction.

Risk-Benefit

DTU establishes and develops models within human health assessment that can be used for risk-benefit assessments and for quantifying health effects of foods and whole diets. In addition, DTU uses mathematical modelling to estimate a documented safe intake level of foods, which includes aspects such as substitution, genetic variation, and uncertainties.

UNIVERSITY OF COPENHAGEN

Microbiological Quality and Safety

Focus is on microbial food safety and quality assurance in food processing and preservation including the use of biocontrol. Foodborne microbes as well as their interactions are investigated and their behaviour and activity determined in food and feed, on equipment surfaces and in the processing environment, including process water. Integrating 3rd generation sequencing technologies into quality and safety programs is an additional focus point. Furthermore, qualitative and quantitative safety aspects of new processing technologies or hygiene interventions are explored. The research covers both basic and applied studies from mechanistic molecular understanding to the operational food production level.
This research area also supports Enablers #1 and #4.

Plant Nutrition

One area of excellence is compound-specific isotope ratio analysis for authenticity testing of high-value plant products: The group has developed mass spectrometry analytical methods for multi-element (ICP-MS) and stable isotope (IRMS) analysis of plant tissue. The developed isotope methods are currently being refined by extraction and analysis of selected plant compounds (compound-specific isotope ratio analysis). This holds promising perspectives for future food authentication but also for studying nutrient availability and utilization in different plant production systems.

THE PAT SOLUTION FOR AVOIDING FOOD FRAUD

Industry can avoid food fraud by implementing Process Analytical Technology (PAT), including so-called "rapid methods" for quality control. The Near Infrared Spectroscopy (NIRS) method of analysing or fingerprinting ingredients or raw materials and chemometrics is currently our best bet for detecting food fraud. NIRS provides immediate answers and it does not destroy the raw material. UCPH FOOD researches the use of, among other things, NIRS and the use of the data that is produced. New algorithms can be used to monitor production and new methods can detect food fraud with an even greater level of detail.

THE (Q)SAR TOOLBOX

The database containing more than 600,000 chemical structures gives companies a unique opportunity to quickly get an overview of the harmful effects associated with substances they are considering using.

When a company wants to replace a harmful chemical substance in its production, it is often a major challenge that possible alternatives have not been sufficiently tested for harmful effects. However, the (Q)SAR database, which DTU and the Danish Environmental Protection Agency are behind, makes it possible to do a search on a chemical substance and quickly find out if there are indications that it has potential carcinogenic effects or other harmful health or environmental effects.

INTERNATIONAL PRESENCE

DTU has a broad international presence in advising regulatory bodies within the European Commission, WHO, OECD FAO, Nordic Council of Ministers and CODEX. Many experts are involved in work in EFSA. DTU houses the European Reference laboratories for Processing contaminants, Metals and nitrogenous compounds, Pesticide residues in cereals and feeding stuff and for Antimicrobial resistance.

MIXTURES OF CHEMICALS

On a daily basis, we are exposed to numerous chemical substances from many different sources. When exposed to a mixture of numerous chemicals simultaneously, the mixture can have a significant negative effect even at low exposure levels. DTU researches the large number of potentially harmful chemical substances and assesses the consequences in regards to food safety with particular focus on endocrine disruptors, cocktail effects and the development of computer models that can predict the harmful effects.

EPIDEMIOLOGY AND MICROBIOLOGICAL RISKS

The Danish integrated national surveillance and control programmes for zoonoses and antimicrobial resistance, as partnerships between industry, government and academia, are some of the most effective in the world. DTU continuously compiles and interprets national data from the programmes and regularly publishes the results in DANMAP and the Annual Report of Zoonoses. The surveillance data are used for research and risk- and effect- assessments to find control options.
The surveillance and control programmes also document the high microbiological food safety status of Danish products.

IMPACT FOR KEY OUTCOMES

As consumers for existing and new markets for the Danish food industry request safety and content documentation, the need for new and rapid methods that enable the industry to secure the documentation grows. Food analytics are moving from time-consuming sampling and analysis methods to rapid and even real-life proxy methods that are coupled to large databases revealing that it is a journey from single analytical measurements to measures that utilize multiple data.

Competences at UCPH and DTU can specifically deliver the following impacts:

- New food control systems that rely on on-line linkage to large databases so that advanced quantitative and qualitative analytical methods, through the European reference laboratories, are exercised and validated.
- The use of rapid advanced analytical chemistry to verify authenticity or to reveal risks of food fraud.
- New paradigms developed for human-relevant risk-assessment to eliminate contaminants and pathogens.
- Advisory services to national as well as multinational organizations provide the consumer with safe foods as well as training for food safety authorities around the world.

#4 OMICS TECHNOLOGIES - FROM MOLECULES TO UNDERSTANDING

NEED

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 analysed. 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.

MAPPING OF COMPETENCES

DTU

Genomic Epidemiology

DTU was among the first global movers in utilizing next-generation sequencing for single isolates as well as metagenomics. Competences are available for analyses and sharing of data. We have also provided online tools enabling the broader research community as well as industry to perform standardised bioinformatics using curated tools and databases.

Microbes, Health and Allergy

DTU applies metagenomics (primarily 16S rRNA amplicon sequencing) together with metabolomics (LC-MS/MS) in order to explore the interactions between the diet, intestinal microbiota, microbial metabolites and human health. With the use of these techniques, we have been the first to identify the link between intestinal transit time and bacterial metabolism in the gut.

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Foodomics for Monitoring of the Foodome and the Human Metabolome

Foodomics has a dual focus; one is to map and gain insight into the food detailed composition (the foodome), and one is to investigate its impact on the human metabolome and microbiome when digested. Focus is typically on large-scale human phenotyping for

identifying food biomarkers or biocontours that relate to human health and secondly to investigate the potential advantages of using stratified or personalized nutrition. Foodomics uses the advanced in-house analytical platform in combination with strong expertise in the analysis of complex multivariate data sets (chemometrics). Special focus is on molecular plant food science and basic research in discovery, structure and functionality of bioactive molecules from plant foods using nuclear magnetic resonance and molecular modelling.
This research area also supports Enabler #5.

Phage Ecology

Bacteriophages are viruses which attack bacteria and they may therefore change the microbial population dynamics. Specific phages may constitute a quality or safety problem as seen in dairy production but some may also be used to decrease the levels of undesirable bacteria in the gut or during colonization. Focus has been on both basic and applied aspects of phages using 2nd and 3rd generation sequencing tools and advanced bioinformatics.
This research area also supports Enablers #3 and #5.

Metabolomics

The metabolomics group is specialized on food metabolomics and is widely recognized as one of the leading groups in this field due to excellent competences in identifying previously unknown human metabolites. Focus is on biomarkers of food intake and of biomarkers related to the effects of food intake on health.

Analytical Chemistry

One of the research areas of the research group is metabolomics. The group has initiated multiple projects focusing on how to use metabolomics to get a more detailed understanding of a given biological system; all the way from microbial metabolomics of wine and cheese to environmental metabolomics of plants.

Microbial Biotechnology

The research group has developed a new technological platform for the study of microbial interactions. The technology comprises the combined use of genomics and molecular genetics, transcriptomics, imaging mass spectrometry and an in-house developed plate reader technology for the study of gene expression in interacting microbes on solid surfaces.

A research project coordinated by DTU with several partners from UCPH, the 3G Center tests the interplay between human host genome expression and gut microbiota and its effect on the development of chronic metabolic disorders. The strength of DTU with its animal studies and UCPH with its human intervention studies together with the power of whole genome sequencing makes a strong collaboration.

The Metabolomics Research Cluster at UCPH is an initiative aiming to unify metabolomics research carried out at the university. The metabolomics groups cover mainly: method development, plant, foodomics and nutritional metabolomics. Together, these fields have great potential to explore metabolic changes in the whole food chain - from growing seeds to consuming foods - and also to join forces in a more practical sense by sharing know ledge, equipment, and ideas.

Our strategy in applications of omics in food and nutrition science is long-term, e.g. developing an objective way to assess diet will have great impact in nutrition science and could become standard practice in 4-5 years. UCPH researchers collaborate in the bridging of food and nutrition science by explaining the impact of specific food components on metabolism, microbiota, and health. In the bioactive foods and health area, applied projects have been more directed towards answering concrete questions, i.e. related to patient health or to mechanisms behind the actions of bioactive foods.

Through a research project, DTU is entering into a pilot project with the European Centre for Disease Prevention and Control (ECDC) and European Food Safety Authority (EFSA) to share, analyze and visualize whole genome sequencing data and epidemiological data across Member States via a secure data hub. The data will eventually be made public for other research institutions to use for improved surveillance.

The UCPH PLEN Dynamo Center of Excellence funded by the Danish National Research Foundation deals with plant-specialized metabolism. The group links cellular processes – pathway orchestration, regulatory networks, transport, metabolite sensing – to organismal biology. The group uses extensive omics tools and mutant collection of Arabidopsis thaliana and its major defense compounds, the glucosinolates. The group takes a pathway-centric approach to study the interconnectivity of cellular components made of DNA, RNA, proteins and metabolites in dynamic processes across all layers of an organism.

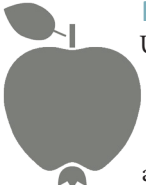
IMPACT FOR KEY OUTCOMES

The merger of biology and technology leads to new insights about molecular interactions; sequencing methods are becoming standard lab equipment, public access to huge databases is growing, and exponential increases in computer power is leading towards a new set of tools to be used in the Danish food industry.

Competences at UCPH and DTU can specifically deliver the following impacts:

- Use of omics tells the other half of the food-effect story.
- Bridging the gap between genetics and improved food functionality and inspire food interventions.
- Increased understanding of the relation between raw materials, food, microbiota and health.

#5 FOODS CONTRIBUTING TO HEALTH AND WELL-BEING



NEED

Understanding the relationships between food and health changes throughout life and how these changes may be influenced by genotype, epigenotype and physical activity, and the microbiota will be a key enabler for the development of personalized nutrition products and diets. Biomarkers may be part of the solution.

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.

MAPPING OF COMPETENCES

The universities contribute to this area with dietary studies (population and intervention), and data from these studies can be used to further develop industry solutions for individual foods, personalized nutrition products and diet development. Knowledge about the gut microbiota and interventions to prevent metabolic diseases is an exciting area of research for both universities; however, each has their area of excellence. The universities' work in sensory and perception studies also play a role in the development of nutritious food products and diet solutions.

DTU

Nutrition and Health Promotion

DTU conducts population-based national dietary surveys to identify challenges in relation to the diet and lifestyle behaviour of Danes. The population-based surveys are a key epidemiological resource from which hypotheses can be formed and modelling can be used to explore 'what if' scenarios, as well as increasing knowledge about the importance of diet composition and nutritional content for health promotion and disease prevention. The surveys are also a resource for different diet preference and personalized nutrition. Additionally, these data provide the reference intake necessary when the safety of new food products needs to be determined.

In addition, DTU performs intervention studies to develop strategies and solutions that stimulate the production of foods contributing to health and well-being and promote healthy eating habits in different population segments. Thus, DTU supplies evidence behind Danish food-based dietary guidelines and nutritional recommendations focusing on life-style disease prevention, customized cultural as well as individual preferences.

Risk-Benefit

DTU makes quantitative risk-benefit analyses of specific nutrients, foods and whole diets using a newly developed substitution model, and quantification and ranking of the major nutritional and chemical risk factors in Denmark. DTU also quantifies health impact of dietary interventions and mathematical models used to estimate the optimal intake of nutrients and foods.

Bioactives – Analysis and Application

DTU develops new technologies that enable enrichment of foods with bioactive compounds such as vitamins and omega-3 fatty acids. Delivery systems include tailor made oil-in-water emulsions as well as electrosprayed nanocapsules.

DTU develops new strategies to extract and fractionate bioactive compounds such as proteins, omega-3 fatty acids, antioxidants and pigments from seaweed and microalgae.

Microbes, Health and Allergy

DTU researches the interaction between diet and the development of immunological and allergic reactions, including an understanding of how the body's bacterial populations (in the intestine and on the skin) contribute to this interaction. In this context, DTU wants to reveal and predict which factors can influence the risk of immunological 'defective reactions', including the significance of the skin as a sensitizing path for food allergies.

DTU has long-term experience with studies of the interaction between diet, the microbiome and health, with particular focus on the potential of microbiota manipulation for prevention of metabolic diseases, ulcerative colitis and food allergies.

Preventive and Clinical Nutrition

Research on potential health effects of diets, foods or dietary components is conducted through human intervention trials in healthy subjects or in patients (clinical nutrition) using a range of clinical, physiological and immunological methods, including metabolomics, and new biomarkers are developed to assess food intake, life style factors, and disease risks. The research includes nutrition in the aging population, where Vitality - Centre for Good Older Lives performs interdisciplinary

research in elderly people. The Centre is an interdisciplinary strategic collaboration between three departments at the Faculty of Science.

Obesity Research

Research in obesity is multidisciplinary. Research includes studies on energy intake and expenditure as well as metabolic health after intake of different diets, food ingredients/nutrients, protein sources, dairy products, various types of carbohydrates, food structures, drugs, surgery. Current research includes exploration of how nutrition can be personalized on the basis of information on individual characteristics, including genetics, gut microbiology, and systems biology. Other studies address how stress, sleep and physical activity interact on the regulation of energy balance and body composition, and how these factors influence cardio-metabolic risk factors related to obesity. The group is specialized in conducting randomized controlled trials applying state-of-the-art research methodologies, while complying with local legislation and Good Clinical Practice quality standards.

Pediatric and International Nutrition

Research in pediatric and international nutrition provides basic and applied knowledge to improve the scientific foundation for better health and reduced disease load in both low and high-income countries. The research covers a broad range of topics relevant for children from birth to young adulthood in both high- and low-income countries, and for some chronic diseases in adults in low-income countries. Internationally recognized important research topics are reflected in new knowledge produced about the effect of a number of different nutrients, e.g., milk (human and cow's milk), insects, fish, fatty acids, protein, vitamin D, etc. The section has many years' experience in doing both observational and intervention studies in all aged children, and the section is thereby able to test the health effects of both single nutrients and food items in high- and low-income countries.

Gut microbiota, Probiotics, and Health

Focus is on microbe-diet-human interactions in the gastrointestinal tract to improve gut health with special expertise in the diverse complex microbial community dynamics in the gut microbiome and by the use of in vitro and in vivo models. The host response to diet, pro- and prebiotics is investigated by combining cutting edge "omics" technologies integrating gut microbiome, immunological and metabolomics data. The combined knowledge on both food matrices and probiotics is used to develop robust food delivery systems for current and next generation probiotics. This research area also supports Enablers #2 and #4.

Choice and Eating Behavior

Focus is on exploring meal design and eating behavior through observation studies and measurements of food selection behavior and meal consumption, e.g., in buffet nudging studies. The research addresses appetite and post-ingestion feelings in different consumer groups across the lifespan including children, elderly and undernourished patients, and utilizes large-scale behavioral consumer intervention studies in both implicit and explicit exposure and educational studies.
This research area also supports Enabler #2.

DANISH NATIONAL SURVEY

The Danish National Survey of Diet and Physical Activity aims to generate current, validated and representative data on both diet, physical activity, anthropometry, lifestyle factors and background information for a wide age range of children and adults from all over Denmark. The data underpins many activities such as nutrition research (identifying the societal challenges), food safety, risk modelling and analysis as well as public health initiatives and public policy decisions.

COUNTERSTRIKE

In the research project COUNTERSTRIKE (Counteracting sarcopenia with proteins and exercise), UCPH works closely with hospitals, industries, and other academia in a full metabolomics investigation of a large intervention sample set (the CALM cohort) with the aim to develop a tool for rapidly assessing age-related loss of skeletal muscle mass, termed sarcopenia, to find individual treatments to promote the maintenance of a healthy level of skeletal muscle mass. The prevention of sarcopenia will have positive effects on each elderly person's quality of life and simultaneously diminish the economic burden on society.

DANISH FOOD COMPOSTITION DATABASE

The Danish Food Composition Database provides important infrastructure for research and advice, e.g., it is the basis for evaluation and calculation of nutrient intakes, for planning of diets for use in treatment, disease prevention and health promotion, and for the industry's calculations of nutrition declarations.

PERSONALIZED DIETARY MANAGEMENT

Through a collaboration between UCPH NEXS and DTU Food, personalized dietary management of elevated glucose response and obesity was investigated.
Feeding the right foods for the right people is important because certain microbiota compositions dictate glucose and weight loss response to specific foods and diets varying in macronutrients and fiber content.

IMPACT FOR KEY OUTCOMES

The phrase "you are what you eat" can be traced back to the early 19th century (Anthelme Brillat-Savarin (1826): Physiologie du Gout, ou Meditations de Gastronomie Transcendante) and as our scientific understanding develops, the phrase actually seems to gain relevance. We understand more about how diet affects health and how the environment and the genetics of the consumers affects the requirements for diet composition. The Danish food industry is at the brink of being involved in personalized nutrition, a concept that is becoming of interest to the consumer.

Competences at UCPH and DTU can specifically deliver the following impacts:

- The development of evidence-based recommendations for diet and nutrient intake and sustainable dietary habits that can contribute to healthy and safe food from infants to elderly.
- Quantification of the health impact of dietary interventions and mathematical modelling used to estimate the optimal intake of nutrients and foods.
- Research-based validation of health-promoting properties of commercially promising ingredients, foods, medical devices or medicine to obtain food-/product-specific health claims or other regulatory approval.
- Potential for personal nutritional recommendations based on omics technologies that provide new insights into the variability between individuals and the potential impact of individuality on dietary needs and personal health outcomes.

#6 AGILE AND INTELLIGENT AUTOMATION

NEED

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.

MAPPING OF COMPETENCES

DTU

Food Production Engineering

DTU contributes to sustainable and efficient food production, to optimize resource consumption, and to design and develop processing technologies and food products for special needs. The research is based on a mechanistic understanding of the interactions between food processing and raw materials, as well as on mathematical modelling and monitoring of food production processes at all levels from unit operations to complex systems.

Food Microbiology and Hygiene

Low-cost and automated sampling and sample preparation prior to rapid testing has created a more intelligent testing scheme, which is in use at Danish slaughterhouses and the food control labs.

Recent developments of advanced micro- and nanotechnology offer new strategies and tools for development of micro and nano sensors, micro fluidics, and lab-on-a-chip systems. Such tools can integrate several laboratory functions onto a small portative platform and are suitable for online or at-site rapid real-time detection and identification of the harmful agents and can be able to analyze multiple samples in one go. It therefore greatly reduces the analysis time for results.

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Process Analytical Technology and On-line Process Monitoring

Process Analytical Technology (PAT) essentially deals with measuring the relevant parameters at the relevant time and interpreting the data you get from the measurements correctly in order to control and optimize the production process optimally in relation to, for example, product quality, sustainability, food safety and ingredient quality.

ODIN CONSORTIUM

In the ODIN industrial consortium, anchored at UCPH FOOD, industry is upgraded with skills in PAT by courses, seminars and workshops in complex data analysis (chemometrics) and on/at-line sensors (spectroscopy), bringing research directly into play in the industry.

CENTER FOR HYGENIC DESIGN

Denmark has a very high level of food safety. Producers of both equipment and food set out strict requirements regarding the ability to properly clean equipment used in the food industry.

At the DTU Center for Hygienic Design, manufacturers can have their equipment tested and assessed according to international guidelines for hygienic design. The center can then certify the equipment, so manufacturers have proof of its hygienic properties.

IMPACT FOR KEY OUTCOMES

Decision makers in the Danish food industry have an opportunity to embrace the automation and sensor technology being developed at the universities. Though the universities may not directly develop robotics for the food industry, cross-discipline projects with relevant departments can be pursued to further industry progression in this area.

Competences at UCPH and DTU can specifically deliver the following impacts:

- More agile and sustainable production lines where sensors and data are used to optimize resource use, equipment maintenance, and quality parameters of the products.
- Hyperflexible production technologies and processes that can be adjusted real-time.
- Data and new algorithms are being used to enhance automation and intelligent robotics.
- New machine-learning technologies have been developed that enable computers to structure, validate and select relevant data.

#7 CONNECTED AND COMPETITIVE THROUGH SMART USE OF BIG DATA

NEED

Establishing of 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, analysing and visualizing data is a key enabler. Furthermore, aggregation of customer and consumer data and making them widely available to improve service level, capture cross- and up-selling opportunities and enable design-to-value (including machine learning) will be important. Lastly, full utilization of Internet of Things should be implemented.

MAPPING OF COMPETENCES

DTU

Genomic Epidemiology

DTU has internationally pioneered the combination of online tools with the ability to securely store and share next generation sequencing data. In addition, the group is increasingly making public data accessible both for download and for analyses, including epidemiological analyses.

Food Microbiology and Hygiene

DTU develops and uses new and innovative methods including “omics” and big data for the rapid detection, typing, quantification, as well as the prediction of the growth and survival of microbes and viruses in food and water. New mathematical models and software are developed for risk assessment and hazard analysis and critical control point (HACCP)-based own control programs, as well as the improved development, processing, and distribution of food products.

Analytical Food Chemistry

DTU strives to contribute with data to food trust and transparency by developing the future food control, discover emerging risk in production and from new food ingredients, documenting quality and reveal fraud and to understand biological effects of chemical in food.

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Chemometric Algorithm Development

The world of food is not univariate and accordingly multivariate strategies must be applied. Multivariate data analysis (chemometrics) includes the development of multivariate tools and methods to be used for process monitoring and control in industry, for understanding interactions between humans and food and for data mining and data fusion in metabolomics/foodomics. These tools include algorithms for data mining, classification, regression, exploring experimental design, curve resolution, peak deconvolution, data alignment, data fusion, etc., which could be used for turning big data into information.

DABAI.DK

The Danish Center for Big Data Analytics Driven Innovation (DABAI.DK) was launched by Innovation Fund Denmark. The aim of this initiative is to make Denmark a pioneer in exploiting the full potential of big data.
The partners include computer science researchers at Copenhagen University, Aarhus University and Technical University of Denmark. The partnership will develop techniques and tools for big data analytics. The work in the partnership will be driven by practical cases with a large business and societal potential. The initial cases will be within Societal Data, Educational Data, and Food Supply Chain Data.

COMPUTEROME

The Danish National Life Science Supercomputing Center, Computerome, is a high performance computing facility specialized for Life Science. Users include research groups from all Danish universities and large international research consortiums as well as users from industry and the public health care sector. They all benefit from the fast, flexible and secure infrastructure and the ability to combine different types of sensitive data and perform analysis. Computerome is physically installed at the DTU Risø campus and managed by a strong team of specialists from DTU.

IMPACT FOR KEY OUTCOMES

Data are valuable information. Governments around the world increasingly work towards open source and making data available to the public. Many of these data have commercial value and new business models have been developed based on public databases. Two examples of such releases in Denmark are FRIDA (frida.fooddata.dk), which is maintained and developed by DTU, and climate data that DMI has recently made publicly available (countries are using the data for climate change research). The Danish food industry can benefit from using available data to stay competitive on the global market.

Competences at UCPH and DTU can specifically deliver the following impacts:

- Analysed and contextualized data can connect manufacturers with their customers.
- Optimized food systems and increased connectivity across the supply chain based on big data.
- Shared framework for data use in the surveillance of pathogens.
- New tools and knowledge have been used to improve safety, quality, and traceability in food production.
- Barriers to 'open data' and 'open science' have been cleared and methods developed for sharing pre-competitive data among industries (sequence data as well as epidemiological).

APPENDIX:
DTU AND UCPH COMPETENCES RELATED TO THE INDUSTRY STRATEGY ON TALENT AND EDUCATION ENABLERS

A key enabler described in "WORLD-CLASS FOOD INNOVATION TOWARDS 2030" is to maintain focus on education relevant to the industry and to attract the very best talents.

It is stated that the education shall be research-based and include a close collaboration between industry and universities.

A number of educations in the core area of food technology, processing and nutrition are directly focused to the food cluster and are offered from Danish universities and other educational institutions (Table 1).

Table 1. Danish educations directly related to the food cluster. Letters in the first column relate to the geographic location in Denmark, see Figure 3.

	EDUCATION	INSTITUTION	GEOGRAPHICAL LOCATION
	PROFESSIONAL BACHELOR		
A	Food Safety and Quality	DTU	Lyngby
B	Chemical Engineering and Food Technology (from 2018)	AU	Aarhus
C	Nutrition and Health	Metropol	Copenhagen
D	Nutrition and Health	Absalon	Sorø
E	Nutrition and Health	UC Syd	Haderslev
F	Nutrition and Health	VIA	Aarhus
G	Food Technology and Application	Business Academy Aarhus	Aarhus
	BACHELOR OF SCIENCE		
I	Food and Nutrition	UCPH	Copenhagen
	MASTER OF SCIENCE		
J	Food Innovation and Health	UCPH	Copenhagen
K	Food Technology	DTU	Lyngby
L	Food Science and Technology	UCPH	Copenhagen
M	Human Nutrition	UCPH	Copenhagen
N	Integrated Food Studies	UCPH (before 2018 AAU)	Copenhagen
O	Molecular Nutrition and Food Technology	AU	Aarhus

FOOD-RELATED EDUCATIONS

The educations in Table 1 are in the center of the food-cluster education landscape covering the chain from the primary raw material to the end product for the consumer. These educations are based on natural science including chemistry, mathematics, physics and computer science. In addition, a number of educations of a more general kind or educations focused on related areas support the main cluster educations (Figure 1).

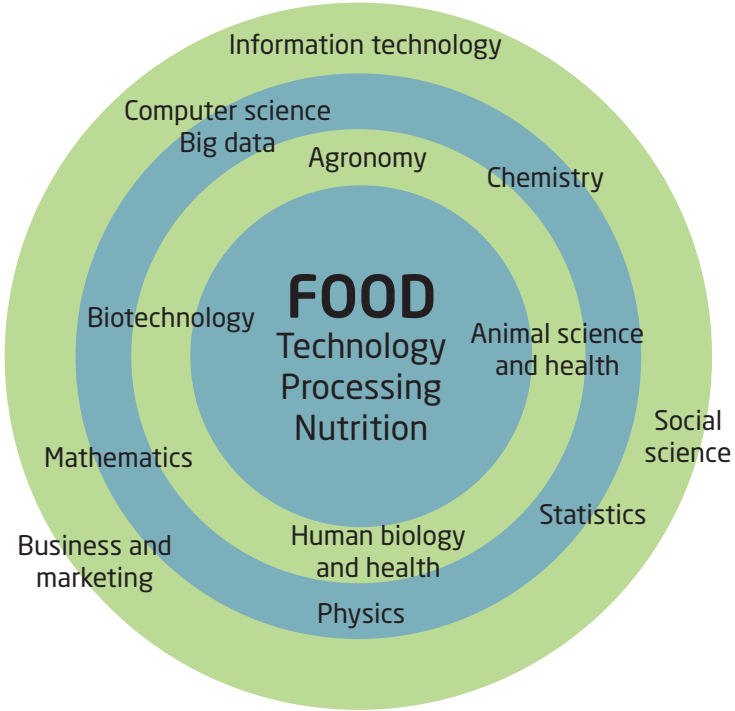
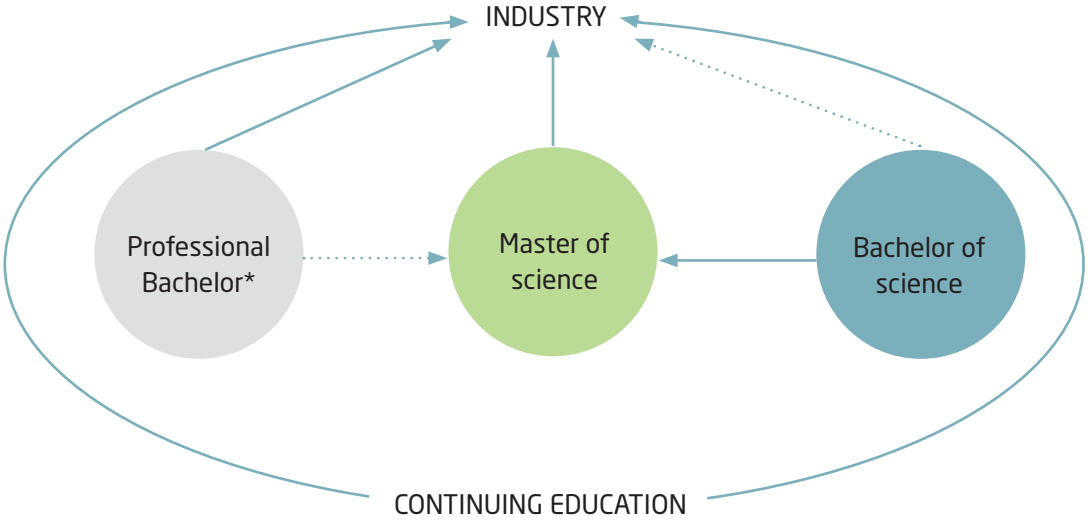


Figure 1. The educational areas of core relevance for the Danish Food Cluster can be found toward the center, with supporting areas of additional relevance radiating from the center.

The different educations are offered in order to reflect different needs and perspectives. Overall, education is offered at all levels from vocational training to higher education at universities. The focus here is primarily on higher education from universities and university colleges with degrees as Professional Bachelor, Bachelor of Science and Master of Science and on the continuing professional development and education. The general pathway for higher education is described in Figure 2.

Figure 2. The Professional Bachelor degree is focused toward direct employment in industry or elsewhere, whereas the Bachelor of Science is focused toward furthering studies through a Master of Science programme. The Professional Bachelor can, however under some circumstances (depending on, e.g., subjects and level), qualify the graduate to further studies in a Master programme. Continuing education programs for professionals are offered via the universities and university colleges.



The educations (higher education) directly focused to the food cluster are mainly situated in Copenhagen and the vicinity (Figure 3). The small geographic distance between UCPH and DTU has been stimulating with respect to collaboration. At present, a bachelor and a professional bachelor program are offered together in order to benefit from different core strengths, with DTU leading within, e.g., technology and food safety, and UCPH having its core competencies within, e.g., food data technology, dairy technology and consumer science. By cooperating, the universities develop a synergy in education that benefit both students and the food industry.

ONE HEALTH INTERNATIONAL SUMMER COURSE

The international summer course in One Health aims to provide knowledge, skills and competences regarding efficient solutions to the multifaceted global challenges to human, animal and environmental health through cross-disciplinary research, education and collaboration between relevant institutions and stakeholders.

The One Health International Summer Course is offered in collaboration between UCPH and DTU, which promotes interdisciplinary scientific excellence in the field of public health, food and veterinary science, and associated technical and life sciences.

Organizers and lecturers are mainly from UCPH and DTU. There are also speakers well-known in their fields from other research institutions and international organizations such as the World Health Organization (WHO).

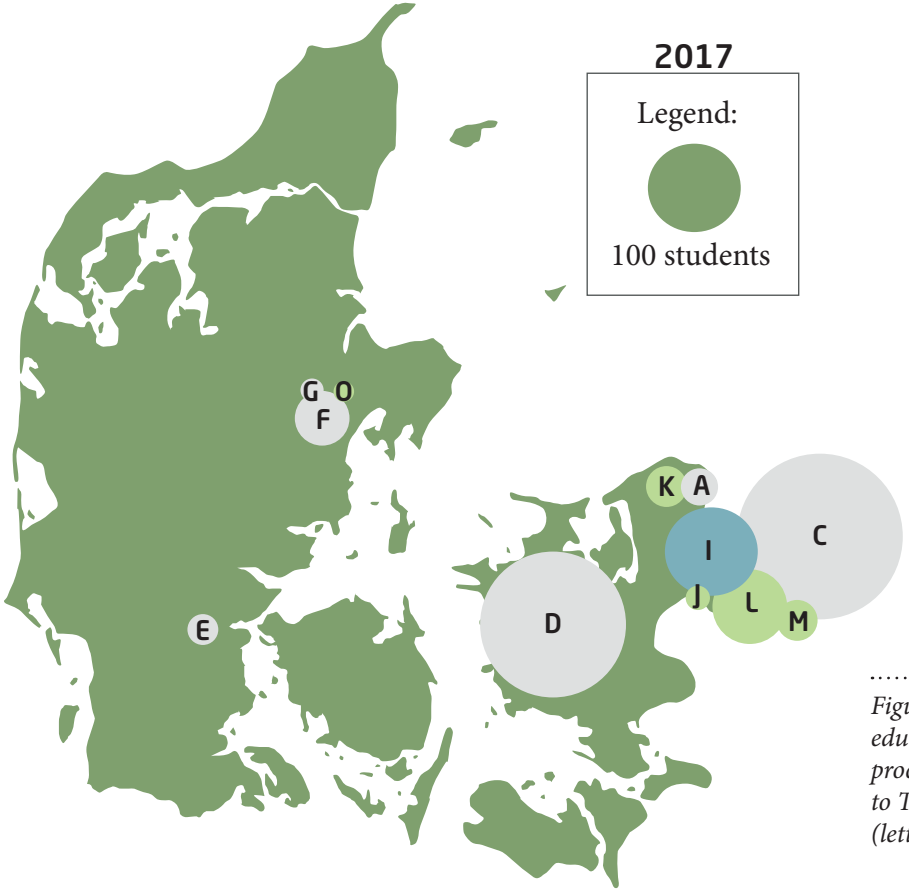


Figure 3. Size and distribution of the core education in the area of food technology, processing and nutrition in Denmark. Refer to Table 1 for a degree (color) and program (letter) legend.

TEACHING BASED ON RESEARCH AND INDUSTRY COOPERATION

UCPH and DTU offer research-based educations of the highest quality that supply students with solid core competencies and ensure the formation of high-quality academics, giving the students a solid foundation for development and lifelong learning. UCPH and DTU actively seek to provide their students with solid academic skills, understanding of practice and abilities to collaborate across fields by providing highly creative learning environments and to enhance the quality of the degree programmes. Research permeates all degree programmes. Furthermore, "projects in practice" are encouraged in order to ensure the students' abilities to translate research-based academic knowledge into practical elements. Particularly talented students have opportunities to participate in extracurricular activities and specific honours programmes. Furthermore, projects are supervised by active researchers through one-on-one courses, and most often, the students are engaged in on-going research projects involving both national and international partners from both industry and academia.

A number of activities at both UCPH and DTU give students knowledge and competences that when combined with extracurricular work gives rise to innovation and business development (OiX,, GrønDyst, etc.). Students are encouraged and motivated by the possibility to participate in national and international competitions and by receiving a special diploma such as the DTU Blue Dot (Figure 4). In addition, students have the possibility to collaborate directly with companies in courses, projects (e.g., projects in practice) and internships, which are of duel benefit for both students and companies, and to take up challenges directly from industry in hackathons.

Figure 4. Diplomas were awarded to the 2017 participants in the DTU Blue Dot event. This group worked on developing innovative new food products for the future. Photo credit: Mikal Schlosser.

Skylab and the coming Foodlab are student innovation hubs at DTU, just as SCIENCE Innovation Hub is a similar hub at UCPH. The hubs value diversity, interdisciplinary and cross-cultural collaboration, and underpin close collaboration between students and industry to share knowledge and strengthen networks by sending both employees and students out to expand the current network and bring back significant, new findings.

Lecturers from industry frequently contribute to courses at both UCPH and DTU, and in some educations (e.g., MSc. Food Science and Technology) more than 50% of all master theses are performed in collaboration with external partners, mainly private food companies. Representatives from the university and the food industry have regular contact through local contact group meetings and through formalized advisory boards.

The following is an overview of the core educations (Professional Bachelor, Bachelor of Science and Master of Science) in the area of food technology, processing and nutrition.

PROFESSIONAL BACHELOR

Chemical Engineering and Food Technology

A new program offered from 2018. The program provides students with knowledge within traditional natural science subjects such as mathematics, chemistry, physics and biotechnology in an engineering context with a focus on food production. The students will acquire in-depth understanding of the food industry and its current innovation needs.

Aarhus University

Food Safety and Quality

An industry- and application-oriented, interdisciplinary and innovative program including a six-month internship in a Danish or an international company. Students will acquire broad-based, expertise in microbiology, chemistry, toxicology, nutrition and production—all disciplines used in state-of-the-art risk-based management and control of food quality and production. The program gives students a theoretical and analytical understanding of food quality.

Technical University of Denmark/ University of Copenhagen

Food Technology and Application

A program providing the students with a natural science foundation in chemistry, physical chemistry, microbiology, biotechnology, statistics and experimental planning. Throughout the program, the theoretical teaching is closely linked to the practical work and students work with cases from companies and in close cooperation with the business community.

Business Academy

Nutrition and Health

A program focused on food, humans and health in an interdisciplinary, social and cultural framework. The meal is a central part, and students learn to work with organizing and managing processes that promote healthy, safe and sustainable meals of high ethical and aesthetic quality. Another focus area is how to work with dietary and lifestyle-related changes through teaching, communication and guidance. Two specializations are offered: “Health promotion and Dietetic” and “Food and Management”.

University College

BACHELOR OF SCIENCE	
Food and Nutrition A program about food and nutrition on a science-based fundament of mathematics, chemistry, physics etc. Underlying themes comprise the food production, what the food consists of, how the food is processed best in terms of achieving good texture, taste and health and how it is ultimately being absorbed and utilized in the body. The main focus depends on specialization: "Quality and Technology"; "Health and Nutrition"; or "Food Engineer" (including a six-month internship in the food industry).	University of Copenhagen/ Technical University of Denmark
MASTER OF SCIENCE	
Food Innovation and Health A program with a focus on innovation in the cross-field between food and health with a view to increasing the offering of healthy, tasty food based on scientific principles. Central elements comprise food culture, food chemistry, sensory science, consumers' experience of food and meals as well as gastronomic techniques and how to work innovatively in these areas.	University of Copenhagen
Food Science and Technology A program aiming at educating highly qualified food science graduates who can grasp and apply the newest technologies. The program has a strong focus on the challenges associated with food production, food safety, food quality and health. Three specializations are offered: "Dairy Science and Technology"; "Brewing Science and Technology"; "General Profile" (e.g. within Ingredients, Food Safety, Meat Science, etc.)	University of Copenhagen

MASTER OF SCIENCE

Food Technology

A program aimed to provide students with profound analytical, design, and development skills in terms of technologies, processes and safety issues related to modern production of healthy, safe food. The programme covers a wide range of courses in technical fields of activity, food science, management, and communication. In addition, the food industry and other external stakeholders also play an active role on the program.

Technical University of Denmark

Human Nutrition

A program offering comprehensive knowledge of the importance of nutrition to human health and a thorough understanding of the principles and methods of nutritional science. The focus is on prevention of life-style related diseases and the curriculum is centred around intake, function and metabolism of dietary energy and nutrients, the importance of nutrition in various life-stages and the effects of nutrition on health and disease at both individual and public health levels.

University of Copenhagen

Integrated Food Studies

A program with a holistic approach to food combining natural science, design and social science traditions. The orientation is towards contemporary and historical meanings and expressions of food through the study of food production, processing and consumption with innovation and sustainability as common key words. Three specializations are offered: “Design and Gastronomy”; “Food Policy, Innovation and Networks”; and “Public Health Nutrition”.

University of Copenhagen

Molecular Nutrition and Food Technology

A program linking food composition and quality and human health. The focus is on knowledge of molecular biology and technical skills at the all-important juncture between food technology, nutrition and health. Courses offered cover nutrition, bioactive components, lifestyle diseases, and food technology, giving the fundament to become experts in development of foods, designed to reduce lifestyle related diseases.

Aarhus University

CONTINUOUS LEARNING

The universities are, just as the industry, aware of the need for continuous learning and training on-job for employees at all levels due to the extensive technological changes and the frequent change of work place among the younger employees. UCPH and DTU offer continuous learning in a flexible setting as single-course students through selected courses from the regular programmes, in defined or flexible diploma or masterprogrammes, by massive open online courses (MOOCs) or by courses and programmes tailored to companies and industries based on their specific needs.

Continuing education at the universities is, as the ordinary education programmes, based on research of the highest scientific level and contributes significantly to the dissemination of research results and implementation of new knowledge in industry. An example of such a research-based activity is the continuous development of the online tool **"Food Spoilage and Safety Predictor" (FSSP)**, which is disseminated to and implemented in the food industry worldwide through workshops.

A new international partnership "BoostEdu" on continuous learning started in late 2017. This partnership is coordinated by UCPH with DTU and other European universities (University of Natural Resources and Life Sciences, Vienna, University of Bologna, Polytechnic University of Valencia and Wageningen University) as partners. In this partnership, MOOCs will be made to ensure lifelong learning among employees in the food sector and strengthen the partnership between this sector and education institutes in all of Europe to create new jobs and reduce unemployment. The core of the strategic partnership is to establish a structure and a platform for co-creating and implementing flexible continuing education within innovation and entrepreneurship for food professionals across Europe. This will strengthen the European food sector to be more competitive through talent and innovation.

DTU Food
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