EPSRC
Engineering and Physical Sciences Research Council

EPSRC CENTRE FOR INNOVATIVE MANUFACTURING IN Food

Annual Report

2017/2018

UNIVERSITY OF BIRMINGHAM

Loughborough University

University of Nottingham
UK | CHINA | MALAYSIA

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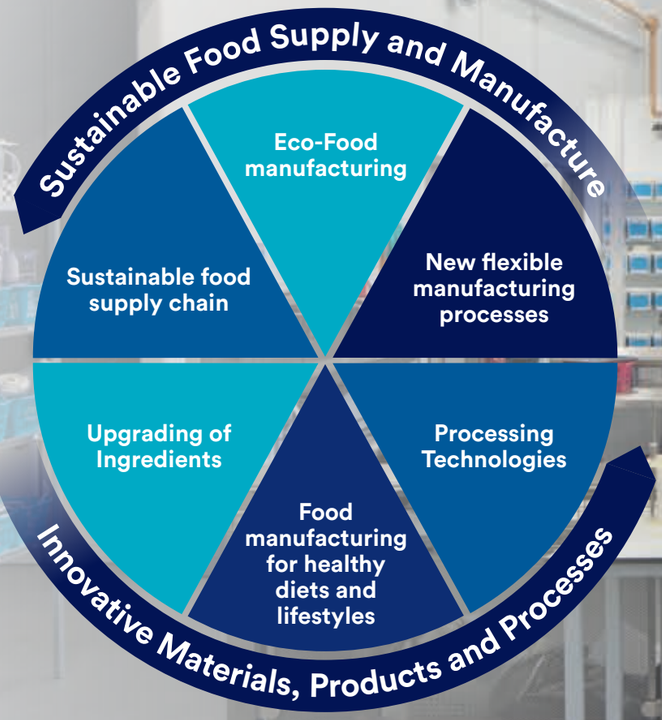
Our Vision

Our vision for the EPSRC Centre for Innovative Manufacturing in Food is to meet the challenges of global food security through developing world-class technologies, tools and leaders, tailored to meet the needs of current challenges whilst redesigned resource-efficient and sustainable, nutritious foods of the future.



Executive Summary

We are now in the final year of the initial EPSRC funding and can have pride in both looking back at our achievements of the last year and through the activities on future strategy also allow us to look forward to a bright future.

Firstly let us begin with the successes that have been achieved within the last year. We have strengthened our contact to industry through secondments with a researcher spending time in the Unilever Vlaardingen laboratory and also transferring CIM technology e.g. to provide sugar reduction in celebration cakes (44%) and frostings (32%), and also contact with other research institutes with a CIM researcher currently spending time in RISE – Sweden's new super-institute.

We have continued to draw down additional funding under the CIM umbrella and the profile of the CIM within the partner institutions has also allowed further alignment of institutional strategy, with ~£7m funding research and new hires across the career spectrum, from Lecturers to full Professors, within the lifetime of the CIM. The total additional income to date in the CIM sphere of influence is ~£15m with notable success in acquiring **Newton Fund: UK-India Research and Innovation Bridges Competition** funding; Project 'NewTrition' to work with industry in the UK and industry and academic partners in India, and also **EPSRC Circular Economy** funding; Project 'Whole systems understanding of unavoidable food supply chain wastes for re-nutrition', engaging with the University of York. Together these grants total ~£2.1m, and both tackle aspects of valorisation of industry co-streams, which was the topic of one of our dissemination workshops, **'Systems Change Thinking - Creating Value from Unavoidable Food Supply Chain Wastes'**, attracting 80 delegates. In September we also hosted the **'3rd UK Hydrocolloids Symposium'** with 110 delegates attending with 27 from Industry and interest from Thailand, China, Malaysia, Iran and Spain. In November we again attended Food Matters Live, picking up new contacts and in December were invited to talk at the Parliamentary and Scientific Committee & APPG for Food Manufacturing discussion meeting on 'Science and Food Manufacturing'. Our outreach activities began with our annual conference in March, held in the Great Hall at the University of Birmingham, which attracted 134 delegates, 62 of whom were from industry.

The end of the conference was followed by a workshop reviewing the outputs of the Technology Roadmap we mentioned last year, to begin to establish future directions and policy influencing, which drew inputs from 41 industry and 35 academic attendees. This was followed by an invitation only workshop in October, hosted by PespsiCo (Leicester), where members from 34 different food companies helped shape the direction of a potential EPSRC Future Manufacturing Research Hub in Food, and contributed to the development of the IUK/KTN's 'Food Sector R&D Need & Alignment with the 2017 Government Industrial Strategy'. The team assembled to form the Hub will build on our success and will involve the 'Centre for Sustainable Energy Use in Food Chains' led by Brunel University and involving the Universities of Birmingham and Manchester and the 'National Centre of Excellence in Food Engineering' at Sheffield Hallam University. Collectively we have developed 80 researchers and acquired £25m in additional funding. The Hub is further strengthened by including the Soft Matter Physics capability at the University of Edinburgh, the Green Chemistry Centre of Excellence at the University of York and the Control Systems Centre at the University of Manchester. The Grand Challenges identified are GC1 - Sustainable conversion of all biomass to safe and nutritious food for a healthy population, and GC2 - Future-proofing today's supply chain to deal with tomorrow's finite resources. We hope to be able to report on the development of this hub at a later date, as it is currently under review by EPSRC.

Finally though it is worth mentioning the examples provided at the end of this report, which are our major deliverables, namely the researchers we have developed and helped move to permanent positions within the industry. Our aim was to develop 'THOUGHT LEADERS OF THE FUTURE' and the examples provided certainly show that this is a goal we have done well in achieving.

Highlights at a glance

The Centre now has more than **100 organisations** connected to its network.

In the period of 2017-2018 our EPSRC Centre has secured additional funding, raising the overall leveraged amount over the last four years of the EPSRC Centre to over **£15m**

Successfully organised **6 different workshops** targeted at the food sector.

A successful annual **EPSRC CIM in Food Conference** in March 2017, attended by 134 delegates with 62 industry representatives.

Continued recruitment for talented new members:

2 new post-doctoral researchers

1 research associate

5 new post graduate research students over the course of the year.

About us and areas of interest

The food and drink industry is the largest manufacturing sector in the UK and has a turnover of £97.3 billion and accounts for 19% of total UK manufacturing. This is an extremely valuable sector to the UK and is critical in shaping how food is produced and consumed, ultimately contributing greatly to the health and wellbeing of the population.

In December 2013, £5.6 million was awarded by the Engineering and Physical Sciences Research Council (EPSRC) to establish the EPSRC Centre for Innovative Manufacturing in Food to support over five years. The Centre addresses the challenges facing the global food system, from farm gate to the consumer and beyond.

The two Grand Challenges (Sustainable food supply and manufacture and Innovative materials, products and processes) and six Research Themes (Sustainable food supply chain, Eco-food manufacturing, New flexible manufacturing processes, Processing technologies, Food Manufacturing for healthy diets and lifestyles and Upgrading ingredients) focused at the Centre reflect the concerns of the sector and ensures the Centre conducts research that will enable the delivery of healthy, nutritious food through resilient and sustainable food supply chains.

The Centre works closely with policy influencers, other institutions and the food and drink sector to ensure that new science and innovation at the Centre remains relevant to the community. The fundamental and translational research carried out within the Centre is helping to shape the national and international food research agenda.

The EPSRC Centre for Innovative Manufacturing in Food is one of the Centres for Innovative Manufacturing funded by the EPSRC through the 'Manufacturing the future' programme. The programme is part of a novel approach to maximise the impact of innovative research carried out within the UK, supporting existing industries and to utilise our resources to enable new industries and growth markets.

The EPSRC Centre for Innovative Manufacturing in Food is a collaborative partnership between the University of Nottingham, the University of Birmingham and Loughborough University. The Centre Director and two Deputy Directors are assisted by the operations team of three and there are six academics involved in the grant. The team currently has nine research fellows and associates, two research assistants, 22 PhD students and one technical support staff member.

Processing influences on food structures

To sustainably engineer foods that are fit for purpose, a better understanding of the relationship between food components and processes is needed. The following projects within the Centre have such a focus:

Oil bodies as a source of naturally pre-emulsified oil

The process of oil extraction and purification form oleaginous seeds using organic solvents, has an high environmental impact, and is hazardous due to flammability and risk of explosion. During this process the oil is released from natural spherical organelles named 'oleosomes'; once the oil has been refined, it is re-encapsulated in the form of emulsion droplets using surfactants and antioxidants for incorporation into a range of foods. Oleosomes are generally between 0.2 and 2.5 µm in diameter. They are made of a core of triacylglycerol surrounded by a layer of phospholipids with embedded surface active proteins (e.g. oleosins).

This project focuses on the extraction and characterization of intact and pure oleosomes as a natural source of pre-emulsified oil to be used in a range of food applications. The extraction method used for the recovery of oleosomes affects their physiochemical characteristics, such as particle size, purity (extraneous proteins and polysaccharides can be carried over from the seed matrix), and zeta potential. This extraction method comprises the following steps: soaking of the seed to increase the internal moisture; disruption of the seed matrix in aqueous media; collection of a 'crude' oleosome cream after centrifugation and washing of the cream. The extraction of these natural oil droplets using an aqueous process is more environmentally friendly, reduces the hazard and, based on preliminary estimates on small scale production, uses one-fifth of the energy consumed. Moreover, the co-extracted proteins can be then exploited in the preparation of protein isolates.

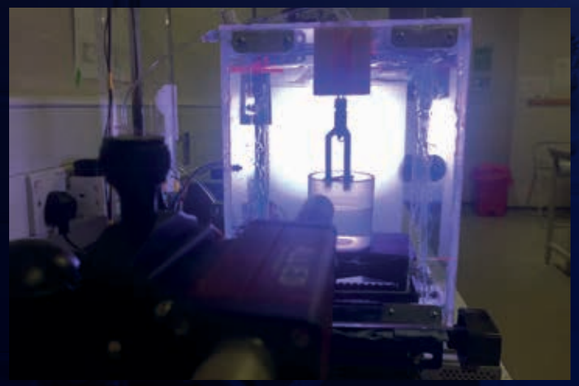
The project has demonstrated a beneficial effect of the use of buffer systems instead of simple distilled water as an extraction media and have created emulsions of intact oleosome with similar physiochemical characteristics to the traditional preparation methods. A journal paper has now been published in Food Chemistry, entitled 'Enhancing the recovery of oilseed rape seed oil bodies (oleosomes) using bicarbonate-based soaking and grinding media'. Investigators are now optimising the combination of time-temperature parameters to extend the stability of oleosome emulsions.

Modelling foam behaviour using stereolithography

Drainage models in foams are based primarily on the flow of liquid through the network of Plateau Borders (PB) and junctions that define the foam geometry. Such models arise from the extension of theory and assumptions made at the micro-scale, detailing flow through isolated PBs and nodes. Despite this, the experimental verification of such microscopic flow models, especially those for nodes, is limited.

The aim of this project is to provide better understanding that could be of great use for tailoring foam longevity to suit industry needs. In this project a novel experimental setup that utilises the convenience and accuracy of stereolithography to allow for analysis of an ideal, isolated PB and node system. A computer modelled geometry has been demonstrated to produce a stable PB and node with PB height and liquid flow rate as user defined variables. Measurements of PB radius, flow pressure changes and velocity of tracked fluorescent particles will enable fitting of theoretical models to data, determining flow profiles, average flow velocity and surface shear viscosity of gas/liquid interfaces for a variety of surfactants.

Initial results highlight the potential of the customised setup (see accompanying figure) to provide reliable data, furthering the understanding of both micro and macroscopic drainage characteristics,as well as providing in-situ micro-rheological measurements of the gas/liquid interface.



Microwave processing of native bioactive compounds

Bioactive compounds are nutritional components found in certain foods that provide several health benefits. However, most of the bioactive compounds have limited bioavailability due to their pharmacokinetic mismatch and the use of nanoparticles is an option to overcome such drawbacks.

Numerous techniques are available for nanoparticle fabrication and these can be classified as being either "top-down" or "bottom-up" processes. Bottom-up processes synthesise nanoparticles starting from an atomic/molecular scale and generally provide better control over nanoparticle properties such as size, degree of monodispersity and morphology.

The microwave precipitation process is a bottom-up technique that represents a novel approach to nanoparticle fabrication. In this project, microwave energy has been successfully utilised to fabricate nanoparticles of organic compounds.

The aim of this project is to take native bioactive compounds with known health benefits (antioxidant, anticancer, antimicrobial etc.) but poor aqueous solubility and nanonise them using the microwave antisolvent precipitation (MAP) technique. Nanonisation is known to improve dissolution velocity and the MAP technique is an example of a 'green energy' process.

Exploring low energy approaches for emulsification

In food emulsions, the emulsification method largely influences the final properties of the product. Established emulsification processes have the major disadvantage of being energy intensive, unavoidably wasting a large part of their energy input.

An important research area focuses on studying low energy approaches to traditional emulsification. In this regard, Confined Impinging Jets (CIJs) seem a potential alternative to industrially established emulsification techniques such as high-pressure homogenisers and high shear mixers.

Emulsion formation via CIJs are promoted through the impingement of two coaxial jets. The head-on impingement generates a localised region of highly-intense energy dissipation. Due to the small reactor volume, the emulsion is forced to pass at high feed velocity through the high-energy dissipation zone. This encourages droplet break-up in very short residence times, which allow tighter control over the emulsion quality. All of this makes CIJs an attractive solution to traditional emulsification techniques when continuous and high-throughput production is required.

The aim of the project is to expand the functionalities which can be imparted to simple as well as complex emulsions produced by CIJs in terms of both process and formulation aspects. The research focuses on the continuous interplay between food structure, processing and design.

Meet the team

University of Nottingham
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Simone De Chirico

Simone started his PhD at the University of Nottingham in May 2015 supervised by Dr. David Gray. Prior to this, he was based in Plant Lipid Biochemistry at Rothamsted Research (2014), and Biotechnology at the University of Tuscia, Italy (2013). Simone graduated from Italy with a BSc degree in Biology at the University of Rome "Tor Vergata", and a MSc degree in Food Science and Technology at the University of "Tuscia" in Viterbo, Italy.

Simone's PhD project builds on the work of Dr. David Gray on the recovery of oleosomes from oilseeds, which aligns with the EPSRC Centre for Innovative Manufacturing (CIM) Research themes identified as "Eco-food manufacturing" and "Upgrading ingredients".

The current research explores recovering natural oil droplets (oleosomes) from rapeseed to be used as a replacement of the current oil-in-water emulsions. Oleosomes are sub-cellular droplets representing the main form of energy storage in oleaginous plant seeds. The current manufacturing process of oil extraction, refining and emulsification, requires extensive use of chemicals and a significant energy input. The release of intact oleosomes by wet milling oilseeds results in a natural emulsion (no need for additional emulsifiers) and is likely to have a lower environmental impact than conventional oilseed processing. The aim of this project is to recover intact oleosomes, free from exogenous seed material, to be used as a sustainable natural ingredient for food production. The main focus of this study is to understand the physiochemical properties of oleosomes as affected by processing conditions, and how the thermal process may enhance their shelf life due to denaturation of carried over enzymes.

Over the course of his PhD he has presented at national and international conferences, as well as public events (Food Matters Live, London 2015/2016). Simone was shortlisted for the "Young Lipid Scientist" award from the SCI scientific community. He also had the opportunity to work in collaboration with national (Rothamsted Research, May 2016) and international (Wageningen, September 2016) institutions. Simone has recently published a journal paper in Food Chemistry (September 2017), and two additional papers are currently under preparation to be submitted in early 2018. The EPSRC Centre for Innovative Manufacturing in Food has provided the opportunity to interact with colleagues from many different research disciplines and backgrounds. Being part of this community has been a great experience, allowing the sharing of knowledge and expertise.

Designing resilient food supply chains

There are major sustainability challenges facing the food and drink sector and environmental impact must be considered to ensure that food production continues in a sustainable manner. The following are some of the projects exploring solutions for more sustainable food supply chains:

Food waste reduction

Globally, one third of food produced is wasted. A considerable amount of waste is generated in the food supply chains of both developing and developed countries. However, another concern is consumer food waste (CFW). In the UK, more than half of the food wasted is post-consumer, making food consumption the largest single contributor towards food waste. Moreover, 60% of the domestic food waste is estimated to be avoidable. In an increasingly resource constrained world, it is imperative to reduce the high environmental, social and economic impacts associated with this type of waste. This demands for the development and implementation of improved, targeted management practices.

Currently, the Centre has multiple projects addressing these concerns:

Optimising industrial food waste management

The project 'Eco-production of food: reducing the impact of food waste' provides a framework to optimise decision-making regarding food waste management. It comprises a detailed review of current literature pertaining to food waste management and its associated ramifications, and defines a novel framework consisting of four stages: clear definition of food waste and the boundaries of food systems; categorisation and quantification across supply chains; assessment of environmental, economic and social impacts; and evaluation of technology/management alternatives. The framework developed is being implemented in a software tool that food businesses can use to select the most sustainable solution to manage their food waste and better understand the sustainability implications of the management of food waste.

Approaches to reducing consumer food waste

Consumer food waste (CFW) has the highest level of environmental and economic negative impacts compared to waste generated at other stages of the supply chain. This is due to the significant additional amount of resources used to produce the final food products, highlighting a need to encourage more efficient and environmentally sustainable consumption. The overall aim of this project is to bridge the gap between food manufacturing and food consumption through a root cause analysis of the main factors contributing to generation of CFW, and to use this new knowledge to influence consumer behaviour towards reducing food waste. By strengthening the relationship between manufacturers and consumers through better understanding and evaluation of CFW, the research identifies specific improvements in manufacturing and retail activities that will reduce CFW generation. The project is acquiring a deeper understanding of consumers, providing support for various food services, and using new advances in information technology to communicate more effectively with consumers to better meet their needs.

Application of internet of things to support sustainable food supply chains

The food sector is increasingly under pressure to improve its resource efficiency. To achieve this, it is vital for the Food Supply Chain (FSC) actors to share information in a timely manner. The technology and tools associated with the concept Internet of Things (IoT) is capable of supporting numerous tasks in real-time.

This project investigates the application of IoT for reduction of food waste. Traditional methods of physical monitoring of food wastes is labour intensive and complex, and is often time consuming and costly. The research examines an innovative approach based on an automated system consisting of an Image Processing Technology (IPT) to monitor and detect the food waste types, Load Cell Technology (LCT) to record the weight of food wastes produced, and a Food waste Tracking Server (FTS) to record in real-time the types and values for various food waste and to provide analytical capability based on historical data.

The automated food waste monitoring and management system is capable of supporting day-to-day waste disposal decisions. It is able to assist with long-term root cause analysis to ensure that preventive measures are implemented to reduce food waste generation.

Resilient Food Supply Chains in Volatile Operating Environments

The project investigates how the increasingly popular topic of resilience in supply chains can be translated to the food industry, given unique considerations of food such as shelf life and natural variability in terms of quality and quantities of food as a raw resource. This research has categorically defined resilience through the development of unique taxonomies of vulnerabilities and mitigating capabilities which can be filtered to represent different key actors from across the UK's food supply network. The taxonomies have been validated by a wide range of stakeholders across UK food supply chains and has developed into a theoretical model for building adaptive resilience. This model will form the basis for simulation of resilience strategies in the face of volatility projected in association with major future stressors such as climate change and population growth.

Energy Efficiency in Food Manufacturing

There is currently a lack of data on energy consumption in the food manufacturing sector at process, machine and machine component levels. The data could inform improvement and innovation in machine design for both retrofitting and in new equipment design.

This project allows a better understanding of energy consumption during food production and identifies new opportunities for energy efficiency improvement and to ensure energy considerations are considered during innovation in food and drink manufacturing.

Sustainable food innovation

Product Innovation is increasingly used to enhance people's lifestyles whilst reducing the negative impact of manufacturing on the planet. In this context, product design and development processes must focus on consumer experience and customisation/personalisation of the product as well as factors such as resource efficiency, resilience in supply chains and long-term sustainability.

This project investigates the benefits and challenges involved in adoption of such radical changes in food product innovation and development processes. The product development process can be seen as a tool to achieve and overcome main obstacles to sustainability and to make improvements throughout early decision-making within a product's life cycle. The research identifies a flexible new product development model adaptable to the specifics of each product range to enable the most sustainable version.

Use of Robots to Provide Flexible Automation in Food Manufacturing

Recently, the UK's food industry has been put under immense pressure to respond to consumer demands, adhere to governmental legislations and regulations, as well as improve their production. Food and Drink (F&D) Manufacturers are facing increasing consumer demands calling for more customised and personalised foods, both of which open new product markets. Governmental bodies are routinely altering legislation and increasing pressures to improve F&D Manufacturer's compliance to them. Furthermore, organisations are struggling to find labour and skilled employees to help fulfil these demands.

Advanced processing technologies are likely to efficiently meet these challenges, and research has found that the food industry would be the biggest benefactor of such technology, especially from industrial robots. Industrial robots are highly flexible, reconfigurable and will ultimately improve the food industry's productivity and competitiveness. Although industrial robots for food processing are becoming more readily available, their uptake has been slow. Existing methods of industrial robot planning and selection have not been appropriate for the F&D sector.

The approach of this project is to comprise a new framework to include planning, investigation, selection and evaluation phases in implementing industrial robots. Furthermore, tools are being devised for the selection and evaluation phases for complete, informed decision making. The main novelty of this research is in the tool(s) designed for selection of industrial robots based specifically on food processing applications.

Water sustainability for the food industry

The true cost of water to manufacturers can be up to three times the supply and effluent charges. In addition, water shortages, lack of water treatment capacity and ever changing legislation are business risks. In mitigation, forward-thinking companies have implemented water management policies, but long-term sustainable reductions of water consumption in manufacturing can only be achieved through understanding and addressing water use by individual process steps. The Centre is currently developing a set of flexible, non-invasive real-time water analysis instrumentation to monitor in-plant effluent flows across various process steps. The data obtained can be used in a Water Management Framework to identify hotspots for process or product re-designs to improve water sustainability. To date, synthetic turbid samples (of different turbidity levels) have been prepared in the laboratory and have already been tested, together with industrial samples from the brick-manufacturing industry and the experimental results are currently being analyzed. In the near future, water samples from the food-manufacturing industry are planned to be collected and analyzed with the aid of a Multi-Analyte Sensor Kit.

Meet the team

Loughborough University

Sandeep Jagtap

Sandeep joined Loughborough University in 2015 as a Research Assistant. He obtained a B.Tech in Food Technology from North Maharashtra University, India (2003); MS in Bio-Food Technology from Lund University, Sweden (2007) and MBA from the University of Applied Sciences-Stralsund, Germany (2007). Prior to joining the Centre, Sandeep worked for leading UK food manufacturers such as Greencore Group, Kerry Group and Noble Foods.

Sandeep's work is particularly aligned to the 'Sustainable Food Supply and Manufacture' global challenge and focuses on improving resource efficiency of food supply chains through an application of the Internet of Things concept. In this research, the primary objective is to minimise the consumption of energy and water and reduce the food waste generated in supply chains.

Sandeep's project investigates environmental sustainability in food supply chains. Primarily the research focuses on identifying issues associated with high environmental impact in food supply chains, with an aim to reduce the consumption of material, energy and water. The project uses the concept of the Internet of Things (IoT) to collect and analyse data related to food waste, energy and water consumption in food supply chains. This effort would allow supply chain actors the opportunity to understand the reason behind resource wastage and take timely action to minimise or completely eliminate it and thus making food supply chains more sustainable.

Although Sandeep already has a food industry background, working with researchers within the EPSRC Centre for Innovative Manufacturing in Food has refined and expanded his knowledge from that prior to joining the Centre. The ability to contact researchers who have expertise from broad backgrounds ranging from food chemistry to engineering has added another dimension to his research area. Furthermore, the annual conference has served as a perfect platform to showcase his research and to get expert feedback from both academics and industrialists, which has shaped his work over the past two years. Considerable interest in his project has been generated as well as future scope for industrial collaboration.

Improving the flexibility of food manufacturing

Changing consumer behaviours and the development of new business operating models is indicating that more adaptable manufacturing is required in the future. The Centre has projects exploring the feasibility of flexible food production in relation to distribution chains, food materials and manufacturing processes.

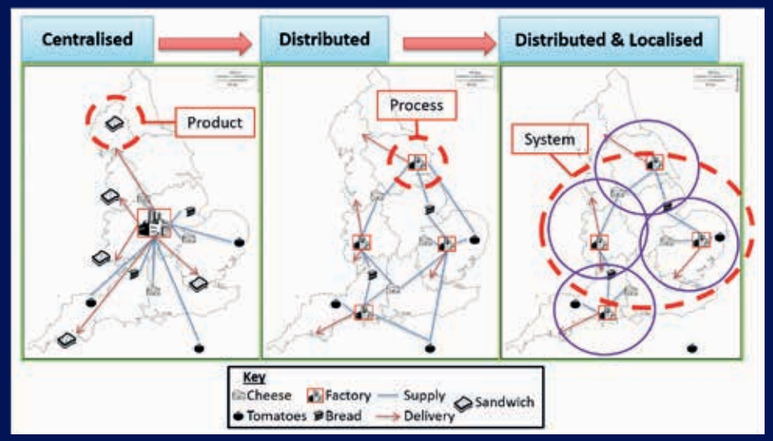
Distributed and localised manufacturing of food

Traditional business models focus on centralisation and large scale production of food products. These concepts are being challenged due to increasing demand for authentic local products, food waste associated with large supply chains, consumer demand for food sustainability, concerns regarding the long-term resilience of complex food systems and the change in consumer purchasing behaviour. The Centre is understanding the suitability of food production using different models (see accompanying image).

This project is focused on the concept of Distributed and Localised Food Manufacturing and the variety of food products make it significantly different to other manufactured goods.

Criteria have been defined and used to demonstrate the suitability and applicability of existing and emerging food technologies to support distributed manufacturing. The research explores a number of related questions regarding the viability of distributed manufacturing within the food sector, including the profitability of traditional technologies in smaller scale; scalability, reliability and ability of novel food technologies to produce high quality food products at affordable prices; and social and societal acceptance of small factories within urban areas.

This project has developed metrics for 'product attributes versus market conditions' to highlight in which food applications distributed and localised manufacturing is economically feasible, can generate environmental benefits and has potential to support local economies.



Drying and rehydration for distributed manufacturing

Drying of foods is one of the most common preservation processes. Water removal inhibits microbial growth and enzyme activity, prolonging the product shelf life; moreover, it reduces the food weight simplifying transportation and storage. The Centre currently has multiple projects investigating the effect of drying on foods:

Examining drying techniques to obtain optimal dehydration and rehydration

Conventional techniques, such as air drying and freeze drying, show some drawbacks, mainly long processing time, low rehydration capacity and change in food properties. In order to improve water desorption, osmotic dehydration pre-treatment can be applied; in this way an intermediate moisture product is obtained, reducing the overall processing time. This project has compared different drying techniques to obtain the highest water removal from fresh food and, at the same time, the highest rehydration ability of the dried product and to ensure that the dried and rehydrated product retains good organoleptic properties. The investigators have published a journal manuscript relating to this work in LWT –Food Science and Technology titled 'Influence of osmotic dehydration pretreatment on oven drying and freeze-drying performance'.

Influence of gel microstructure on drying and rehydration processes for food industry applications

This project studies the drying and rehydration mechanisms of quiescent gels, in particular gellan gum, carrageenan and gelatin. Freeze-, air- and supercritical fluid drying are the investigated processes that generate completely different dried gel structures. This work provides an understanding to how the drying technique can modulate the bulk porosity of gels and how the rehydration rate is consequently affected. The novelty of this work is the comparison of drying techniques in terms of generated porosity, without changing the system formulation, and assessing the induced rehydration rate. To date, two journal manuscripts have been published on this work in: Food Structure entitled 'Effect of alcohols on gellan gum gel structure: Bridging the molecular level and the threedimensional network', and Food Hydrocolloids entitled 'Role of gellan gum microstructure in freeze drying and rehydration mechanisms'.

Re-dispersible dry emulsions

Dry oil-in-water emulsions specially formulated to be able to be reconstituted after they have been dried has been produced. The emulsions are successfully reconstituted when droplet size, stability and rheological behaviour after rehydration are the same as the native emulsion. To produce re-dispersible dry emulsions, consideration for the emulsifier used is important for mechanical protection of the oil droplet during drying but it also becomes the outer layer of the resulting powder. The focus of this project is to understand how the emulsifier should be chosen so that structure is retained during the drying process whilst optimising the reconstitution after rehydration.

Meet the team

Loughborough University

Pedro Gimenez-Escalante

Pedro started his PhD in Distributed Localised Food Manufacture in 2015. Before joining the Centre, Pedro obtained his MEng in Agricultural Engineering with specialisation in Rural Engineering from the Polytechnic University of Madrid in Spain and his MSc in Engineering and Management of Manufacturing Systems from Cranfield University obtained through a Double Degree Erasmus agreement programme.

Pedro's research is focused on the understanding and development of the concept of Distributed and Localised Food Manufacturing (DLM). This theory refers to a conglomerate of distributed and autonomous production units which operate as a set of cooperating entities. The unique attributes of food products, such as perishability and stringent storage, make them considerably different to other manufactured goods, and particularly suitable for localised, distributed manufacturing. There is a need for a shift towards smaller-scale local manufacturing which has been highlighted by a range of factors such as changes in transport and labour costs, the availability and access to materials, energy and water and the need for long-term resilience to market changes.

This project has identified a number of metrics for 'product attributes versus market conditions' to highlight in which food applications distributed and localised manufacturing is economically feasible, can generate environmental benefits and has potential to support local economies. This work encompasses the creation of an AHP based decision support method for the assessment and identification of products with potential to be manufactured in distributed and localised systems. The method will additionally support the identification of the most suitable models for the future manufacture of food considering the four proposed DLM system models developed during this research.

The Centre has helped him in developing his professional career by providing numerous personal growth opportunities such as attending and presenting in the annual conferences or participating in the additive manufacturing in food workshop. Additionally, the CIM has given him the opportunity to discuss his research with the advisory board formed by multiple food sector experts who provided valuable feedback to improve and advance his personal research project.

In addition, the Centre has given Pedro the opportunity to work in collaboration with other Centre colleagues and external organisations which resulted in the creation of a report published nationally, placing his research in a leading position. The CIM reputation has also increased the impact of his research by providing multiple dissemination opportunities and a platform to collaborate and interact with researchers with similar interests.

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Valentina Prosapio

Valentina was awarded her Ph.D. in Chemical Engineering at the University of Salerno Italy) in April 2016. Her doctoral project focused on Supercritical Antisolvent (SAS) precipitation, an innovative micronization technique, based on the use of supercritical carbon dioxide ($scCO_2$), that allows low-temperature processing and the a completely solvent-free product to be obtained.

In June 2016, she moved to the UK and started to work as Research Fellow at the School of Chemical Engineering of the University of Birmingham, within the "Microstructure Engineering Research Group". Valentina's main post-doctoral project is about "Drying and rehydration".

Drying is a conservative method that aims to prolong the product shelf life, minimise packaging requirement and reduce the transport/storage costs. She is currently working with different drying processes (osmotic dehydration, ultrasound, freeze-drying, oven drying and $scCO_2$ drying) in order to identify the techniques, and the related operating conditions that allow an efficient water desorption with a good retain of the food properties. In addition, she started to study the environment impact of the drying process using the Life Cycle Assessment (LCA) methodology to identify the most energy consuming steps and understand where it is possible to intervene to minimise the emissions.

Valentina also works on the incorporation of active compounds into polymeric carriers for controlled drug delivery. Specifically, she studies how it is possible to modulate the drug release rate from a gel by changing its mechanical properties. According to the specific application, the release could need to be fast or prolonged. However, several mechanisms (diffusion, swelling, osmosis, etc.) can occur simultaneously and alter the leaching, resulting in difficulty controlling the release rate. In this context, the design of the delivery system's microstructure is crucial to impart specific properties. In particular, the gel formulation can play an important role: the use of acidified/basified gels or the use of mixtures of polymers with different properties can lead to targeting the drug release rate. Moreover, the loaded gels can be dried to prevent bacteria proliferation, thus allowing safe storage.

During her time working within the CIM, she had the opportunity to network with different groups across the Centre and be involved in collaborative projects. CIM members have brought together expertise from different fields and the discussions about the future of the food industry has contributed to her growth as a research fellow.

Utilising additive manufacturing with edible materials

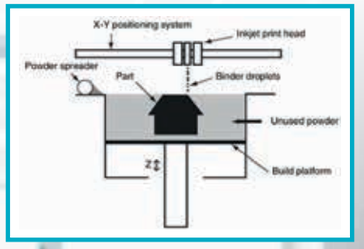
Additive manufacturing of food can offer the food and drink industry a number of competitive advantages including the potential to significantly change the way that food is produced. Its versatility and ability to produce novel structures is thought to lead to methods of producing and reproducing food microstructures with predefined textural and release properties. Different projects at the Centre are exploring the uses of edible material for additive manufacturing:

Development of edible filaments for fused deposition modelling

This project explores the use of additive manufacturing, specifically using the fused deposition modelling technique (FDM), to create edible filaments. This technique typically uses a solid filament, which is heated and extruded through a nozzle to create an object layer by layer. Mixtures of two food hydrocolloids, gelatine and kappa-carrageenan, have been characterised to determine if such mixtures are suitable as printing medium. The project is understanding how edible and non-edible materials react throughout the printing process and how their properties are affected after the process. Investigators have demonstrated the possibility of printing shapes that are self-supporting with multiple layers using edible material.

3D Printing using edible biopolymers

The project investigates the use of edible materials in established Additive Manufacturing (3D printing) processes to enable incorporation of 3D printing to food manufacturing. Thus far application has been extrusion (via 'fused deposition modelling' approach) of paste-like or meltable materials e.g. chocolate, pasta dough, mashed potato etc to create interesting geometries, therefore mostly for aesthetic appeal rather than specific functionality and at a resolution no less than 0.5-1mm feature size due to the limitations of FDM. Binder jetting involves using an ink jet printer head to deposit a binding material in an exact pattern onto a powdered material bed sequentially, typically usually 100µm thick layers of powder alternating with a layer of the binder, to result in a 3D object (See image below). With this technique dietary fibre is utilised to create structures relevant to the food industry. A journal manuscript titled 'Design and characterisation of food grade powders and inks for microstructure control using 3D printing' is now published in the Journal of Food Engineering.



Meet the team

University of Nottingham
UK | CHINA | MALAYSIA

Sonia Holland

Sonia started her PhD research at the University of Nottingham on the application of food materials to 3D printing in 2015. Before starting her PhD, Sonia obtained her BSc Food Science from The University of Leeds where she received First Class honours. During her placement year, Sonia was based in the Research and Development Centre at PepsiCo International. Her team filed for and were awarded a patent (GB2525405) during her time at PepsiCo.

Additive manufacturing, often referred to as 3D printing, is a technique whereby objects are built layer by layer as opposed to in a subtractive manner from a bulk material. To date, the application of food materials to 3D printing processes has mainly involved printing of macrostructures that are either ready for direct consumption or require some conventional cooking (e.g. boiling or baking) before consumption. Usage in this way favours retailers and consumers, but has limited applicability for industrial food manufacturers.

This project explores how we might utilise 3D printing to create and control microstructure, with a view to enabling food 3D printing to be incorporated into food manufacture. Materials used for the work are plant polysaccharides – namely cellulose, glucomannan, galactomannan and agar. Two types of 3D layering processes are being explored. The first, binder jetting, involves spreading a thin powder layer (typically 100µm thick) and selectively jetting an ink formulation to bind powder particles together, these processes are done sequentially and repeated to form a 3D object. Mechanical attrition of cellulose via ball milling reduces sample crystallinity. Through control of moisture, temperature and interaction with stereochemically similar polymers, binder jetting can be used to selectively recrystallize and create 3D structures from ball milled cellulose powder. The second 3D process is a jetting procedure capable of ejecting droplets of higher viscosity liquid than in conventional ink jet. Agar fluid gels, suspensions of gel particles created by shearing the hot polymer solution through its gelation, are used in this project as the feedstock for this process. By controlling the temperature during printing, both at the nozzle and of the substrate, the end gel strength can be modulated. Sequential layers printed with different temperature conditions will create structures with modulated texture throughout.

Her work is published in the Journal of Food Engineering titled 'Design and characterisation of food grade powders and inks for microstructure control using 3D printing'. In addition, she has co-written a book chapter and has another journal manuscript accepted for publication in Food Biophysics entitled 'Fluid gels: A new feedstock for high viscosity jetting'.

Sonia has benefitted greatly from the CIM in Food because of the opportunities it has given her for collaboration and networking. She has found that the annual conference, in particular, provides a brilliant opportunity to showcase her work to others from both academia and industry and create talking points to make valuable connections for the future. Additionally, the different expertise of each university involved has meant that a wealth of varied knowledge exists to draw upon for consultation and capability sharing based on the experiences of others.

Exploring natural ingredients and designing products to improve health and wellbeing

The Centre aims to challenge traditional food production by finding more efficient and effective uses of ingredients and food materials. To align with changing consumer lifestyles, the Centre is exploring ways to meet demands to produce novel products for healthier diets using natural ingredients and is examining alternative sources to achieve traditional structures. Here are some of the projects which are focused in this area:

Food grade particles stabilising emulsions and foams

Hydrophobic particles that absorb to oil water or air water interfaces and are able to stabilise them are known. However, many of these are not food grade particles. The aim of this project is to create structures made from food grade materials that can stabilise both emulsions and foams.

A material which has demonstrated potential to create hydrophobic particles that can stabilise emulsion droplets is wax. The current focus of the work is utilising waxes to create particles which can adsorb on air water and oil water interfaces to stabilise them. Furthermore, the project examines the processes that lead to the production of particles or systems with particulate structures that have foaming/emulsifying abilities. Submicron particles were present in both Paraffin and Bees wax, with Bees wax being able to create smaller particles than Paraffin. The functional properties of both systems were evaluated in terms of emulsion stability and foaming. The wax particle emulsions were stable to coalescence for at least 2 weeks and both wax particle foam systems exhibited improved stability.

Formulating oleogels for healthier products

Aimed at addressing one of the key challenges for the developed world: the reduction of saturated fats in food products. 'Rice bran wax' (RBW) was selected as 'oleogelator' as it is an abundant food grade by-product available worldwide. In order to understand the 'in-food' behaviour and design the performances of these new ingredients the project began by studying the thermo-mechanical and microstructural fundamental properties of RBW oleogels. The aim of this project uses oleogels; a novel route for the replacement of saturated and trans-unsaturated fats to structure edible oils in foods. The project investigates the use of oleogels in baked food products (cakes and pastry) and it aims to achieve the same textural and sensorial properties of baked goods prepared with standard fats. This has set new exciting challenges which include understanding the functional role of fats in batters and dough as well as in the final products. In order to achieve a real impact on society, collaborations with industrial partners of the CIM are ongoing. Examples of industrially relevant case studies are (1) the use of oleogels to replace margarine in cake frosting (2017 summer secondment) and (2) the use of oleogels in frying technology (ongoing Master of Research project).

Encapsulating air micro particle

The aim of this research is to provide the food industry with encapsulated air micro particles as an ingredient to manufacture foam based products. This would cut out conventional whipping processes and opportunities for novel product development. The project is exploring spray drying to produce hollow air particles. It is important to carefully consider the materials as it must retain its microstructure during incorporation into the food matrix and in subsequent processing steps, unless, the subsequent processing steps kinetically trap the air allowing then for the hydrocolloid based particle shell to hydrate. It has become apparent that particle contact angle or wettability is a key property requiring control through surface active components in the formulation, which will also critically impact on the spray drying process and the morphology of the particles produced.

Exploring lignin as a functional ingredient

After cellulose, lignin is the second most abundant natural polymer found in vascular plants. As such it finds its way into many waste streams and by-products of the food industry. Lignin is a class of complex organic molecules found in the cell wall tissues of vascular plants. The Centre currently has two lignin focus research projects:

Lignin-based ingredients for healthy snack foods

The hydrophobic character of lignin renders lignin-rich feedstocks from food waste interesting for the generation of emulsifiers and foam stabilisers through extraction and precipitation into micro-particles.

The aim of this project is to design a lignin-based particulate food ingredient with controlled surface hydrophobicity. Extraction and precipitation approaches discussed in literature predominately involve solvents or processing aids which would preclude application of the particles in food systems. A method has been developed to relocate and extract lignin which may be suitable for food application. The current work focuses on functionalising this extract by manufacturing and characterising the lignin-based microparticles.

Investigate process-based modification of lignin-rich feed material into functional food particles

The aim of this project is to explore process manufacturing routes to impart emulsifying ability to a range of lignin-based feedstocks and to assess their commercial viability as a future functional food ingredient.

Relocation of lignin from the plant cell walls onto the particle surface using a hydrothermal treatments may alter the hydrophobicity of the particle. Brewers' Spent Grain (BSG), a widely available and lignin-rich by-product, has been selected as the initial feedstock a being. The project is investigating established thermal process technologies and is also comparing microwave technology to functionalise the feedstock imparts superior functionality.

Understanding Cellulosic Systems

This project aims to build understanding of the quality of food waste and potential to be utilised as a functional food ingredient within model systems. In this project a particular model of naturally occurring 'green' cellulosic waste stream was investigated: *Pisum sativumn* vines, stems and leaves (pea plant biomass once seeds are removed). The recovered fibre (pulp) fraction from the pea biomass, after juicing, is of particular interest.

Cellulosic material from pea biomass has been functionalised by either colloid mill or ball milling and incorporated into model snack food formulations. This material has the potential to replace or work in combination with starch to produce low/ lower calorific products.

Properties of high protein plant-based sources for food structure

Interests in protein-rich foods are rising favoured by their health-promoting effects. The benefits of dietary protein intake has been associated with body weight management and maintenance of muscle mass and function. The urge to search for alternative food protein sources have led to valorisation of underexploited plants and side stream agricultural products. Combinations of various plant-based proteins in foods, rather than a single source, has been suggested to overcome a less balanced amino acid profile. However, palatability of plant proteins in foods has been a challenging issues due to inferior functional properties compared to the animal-derived proteins. Food structure is one of the driving factors of food texture that lead to food palatability.

This project investigates the structure of proteinrich food made from plant-based protein blends. The early part of work provides insight on ball milling effects, as a means of physical modification, on the structural, thermal, and rheological properties of low purity oat bran protein concentrate. A journal manuscript on this work titled 'Effects of Ball Milling on the Structural, Thermal, and Rheological Properties of Oat Bran Protein Flour' has been accepted and will be published in the Journal of Food Engineering. Current ongoing investigation focuses on the structure of oat bran protein particle-filled soy protein isolate gels.

Microstructural design of starch and gluten-free products

This project is to attain microstructure design rules for the replacement of starch and gluten in bread and crackers (medium and low moisture) with the purpose of dealing with gluten intolerance and obesity, and meet 'free from' trend, without losing taste, texture and flavour. The work builds on the application of low energy density cellulose and other hydrocolloids for gluten and starch replacement.

In the absence of gluten whose function is maximised in normal wheat bread as structure creator and stabiliser, gluten free bread tends to have inferior qualities such as small loaf volume, fragile crumb, sandy texture etc. These problems can be solved to some extent by hydrocolloids, especially cellulose derivatives; but the properties of flour applied also exert a dramatic influence which, in addition to the variability and versatility of hydrocolloid properties and functions, bring about extra complexity in gluten free bread production. The chosen hydrocolloids, methylcellulose and psyllium and two types of rice flours which are available for gluten free goods have been characterised. Currently, two product formulations, bread and cracker, are now being developed.

Redesign of collagen casings to deliver high quality performance

The utilisation of collagen casings for sausage manufacturing as an alternative to casings made from animal intestines is of growing interest in the meat industry. Collagen casings are made from collagen paste through an extrusion process. There is also a need to understand how collagen casings can be adapted to provide new properties, beyond what natural casings can offer. One potential approach is to add natural biopolymers such as polysaccharides to the collagen paste. Therefore, the aim of this project is to investigate how polysaccharides can impact the structure and functionality of collagen paste for the development of collagen casings with new and desirable casing properties.

Meet the team

UNIVERSITY OF BIRMINGHAM

Abigail Norton

In September 2015, Abigail joined the EPSRC Centre of Innovative Manufacturing (CIM) in Food as a Research Fellow. Abigail achieved her PhD at the University of Birmingham, researching hydrocolloid structures and emulsion formation, focusing on their use in biomedical applications.

Part of her research continued from the work achieved during her PhD, however now with a food and drink focus. Her research investigates how changing the solvent quality, including using salts, sugars and alcohols, influences the structuring process. This has, in part, resulted in a patent application.

The research developed to investigating how temperature set hydrocolloids (such as carrageenans and gellan) could be structured at 30°C. Abigail developed a new method of forming hydrocolloid gum structures, which had the rheological behaviour of a hydrocolloid fluid gel, but without needing to process at high temperatures. These gum structures were then used to stabilise emulsions and double emulsions for significantly longer periods of time, compared with the corresponding formulations where the gums were not present. Her research resulted in a patent, which highlighted both the novel structures, and the low energy processing which was developed during this research.

Abigail also has a keen interest in mixed hydrocolloid gel systems and the influence on a secondary polymer on the gel properties. Abigail has researched the addition of a second polymer, such as maltodextrin, to gellan and kappa carrageenan fluid gels. Mixed gel systems have been shown to enhance some gel properties, and have allowed for hydrocolloid gels to benefit a greater number of applications.

Joining the CIM was an exciting venture for Abigail, as it meant both the continuation of developing innovative formulations and processes, while giving a fresh challenge by applying her previous knowledge into the food sector. The Centre has also allowed Abigail to interact with researchers and academics from the other institutes, as well as company connections, which has helped to broaden her research areas and ideas.

While working within the CIM, Abigail also co-supervises PhD and EngD students based at the University of Birmingham. Abigail has also developed two PhD proposals in collaboration with two companies, with both being successfully granted. Abigail has built good relationships with the company sponsors and aims to broaden her industrial collaborations during the remaining time of the CIM.

Meet the team

UNIVERSITY OF BIRMINGHAM

Aris Lazidis

Aris is a research fellow at the University of Birmingham. He holds an Engineering Doctorate from the same department, an MSc in Food Technology from Wageningen University (The Netherlands) and a BSc in Food Technology from the Technological Institute of Thessaloniki (Greece). During his career, he has worked on research projects closely with several food companies including Kerry, Mars, Cargill and Nestlé.

Aris has a number of research interests including:

- Designing interfaces (emulsions and foams) using surface actives materials (proteins and surfactants) and/or particulate structures (solid particles, microgels and crystals).
- Utilising hydrocolloids, fats and waxes in creating microstructures as structural elements of food with healthier nutritional profile compared to conventional ones.
- Developing low energy methods to create emulsions.
- Investigating the properties of new structures created in respect to the way they are processed in the mouth and to compare them with well-established foods for indulgence.
- Examine the effect of air bubbles on the sensorial properties of simple water and oil continuous food matrixes both in vitro and in vivo.

In Aris's current project, he is exploring waxes as materials to create particles with an enhanced ability to adsorb and stabilise interfaces. Waxes, materials present in several natural foods that have been overlooked so far, poses the hydrophobicity necessary to adsorb on different interfaces (oil/water, air/water and air/oil). Work has been done to create spherical particles out of waxes that have shown exceptional foaming properties. Moreover, waxes have been utilised in creating a viscoelastic crystal network within oils which not only provides structure to liquid oils, that pose a healthy triglyceride profile, but also allows the incorporation and stabilisation of gas bubbles that can further reduce the calorific density of foods.

In association with his current work, Aris has published a review paper in Food Hydrocolloids entitiled *'Microstructural design of aerated food systems by softsolid materials'*. He currently has another manuscript under review. Aris is also part of the editorial team for the Food Structure Development book which will be published by the Royal Society of Chemistry.

During his time working in the Centre he had the opportunity to work together with some of the other members with a wide-range of skills on collaborative projects related to his research but also towards fulfilling some of the goals of the Centre in Road mapping its future. His involvement in the Centre's cohort events and annual conferences has given him the chance to present his work on a wider audience and network with different people from within academia and industry.

University of Nottingham
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Jade Phillips

In 2015, Jade joined the EPSRC CIM to start her PhD. Before her PhD, Jade completed her undergraduate degree in Nutrition at the University of Nottingham. She is currently in her final year and expects to finish in the autumn of 2018.

Jade's project involves utilising food waste from pea plant biomass, produced after pea harvest, in order to create functional novel food ingredients. To do this, Jade has focused on manipulating the structure of natural cellulosic materials within the *Pisum Sativum* system. Firstly, the material is juiced and separated into a fibre/pulp fraction and further manipulated using ball milling or fibrillation. Jade aims to apply these materials to applications for a food product.

Ball milling and fibrillation bring about changes to crystallinity within differing polymorphs of cellulose. Although ball milling is used to decrease particle size, it also optimizes interactions between the fibre and matrix within polymer composites.

Fibrillation, on the other hand, is performed in a wet system, after chemical and or mechanical pre-treatments. The fibres, once modified, increase the surface area of a typical colloidal suspension; once transformed into either microfibrillated fibres or nanofibres.

Following ball milling or fibrillation, the resulting sample has the necessary functional properties to be utilised in a product as a thickener or gelling agent. These ingredients are low in calories and high in fibre. Furthermore, creating this ingredient would utilise what would be otherwise wasted. Thereby aiding a sustainable production of food ingredients.

Out of over 500 candidates, Jade was one of ten finalists for the L'Oreal-UNESCO For Women in Science 2017 and asked to present at the Royal Society in London. In summer 2017, Jade was selected for an oral presentation at the Gums and Stabilisers for the Food Industry Conference, Berlin and the 5th EPNOE International Polysaccharide Conference, Jena. Industrial sponsorship of her PhD project from PepsiCo has meant Jade was 1 of 2 UK applicants selected for a competition to present her work at PepsiCo headquarters in New York, USA, although unsuccessful in the prize giving, Jade had a fantastic opportunity to share her research and learn from other's research.

Jade has benefited immensely from being a member in the Centre. Being affiliated with the Centre has enabled me to network with multiple industries and other key stakeholders. The CIM has also provided numerous opportunities to attend events both within UK and internationally.

Case study

Sugar reduction in cake manufacturing

There is an increasing demand both at the consumer and governmental level for food products with enhanced nutritional properties, whilst preserving the positive sensorial attributes of foods. Manufacturing consumer accepted healthier food products presents a huge challenge for food. Success in product re-formulation requires a deep understanding of the ingredients' role and the processes required to achieve a desirable food structure. Within this landscape of rapid product re-design, sugar reduction in foods, as imposed by the introduction of the "sugar tax" (6th April 2018), is a top priority in the agenda of many food manufacturers. Sugar is a key ingredient in delivering acceptable products as they contribute to structure development and stability, to product weight, volume, flavour, and sweetness. The replacement of this latter functionality of sugars can, to some extent, be considered the easiest to achieve given the availability of a range of sweeteners, whereas the possibility of matching the other functionalities requires a combination of approaches and technologies.

A preliminary explorative project carried out by researchers at the Centre, in collaboration with industry, aimed to understand the role of sugar in cakes and investigated innovative formulation routes to successfully reduce its content in the sponge. The project also investigated routes to reduce sugar and fat content in frostings.

Experiments showed that direct reduction of sugar content by 50% in the sponge would lead to a less developed product with a structure characterised by large holes, considered a structural defect (Figure 1, left cake) compared to a standard cake (Figure 1, right cake). In Figure 2 details of the structure of the standard (Figure 2a) and reduced sugar (Figure 2b) cake are provided; images are cross-sectional areas, measured by C-Cell. Large holes (in yellow) were present only in the reduced sugar product.

The addition of fibres (4%, wt%; Figure 3a and 3b) and protein (10%, wt%; Figure 3c) allowed a 50% reduction in the sugar content, whilst preserving the desired aerated structure and minimising the number of structural defects.

Fibres also proved to be a functional structural ingredients in frosting formulations allowing the replacement of 45% sugar producing products with comparable rheological and spreadable behaviour, compared to standard formulated products. Furthermore, the use of rice bran wax oleogels, showed that it was possible to reduce the fat content up to 25% (wt%), without affecting the product quality.

This work has demonstrated that fibres, as structural active fillers, and proteins, as foam stabilisers, can be used as functional ingredients for the replacement of sugars in cakes obtaining well aerated structures. From an industrial point of view, this work is particularly relevant as it indicates that a deeper micro-structural understanding of the role played by ingredients can lead to healthier products without affecting their quality.

Project team:
Prof Tim Foster, Dr Vincenzo Di Bari, Dr Jo Gould and Khatija Nawaz Husain

Figure 1: Comparison between a standard cake (right hand side) with a 50% reduced sugar one (left hand side).

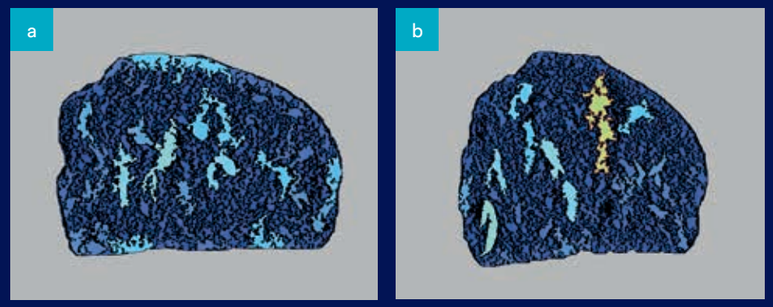

Figure 2: C-cell cross sectional visualisation of cakes; (a) standard cake; (b) 50% reduction.

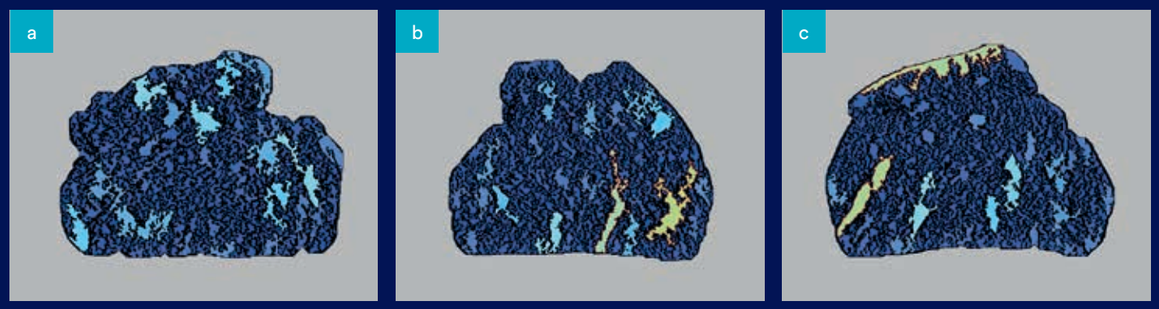

Figure 3: C-cell cross sectional visualisation of cakes with a sugar content reduced by 50%; (a) and (b) replacement by 4% of fibres; (c) replacement by 10% protein.

Case study

Resilience in the UK Food and Drink Manufacturing Sector

It is increasingly accepted that supply chains in all forms face growing volatility across a range of business parameters from energy cost and raw materials, to currency exchange rates and changing consumer demands. Agri Food Supply Chains (AFSCs) not only share these general risks, but also face their own unique vulnerabilities due to the inherent natural variability in quality and availability of raw materials, the fact that many raw ingredients have a short shelf life, resulting in heavy reliance on chilled transportation, and also the overriding necessity to avoid cross contamination. These vulnerabilities are only likely to become more pronounced in future. For example, the already variable quality and quantity of raw ingredients will likely be adversely affected by projected increases in volatility of extreme weather which could limit yields and hinder logistics through drought, flooding, and increased occurrence of pests, diseases and weeds. Changing climate may also disrupt the extent of fisheries as key species migrate or are adversely affected by changing climate. Moving beyond the projected impacts of climate change, the global population is expected to plateau at around 9 billion by 2050, with much of the growth on current population projected to be in the developing world AND in rapidly growing urban areas. Herein lies a major challenge- referred to as a 'perfect storm' by many. Not only are we likely to require more food to feed the worlds growing population but our ability to produce and deliver this food without disruption, thus delivering food security, is likely to be constrained.

These challenges are arguably compounded by the way that AFSCs function. In the UK, which is a good representative example of the highly international AFSCs seen in Europe and North America and increasingly in the developed world, AFSCs are dominated by large 'multiple' retailers who are heavily reliant on import of very large amount of food ingredient and/ or products. This dominance is due to a number of socio-technological developments in recent decades, such as changes in peoples working hours, and increasing prevalence of cars and freezers, which have positioned large, often out of town retailers, to best meet consumer demands for convenience, variety and value. In order to meet these demands, retailers have adapted 'Lean' supply chain strategies which, of particular relevance for resilience, emphasise the elimination of non-value adding activities such as the holding of surplus stock. There is concern that such a structure limits flexibility to deal with growing global volatility.

In response, in this PhD programme a model has been developed for understanding resilience in a Food and Drink Manufacturing context and from this, a toolkit for enhancing resilience at a company level. In this toolkit, the KPIs for measuring adaptive resilience can be selected by user and the underlying causal vulnerabilities is not solely identified based on traditional risk scenarios, but rather based on a real-time mapping process which identifies key exposure points in a company's supply network. The identified vulnerabilities can be individually mitigated by specific actions taken by a company, termed 'resilience elements'. This research has introduced a comprehensive taxonomy of resilience elements for the UK Food and Drink Manufacturing, and the vulnerabilities which they mitigate. These resilience elements must be carefully evaluated as they often have side effects (e.g. holding buffer stock can have serious inventory management costs). This is achieved by cross referencing resilience elements with the previously identified resilience KPIs. In this way, those resilience elements with only positive impacts on KPIs can be categorised as first choice elements. Those with some minor negative impacts are categorised as second choices. Resilience elements which have a major negative impact on KPIs are discarded. The shortlisted resilience elements is then ranked with priority given to those targeting the highest number of identified vulnerabilities.

This toolkit has been empirically validated through a number of case studies which has highlighted the limited effectiveness of resilience strategies that simply focus on a quick and cheap return to the status quo. The case studies have focussed on the chilled convenience food sector, which is an ideal initial model because the tight lead times involved mean that any disruption can quickly amplify. However, there are plans to expand this research to cover not only other food and drink manufacturing operations, but also other stages of the UK agri-food system, such as primary production and retail. The overall conclusion from these case studies is that resilience strategies needs to be 'adaptive', or in other words, able to do more than just respond to a disruption and instead, to learn and adapt from past disruptions to ensure that the business is always best prepared to deal with future threats.

This approach is particularly beneficial for industry because it targets real-world vulnerabilities and prioritise resilience elements with potential with the best impact on key KPIs.

Project team:
Prof Shahin Rahimifard and Jamie Stone

Case study

In-plant real-time food-manufacturing water content analysis

A barrier to achieving a long-term strategy for improving industrial water sustainability is the general dearth of information on water consumption within the manufacturing process chain. In particular, there is no or little off-the-shelf instrumentation available to characterise effluent content in-plant. In an attempt to deal with the barrier mentioned above, some initial steps towards the development of in-line instrumentation for continuous monitoring of water content within a manufacturing plant and determination of the effects of individual process steps on individual flows are currently being taken at the Centre for SMART at Loughborough. The requirement for a continuous data stream arises from the need to capture the time variations in water content related to the batch nature of production and varying manufacturing schedules. A Multi-analyte Sensor Kit (MASK) which includes optical property measurement is in development for this purpose.

The above concept is being tested with food industry partners. Food manufacturing is a major consumer of water for many different purposes including raw ingredient washing, flushing through, cleaning and sterilisation of processing equipment, cleaning and sterilisation of processing facilities, cooking, heating, and cooling and fluming.

In order to scope the potential of MASK an initial trial was conducted using samples obtained from a manufacturing plant making frozen, pre-cooked, filled and unfilled pastry products. The samples were taken from different areas of the plant during the weekly deep clean. The deep clean takes place at the weekend after all production is stopped and involves partial disassembly and mostly manual washing of equipment and pipework using a sequence of fluids, including caustic cleaners, acid cleaners, disinfectant and rinse steps. Floors are washed manually using hoses with automated dosing of chemical into the flow.

MASK measurements of the food factory samples showed correlation with conventional off-line laboratory based effluent characterization measurements in terms of water contaminants, together with the capability to distinguish between different effluent types. It was concluded that both the concept and the equipment set chosen to implement it show promise.

Further research using MASK will concentrate on proving specific applications including active control of processes to improve water usage efficiency, and use of the data obtained for product and/or process redesign to improve water sustainability in industrial applications.

Project team:
Prof Shahin Rahimifard, Dr Patrick Webb and Dr George Skouteris

Reaching out as a National Centre

The EPSRC Centre for Innovative Manufacturing in Food is delivering impact through multiple avenues. The Centre is a proud advocate for disseminating knowledge though different activities. As a national Centre, we continue to build and strengthen our links within the UK to ensure that our research outputs are actively shared.

Our research has been disseminated at national and international audiences through various conferences, workshops and other events. Here are some of the events our researchers have presented and participated in:

February - April	International Conference on Sustainable Energy and Resource Use in Food Chains, London, UK 4th International Conference on Sustainable Design Manufacturing, Bologna, Italy Oracle Brand Compliance Industry Consultation, Loughborough, UK 11th EFFoST European Workshop on Food Engineering and Technology, Singen, Germany
May - July	Congress of Food Science and Technology Congress 2017, Santiago, Chile SCI Young Lipid Scientist presentation, London, UK 19th Gums & Stabilisers for the Food Industry Conference, Berlin, Germany
August - September	Rank Prize Fund Symposium on Carbohydrates and Health, Cumbria, UK Euro Fed Lipid Congress 2017, Uppsala, Sweden Processing, Operations and Preservation Member Interest Group - Campden BRI, Chipping Campden, UK
October - January	Innovate UK / KTN network Early Career Researchers Food Sector, Birmingham, UK 7th International Conference on Food Studies, Rome, Italy Total Food 2017, Norwich, UK APPG for Food and Drink Manufacturing, London, UK Institute of Physics Conference

Over the course of the year, a number of targeted outreach events and activities have been organised, designed to engage with the Food industry and the wider public.

Institute of Food Science & Technology Article

The EPSRC Centre published a Spotlight article in the March issue of Food Science and Technology, the quarterly journal of the Institute of Food Science & Technology. The article highlighted the challenges and needs of the food and drink sector, the expertise of the Centre and how the Centre's research areas, activities and training are supporting the food and drink manufacturing industry.

EPSRC CIM in Food Conference 2017

In March 2017, the annual EPSRC CIM in Food conference was held at The University of Birmingham and was attended by over 130 delegates. The two-day conference showcased the Centre's research portfolio and also invited numerous world-leading experts including, Professor José M. Aguilera Radic, Pontificia Universidad Católica de Chile, Dr. Paul Clegg, University of Edinburgh, Professor. Dr. Alexander Mathys, ETH Zurich, Dr. John Ingram, University of Oxford, Dr. Gavin Milligan, William Jackson Food Group and Professor. Savvas Tassou, Brunel University, to speak on complementary topics. During the conference, a Food Futures workshop was organised. The workshop invited experts of the food industry, academia and other key stakeholders to discuss and highlight key areas of interests within the food sector to enable more research to take place. In addition, the workshop outputs have contributed to the iChemE response to the BEIS Building our Industrial Strategy green paper consultation.

Summer School

In July 2017, a group of Centre researchers were involved in a three day summer school. The Centre was delighted to welcome twenty-four students from twenty-two different schools are the UK. Many different activities took place during the summer school to give the students an overview of food science and the food and drink industry. Researchers from the Centre organised activities which focused on food microstructures. The interactive workshop allowed the students to create structures regularly found in food products. At each station, the researchers would facilitate the discussions to help the students understand how the food microstructures were formed. The aim of the activities was to inspire students to consider studying food science and the potential opportunities within the sector.

3rd UK Hydrocolloids Symposium

In September 2017, the EPSRC Centre hosted the 3rd UK Hydrocolloids Symposium. The theme of the symposium was *Hydrocolloid structures determining functionality*. The oneday event was attended by over 100 delegates and overseas delegates from Spain, Thailand, China, Malaysia and Iran. At the symposium, 17 speakers, including 3 keynotes: Professor Alan Mackie, University of Leeds, Dr Alan Smith, University of Huddersfield and Professor Henk Schols, Wageningen University and Research Centre, were invited to present at the symposium and 14 posters were displayed. The presentations highlighted the diversity of hydrocolloid research and promoted the exchange of ideas between disciplines for hydrocolloid application.

Food Matters Live is the UK's

In November 2017, a group of EPSRC Centre researchers attended Food Matters Live to showcase the Centre's research activities. Food Matters Live aims to bring together the food and drink industry to enable collaboration and innovation. The Centre were among the 800 exhibitors at the event. The exhibitors included research groups, multinationals companies and new enterprises. Food Matters Live provided an ideal platform for the researchers to share and exchange ideas with the thousands of delegates who visited over the course of the three days.

Members of the Centre had the opportunity to attend live discussions with expert panels, seminars and workshops. Speakers including food and drink manufacturers, retail, nutrition and academia shared insight, ideas and best practice to support change. The topics covered at the event were wide-ranging from Food policy and regulation to Sustainable food and drink manufacturing and Population health and wellbeing.

Teaching Food Science and Engineering in Cooking Master School

In December 2017, one of our EPSRC Centre researchers Mattia Cassanelli, delivered an exciting three-day training course to a group of students at the Cooking Master School. The course covered different ingredients, such as chocolate, ice cream, mayonnaise and emulsions, gels. Spherification techniques as well as an overview about drying techniques in the food industry were also presented, combining both theoretical and practical parts. In particular, the influence of water on chocolate and blooming, 3D food printing, emulsion stabilisation, quiescent and fluid gels, the role of ice cream ingredients, drying and caffeine extraction were considered in detail throughout the session. At the end of the course, the students were split into three groups and they were asked to prepare some desserts using these specific ingredients. Creativity, oral presentation embedding scientific terminology and organoleptic properties were the three main evaluation criteria. The best ranked sweet was created by using liquid nitrogen to make ice cream, cocoa gellan gum sheets and strawberries juice bites in a revised version of Sicilian Cannoli.

Systems Change Thinking - Creating Value from Unavoidable Food Supply Chain Wastes

The aim of the event held on 16th January 2018 was to explore unavoidable food supply chain wastes as a unique bioresource: a treasure trove of unexploited, bio-based materials and chemicals, with a range of potential commercial applications. The event was supported by the FoodWasteNet and was a collaboratively organised with another EPSRC funding project (Re-SAUCE - Sustainable, Alternative Uses for food waste in the Circular Economy) and also a Newton Fund project 'Fabrication of innovative biopolymer nanocomposites thin films for degradable food bags and active food packaging' with the Nile University, Egypt. The workshop attracted over 60 delegates and provided an excellent opportunity for delegates to explore further opportunities for collaborative work.

Progression of our team

One of the objectives of the EPSRC Centre for Innovative Manufacturing of Food is to develop thought leaders of the future. Over the course of the Centre, team members have progressed through multiple avenues including industry and academia. Previous team members are currently working as academics in Imperial College London, Loughborough University and University of Nottingham. Other members have taken up roles in the food and drink industry in companies including PepsiCo, Mondelēz International, Unilever, Diageo and Carlsburg. A few examples are provided in the next few pages.

Jo Gould

Assistant Professor in Food Science at the University of Nottingham

I attained a BSc in Food Science and Nutrition, which included a 1 year placement as a New Product Development Technologist at Northern Foods, and a Ph.D in Food Science from the University of Nottingham. My Ph.D research focussed on understanding the functionality and applicability of cocoa particles as a natural particulate emulsifier. The results from which were applied during a placement at Nestlé Product Technology Centre to assess whether cocoa particle structured emulsions were capable of producing a nutritionally enhanced confectionery product. Following on from my Ph.D, in a postdoctoral research role I continued research into natural particulate emulsifiers confirming the role of lignin in the emulsifying properties of cocoa particles and utilising existing processes in the bioenergy industry to create hydrophobic natural Pickering particles from food waste.

After completion of my Ph.D I was employed as a Research Fellow in the Centre until September 2017. My involvement with the CIM included attendance and oral presentations at the first three annual conferences, Food Matters Live, researcher cohort meetings, advisory boards and the mid-term review. During the three year post, I completed two research secondments with two of the CIM's industrial partners. I continued to investigate natural Pickering particles but was also encouraged to start developing my own area of research - Sustainable Proteins - starting with a focus on insect proteins. Research carried out during my time in the CIM was presented at international conferences such as Food Structure, Digestion and Health (New Zealand, 2015), Congress on Particle Technology (Germany, 2016), IUFOST World Congress (Ireland, 2016) and Insecta (Germany, 2017) and published in two peer reviewed journals.

On Day 1 of postdoctoral life being given the autonomy to work within the themes of upgrading ingredients and food manufacture for healthy diets was daunting and after a relatively outlined studentship it felt like I had fallen off a cliff. However, the freedom to explore research ideas and publish these gave me the skills, confidence and eventually an actual research area for the next step of my career. The Centre's core of Birmingham, Loughborough and Nottingham alongside the Industrial partners introduced and gave me skills to deal with a completely different side of research forming ideas across universities, engaging in collaborations to writing grant applications. These and additional opportunities such as organising events, writing research summaries, justifying projects, secondments, industrial collaboration meetings, project management training, dissemination and outreach of the Centre's work were countless, challenging, often completely out of my comfort zone and at times they felt never-ending, but I could not have asked for a better foundation to an academic position.

I was appointed as an Assistant Professor in Food Science at the University of Nottingham in September 2017. My teaching responsibilities encompass protein and meat science to Undergraduates and Master Students as well as supervising research into the functionality of sustainable proteins in food microstructure design. Since being appointed, I have secured funding from the Industrial Challenge Strategy Fund for a PhD studentship investigating thermomechanical extrusion of future food materials and from the University for an MRes studentship studying the manufacture and consumer acceptance of insect protein gels.

Ourania Gouseti

Assistant professor in Food Process Engineering at the University of Nottingham

My background is in Chemistry (BSc), Food Sciences (MSc), and Chemical Engineering (PhD). My PhD work was on studying structure formation under shear. I have specific research interest in understanding structuring and de-structuring of food materials and linking these properties with performance and functionality of the product. One aspect of functionality I am pursuing relates to the behaviour of food materials during digestion. The aim of this part of the work is to identify links between food formulation and digestion to promote design of healthy foods with desired digestibility characteristics. I have also interest in studying crystals, including crystallisation processes and crystal networks. The aim of this part of the work is to understand formation, prosessability (e.g. freeze-drying), and breakdown of crystalline/porous structures. I am further interested in food waste valorisation and I am currently working on dehydration of fresh vegetables and roots.

I have been an associate member of the CIM through my post-doctoral work on crystal networks. This work was funded by a private company. Work has been conducted under the supervision of Prof. Ian Norton at the University of Birmingham. My involvement with the project was from June 2016 until February 2017. The reason for terminating my contribution to the project is career progression, which has been fully supported by the CIM and my line manager (Prof. Norton).

As an associate member of the CIM I had the opportunity to become part of a wide network comprising of established and early career individuals with interests in innovative manufacturing in foods. This enabled me to familiarise with aspects of food manufacturing outside my core research topics thus to gain a broad understanding of the field. It further enabled me to get involved in discussions related to the future and trends of food production with experts in the area, which influenced my research interests. The project I was involved in during my CIM involvement, further enabled me to build link with the funding company. At an individual level, members of the CIM fully supported my career progression.

I was fortunate that I have been working as an assistant professor in Food Process Engineering since the end of my involvement in the CIM. I have enjoyed full support in my first academic steps from CIM members, including Prof. Tim Foster, Dr. Bettina Wolf, Dr. David Gray, and Prof Ian Norton. Overall, I am grateful that I have been included in the CIM activities and I'm also grateful for the support I enjoyed as an associate CIM member and well beyond.

María Natalia Mena Garza

Production Team Leader at Mondelēz International

After completing my studies in Chemical Engineering in Mexico I decided to pursue a Masters in Food Science. In 2014, I started my Master of Research in Food Science and Engineering and was part of the EPSRC Centre for Innovative Manufacturing (CIM) in Food team.

My research project focused on redesigning the biscuit manufacturing process. The project examined the traditional baking methods and how the process could be modified to reduce processing times whilst still obtaining desirable organoleptic properties. During my time with the CIM, I presented my project "Redesign of biscuit manufacture" at the "M5 Universities Advanced Manufacturing Conference" and was awarded with best poster in 2015. In addition, I also had the opportunity to present my poster at the "29th EFFoST International Conference" in Athens, Greece. This was a great experience and I was able to find out about some of the latest research with the area. Being part of the CIM has been a very valuable experience and it has provided many opportunities to network and meet many academic and industry members.

Immediately after finishing my Masters degree, I worked with PepsiCo on a project which built on the work from my Master research project. Currently, I am working in Mondelēz International in the Milka chocolate plant in Bludenz, Austria. I joined the Junior Management Program and I am currently the Team Leader for the Molding and Packing Line of the future. I look after a team of 20 employees and I am responsible for the safety, quality and productivity of the line.

Michelle Neville

Product Scientist for Unilever

After completing my BSc in Food Science at The University of Nottingham, I stayed to complete a PhD as part of the CIM. This PhD took me to represent the CIM at numerous international conferences and I even worked in Denmark for a short period.

I feel the greatest part about the CIM and how it has helped me in my career is the contacts and networks I have made through it. The CIM has allowed me to build key networks with people that a usual PhD student without the support of the CIM would struggle to make. The CIM was also a very supportive environment for PhD students to develop both their scientific and professional skills.

The CIM annual conference was the highlight of the CIM calendar, it really broadened my knowledge and understanding of the food sector through the collaboration across the three universities involved and it was great to see that some of the future challenges we are facing are being addressed by the research topics.

Since leaving the CIM in July 2017, I now work as a Product Scientist for Unilever and have continued to build on those networks gained from my PhD as well as carrying forward into the business some of the research undertaken during my time in the CIM. It is great to see some of the CIM research outputs being used in the food industry.

Leila Sheldrick

Lecturer in the Dyson School of Design Engineering at Imperial College London

I am a lecturer in the Dyson School of Design Engineering at Imperial College London. I coordinate the Global Innovation Design MA/MSc degree course in partnership with the Royal College of Art and conduct research exploring the future of design and 'Ubiquitous Sustainability', aiming to identify how to develop and realise sustainable systems of consumption and production.

I have a broad industrial background having spent a number of years working in industry as a Design Engineer. After this time in industry I returned to academia to gain my PhD in Sustainable Design Futures and undertake both teaching and research within the Centre for Sustainable Manufacturing and Recycling Technologies at Loughborough University, working as part of the EPSRC Centres for Innovative Manufacturing in Industrial Sustainability and in Food.

I worked to help set up the context for a number of the projects in the early stages of research development at Loughborough by writing job descriptions for postdoctoral researchers and PhD students which combined my personal research interests in user engagement in design of personalised foods and new networks of localised production.

The CIM exposed me to new people, and new radical ways of interdisciplinary working. Through the events and collaborations established I have learned how to successfully spark new conversations and get people excited about working across disciplinary boundaries.

I joined Imperial College London to help build and grow the new Dyson School of Design Engineering which was established in 2015. We are working on developing a brand new undergraduate programme and I have been working on the next stage of growth for our postgraduate programme, Global Innovation Design, run in partnership with the Royal College of Art. In addition, I have been establishing new research connections and focuses including envisioning future scenarios, developing new approaches for incorporating sustainability into product development processes, and harnessing ubiquitous computing and interactive technologies in design engineering.

Dr. Antonio Sullo

Research Scientist at Diageo Global R&D Centre

I am a Research Scientist at Diageo Global R&D Centre where I lead projects in Physical and Colloid Chemistry. I hold a degree in Food Science and Technology from the University of Foggia (IT) with a specialisation in Food Analytical Chemistry and a Masters in Food Science from the University College Cork (IE) where I worked in the group of Prof. Ed Morris on the rheology of high sugar/ polysaccharides systems. In 2009, I was awarded the Marie Curie Fellowship and moved to the University of Nottingham (UK) where under the supervision of Prof. Tim Foster I completed my Ph.D. for research on Self-Association of a New Modified Cellulose.

In December 2013, I joined the CIM and continued my work on food microstructure in relation to fat crystallization in emulsion based chocolate and filled protein particles at the University of Birmingham in the group of Prof. Ian Norton. At that time the research activity had just started and I contributed to the writing of a project proposal in drying and rehydration of food microstructures in relation to one of the CIM Grand Challenge (New Processing technology). During my year at the Centre I followed the initial stages of the project from presenting the research idea to the other partners of the Centre to the recruitment of PhD candidates and their guidance where appropriate.

My experience at the CIM has been without doubt central to the role I have today in DIAGEO. The CIM provided a scientific network where to explore opportunities for collaborative research as well as exchange project ideas with R&D professional and experts from academia and industry. This diverse environment of technical experts helped me not only to progress my own research but also to develop skills beyond science. I learned to leverage external experts, to focus more on research impact, to link fundamental research to meaningful technology and to convey complex scientific information in an accessible way. All of the above skills have been extremely valuable for transitioning from academia to industry and overall for my career so far.

Since the CIM I have been working at DIAGEO Global R&D Centre where I lead projects in the area of Food Colloids for iconic brands such as Baileys and Smirnoff. My role combines technical expertise with business knowledge to identify areas of high technical potential for the company. What makes my job scientifically challenging is the presence of ethanol in our products which adds an extra level of complexity to my research. Together with managing projects, I provide technical support to colleagues in other functions or other markets to solve complex, business-related problems with high commercial impact.

Our team

Directors

Prof Tim Foster
Centre Director

Tim worked for over 15 years in Unilever's R&D organisation leading groups in the areas of biopolymers and new technology development. Advisory roles include groups such as the European Technology Platform Food for Life and WCFS/TIFN, and has supervised post-graduate and post-doctoral researchers in a number of publically funded projects. He left his position as Senior Scientist in Unilever to take up a role in the University of Nottingham in 2007.

His current work focuses on natural structuring agents including cellulose, rehydration phenomena and microstructure changes in food products during digestion. Optimal nutrient delivery through the microstructure of manufactured foods is something being developed with colleagues in the current collaboration between Nottingham and the Universities of Birmingham and Loughborough in the EPSRC Centre for Innovative Manufacturing in Food.

He currently sits on various steering committees, on the Editorial Boards of' Food Hydrocolloids' and' Food Digestion', is Associate Editor of 'Food and Function' and is a Fellow of the Royal Society of Chemistry.

Prof Ian Norton
Deputy Director

Ian joined industry after obtaining his doctorate in Physical Chemistry of polysaccharide conformational transition, moving into the area of colloids and interfaces. He developed a microstructure approach, designing materials properties by choosing the ingredients based on their physical interactions, and then designing the process to physically structure and trap the microstructure in the desired state. The resulting material and its properties can allow ingredient flexibility in terms of alternatives and replacement.

Ian left his role as Chief Scientist at Unilever to take a Chair as Professor of Soft Solid Microstructural Engineering in the Department of Chemical Engineering at the University of Birmingham, where he continues his microstructure work, extending into a wider range of soft solids, which are used extensively in foods, personal care products, and pharmaceuticals.

He has authored more than 100 original refereed papers on the science and engineering of biopolymers, fat physical chemistry, kinetics, emulsions, rheology and material science and is an inventor on more than 60 granted patents covering ingredients, spreads, dressings, sauces, skin creams, shampoos and ice-cream.

Prof Shahin Rahimifard
Deputy Director

Shahin is a Professor of Sustainable Engineering in the Wolfson School of Mechanical and Manufacturing Engineering at Loughborough University. He is the Founder and Director of the Centre for "Sustainable Manufacturing And Recycling Technologies (SMART)", which was formed in 2004.

He is leading a wide range of research focused on sustainability issues within 'Life Cycle Engineering', including projects on sustainable product design, low carbon manufacturing, sustainable business and consumption models, product service systems, and product end-of-life management, recovery, reuse and recycling technologies.

Shahin has an extensive range of editorial experiences. He was the Principal Organiser and Chair for the 5th International Conference on "*Design and Manufacturing for Sustainable Development*" which was held at Loughborough in July 2007 and has been the Editor-in-Chief of the '*International Journal of Sustainable Engineering*' since its launch in 2008.

Academics

Dr David Gray
University of Nottingham

David obtained his PhD in Plant Lipid Biochemistry from the University of Birmingham in 1992, joining the University of Nottingham's Division of Food Science in 1993. David is interested in the general area of lipids, and exploring novel ways of incorporating healthy lipids into foods, with maximum benefit to the consumer and minimum impact on the environment. Research interests include sustianable nutrition, characterisation of functional and nutritional properties of plant cell organelles (*ex vivo*), alternative sources of omega-3 fatty acids, microalgae as food / feed, novel processing of oilseeds.

Dr Tom Mills
University of Birmingham

Tom is a lecturer in Food Manufacture, Chemical Engineering. His primary research interest is in the area of *in-vitro* methods to study the mouth, focusing on tribology as a method to look at thin film and lubrication behaviour. Additionally he is involved in projects looking into edible 3D printing technologies, saturated fat crystallisation and emulsifier performance, the production and behaviour of particle-stabilised emulsion systems and particulate fluid gels. The aim of this research as a whole is to understand material property and behaviour from formulation through production, into breakdown and in-mouth experience.

Dr Fotis Spyropoulos
University of Birmingham

Fotis completed his PhD on 'The phase, rheological and interfacial behaviour of water-in-water emulsions' at the School of Chemical Engineering at the University of Birmingham in 2006, where he remained as research fellow until his appointment as Lecturer of Chemical Engineering in 2010. Fotis' research interests lie in the areas of 'Food Structure Development', 'Encapsulation and Release' and 'Formulation Engineering of Emulsions and Soft Solids'. Fotis is a member of the Diet and Health Research Industry Club (DRINC) steering group and of the "Gums and Stabilisers for the Food Industry" Conference Organising Committee.

Patrick Webb
Loughborough University

Patrick is a lecturer with the Centre for Sustainable Manufacturing and Recycling Technology (SMART) at Loughborough University. The focus of his research is to gain an in-depth understanding of water consumption and waste at the unit operation level in food manufacturing, in order to develop appropriate tools and technologies to better manage this consumption in the future. Dr Webb brings a combination of commercial and academic experience in manufacturing to the research, including over three years as a Technical Specialist serving industrial clients at the Manufacturing Technology Centre in Coventry, and previous posts at universities in Hong Kong and Italy.

Dr Bettina Wolf
University of Nottingham

Bettina completed her PhD in Technical Sciences in the Food Process Engineering group at the Swiss Federal Institute of Technology (ETH), Zurich. In 1997 she joined the Product Microstructure unit and then Corporate Research at Unilever Research Colworth, UK, as research scientist. In 2006 Bettina left Unilever to take up a post as Associate Professor in Biomaterials Science in the Division of Food Sciences at the University of Nottingham, UK. Her research interests lie in the fields of rheology, food microstructure and processing, oral processing and food interfaces.

Elliot Woolley
Loughborough University

Elliot obtained his PhD in the field of atomic physics and nuclear magnetic resonance in 2007 from the University of Nottingham, joining Loughborough University in 2010 in a business strategy development role for the Competitive Sustainable Manufacturing research cluster. In April 2012 he was appointed as Lecturer in Sustainable Manufacturing within the Wolfson School of Mechanical and Manufacturing Engineering.
Elliot's research focuses on energy minimisation and intelligent management of operations and process planning within manufacturing. Research activities include eco-intelligent manufacturing and planning response to uncertainties in supply.

Our team

Research Fellows/Associates

Dr Vincenzo di Bari
Research Fellow,
University of Nottingham

Dr Aris Lazidis
Research Fellow,
University of Birmingham

Dr Abigail Norton
Research Fellow,
University of Birmingham

Dr Valentina Prosapio
Research Fellow,
University of Birmingham

Dr George Skouteris
Research Fellow,
Loughborough University

Phil Sheppard
Research Associate,
Loughborough University

Research Assistants

Pedro Gimenez-Escalante
Research Assistant,
Loughborough University

Sandeep Jagtap
Research Assistant,
Loughborough University

Lucia Azanedo
Research Assistant,
Loughborough University

Students

Panos Arkoumanis
PhD Student,
University of Birmingham

Farah Bader
PhD Student,
Loughborough University

Mattia Cassanelli
PhD Student,
University of Birmingham

Tengku Farizan Izzi Che Ku Jusoh, PhD Student,
University of Nottingham

Simone De Chirico
PhD Student,
University of Nottingham

Christopher Clarke
PhD Student,
University of Birmingham

Holly Cuthill
PhD Student,
University of Nottingham

Rania Harastani
PhD Student,
Loughborough University

Sonia Holland
PhD Student,
University of Nottingham

James Huscroft
PhD Student,
University of Nottingham

Aicha Jellil
PhD Student,
Loughborough University

Gladness Manecka
PhD Student,
University of Birmingham

Our team

Students

John Noon
PhD Student,
University of Birmingham

Jade Phillips
PhD Student,
University of Nottingham

Kurnia Ramadhan
PhD Student,
University of Nottingham

Yi Ren
PhD Student,
University of Nottingham

Saniye Samanci
PhD Student,
University of Nottingham

Fabio Smaniotto
PhD Student,
University of Birmingham

Motolani Sobanwa
PhD Student,
University of Nottingham

Ernesto Tripodi
PhD Student,
University of Birmingham

Konstantinos Tsiamas
PhD Student,
Loughborough University

Eleanor Warner
PhD Student,
University of Birmingham

Robin Leaper
MRes Student,
University of Nottingham

Outreach Officer, Administrators, Teaching & Technical

Dr Natalie Chiu
Outreach Officer

Julie Corden
Administrator,
University of Nottingham

Hana Trollman
Administrator,
Loughborough University

Khatija Nawaz Husain
Technical Specialist,
University of Nottingham

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Engage and collaborate with us

We are always seeking to collaborate on projects that leverage our knowledge and expertise. As a national centre, we are interested in working with partners to achieve our mission and the meet the challenges of the food sector.

Here are some of the ways to engage with us:

- Sponsor a studentship (Undergraduate, Masters or PhD) on a topic of interest.
- Sponsor a Postdoctoral researcher
- Secondment of EPSRC Centre staff to work in your institution or organisation
- Work in the Centre through KTP or other schemes.
- Collaborate on a publicly funded project

For more information about our work, please visit:
www.manufacturingfoodfutures.com

Thank you to our Advisory Board, Centre Network Members and collaborators

Our Advisory Board Members

Peter Lillford CBE
Chiarman

Savvas Tassou
Brunel University

Richard Akkermans
Campden BRI

Didier Bonnet
Cargill

Felicity Aylward
Sainsbury's

Stephen Parry
KTN

Ian Noble
Mondēlez International

Eddie Pelan
Unilever

John Gray
University of Manchester

Bruce Linter
PepsiCo

Nigel Titchener-Hooker
UCL

Rebecca Williams
EPSRC

Kathryn Miller
Innovate UK

Contacts

Prof Tim Foster
Centre Director
tim.foster@nottingham.ac.uk

Dr Natalie Chiu
Outreach Officer
natalie.chiu@nottingham.ac.uk
+44 (0)115 951 6154

Julie Corden
Centre Administrator
julie.corden@nottingham.ac.uk
+44 (0)115 951 6012

@cim_food