Applied Microbiology International

Food manufacturing and processing

Outline of project

Achieving and then maintaining a secure global food supply presents a significant challenge for today's industry and policymakers that is increasingly complicated by factors including climate change, regional volatility and an ever-expanding global population. Advances in science and technology have the potential to transform how food is produced, which will help address current and future global demand.

Ensuring that food is safe remains a basic necessity for public health systems. Given the need for an increased supply of food, it is more important than ever that innovation in food safety science keeps apace with advances in food production.

Foodborne illnesses, caused by microbes (such as bacteria, viruses and fungi) and where relevant their toxins, are a significant hazard to human health both in the short and long term. Applied microbiologists play a central role in identifying, understanding and tackling harmful microbes and their toxins.

The science of microbiology has applications throughout the food chain, from activities on the farm and in food manufacturing through to retailers and consumer behaviours at home.

Applied Microbiology International has produced a series of briefings highlighting upcoming impacts on food safety and advances in applied microbiology, covering topics including:

- **primary food production (agriculture and aquaculture)**
- **food manufacturing and processing**
- **food and people (consumer behaviours)**
- **the potential impact of the UK's exit from the European Union.**

All reports may be viewed online at **www.appliedmicrobiology.org**.

Applied Microbiology International

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Applied Microbiology International is a global membership organization that seeks to bring the international microbiology community together to advance scientific impact. We are the oldest microbiology society in the UK and with more than half of our membership outside the UK, we are truly global, serving microbiologists based in universities, private industry and research institutes around the world.

Food safety is a critical component of food security. Each year, unsafe food affects 1 in 10 people, causes at least 420,000 deaths globally and is responsible for 33 million healthy life years lost.

The adoption of 'Fourth Industrial Revolution' technologies in the food industry will transform how food is produced, fuelled by the need for improved sustainability and efficiency. Innovation in food safety science must be supported to keep apace.

Future innovations in the manufacturing process, particularly microbial detection, control, packaging and storage will be crucial to tackling threats to food safety posed by microorganisms and their toxins.

There is a need to support collaboration between microbiologists, food technologists and consumer science experts in industry, academia and the public sector.

There must be urgent improvements in public awareness and education of food safety science in manufacturing.

INTRODUCTION

By 2050, it is estimated that 60% more food will be needed to feed a global population of 9.8 billion.[1] This demand must also be reconciled with the need to produce and process food more efficiently whilst using less land: one-third of global food production is lost in the agricultural chain.[2] Meeting international targets such as the UN Sustainable Development Goal 12.3 (to reduce global food waste by 50% by 2030) and curbing greenhouse gas emissions to keep global warming below 2°C will require significant changes to how our food is produced. Technology will play a vital role in achieving these goals; the Fourth Industrial Revolution [3] is being heralded as a turning point in how innovation will transform global food systems and production. Reflecting this, the UK government called for a 'new tech revolution in agriculture',[4] investing £90 million through the Industrial Strategy Challenge Fund programme 'Transforming Food Production'.

As technology progresses, and the ways in which food is produced, processed and offered to consumers changes, it is crucial that innovation in food safety science is supported to keep apace so that public health may be safeguarded. And not only must food safety innovation keep up, it must also lead the way; the current global burden of foodborne illness provides a stark context for this need. In 2015 the World Health Organization published a global estimate that 1 in 10 people suffer annually from foodborne illness,[5] which is responsible each year for the loss of 33 million healthy life years and at least 420,000 deaths – 33% of which are suffered by children under the age of five.

Food safety covers a gamut of hazards, including microbiological, physical and chemical contamination as well as allergens, and food fraud. This briefing focuses on recent and upcoming developments in food processing, food manufacture and the wider food supply chain, which will have an impact on risks related to harmful microorganisms (such as bacteria and viruses) and their toxins in foods. Whilst this document does not present a comprehensive view of new technologies and developments, we have aimed to discuss some of the more significant, high-impact and high-profile developments.

Automation

Food factories of the future will look significantly different to those today, as the food and drink sector evolves to satisfy public desires including a drive towards minimally processed foods and fresh, ready-to-eat convenience foods.[6] Manufacturing is currently shifting towards increasingly complex automated processes, making use of advanced robotics and digital approaches.[7] In some cases the food industry already makes use of automated approaches with little human invention, such as in the meat industry where video image analysis is used to evaluate the quality of carcasses.[8]

The drive to maximise efficiency may bring about the advent of fully automated factories that operate 24 hours a day. Full automation carries some potential food safety benefits. For example, the requirement for fewer workers will reduce the risk that contamination occurs through manual handling. However, the formation of **biofilms** on machinery is a significant challenge in food processing that must be addressed (**BOX 1**).

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BOX 1: What is a biofilm?

A biofilm is a coating that is produced by certain microorganisms when they stick to surfaces, such as metal, plastic or food itself (**Figure 1**). Biofilms provide a safe harbour for large communities of many different microorganisms – dental plaque, pond scum and kefir grains are all types of biofilm. In environments where food is handled biofilms may contain harmful bacteria including species of *Listeria*, *Salmonella* and *E. coli*.

Biofilms are notoriously difficult to remove as they can be resistant to chemicals and may form in hard-to-reach areas.

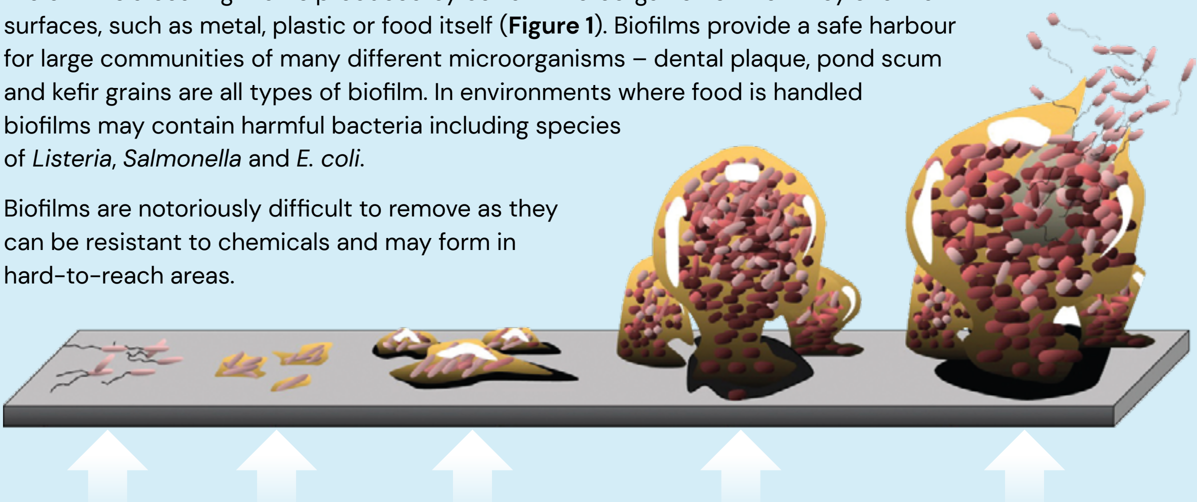


Figure 1: *Biofilm formation. Author: CNX OpenStax. Source: wikimedia commons.*

Detecting and fully removing biofilms can be difficult and may require the full disassembly of machines prior to cleaning (a longstanding industry practice). Tackling biofilms without the need for full disassembly remains a significant challenge for the food industry, but may be needed to improve efficiency whilst maintaining safety. The need for innovative approaches to tackle biofilms will become greater as 24-hour automated food production lines become more common and more advanced machinery is employed, such as robotics and 3D printers.

In the case of 24-hour automated production lines, it is paramount that full cleaning regimes are developed to avoid increasing the risks associated with biofilms. For example, an independent investigation into the 2008 listeriosis outbreak in Canada (where 22 people died) found that the meat processing plant at the source of the outbreak had increased its operation times to meet demand in the lead up to the outbreak.[9] Experts concluded that the source of contamination was meat-slicing machinery, which had not been fully dismantled for routine cleaning (although surface cleaning had taken place).

Research is essential to improve our understanding of biofilms so that effective strategies may be developed for the detection, inhibition and removal of biofilms in food-handling environments. The UK National Biofilms Innovation Centre (NBIC) was established in 2017 with the aim to understand and exploit biofilms by bringing together researchers from industry and academia. Food safety projects announced in 2018 by the NBIC focus on the use of blue light and plasma to prevent and remove biofilms.[10] The UK also participates in international research projects, for instance EU-coordinated training grants.[11]

It is crucial that these research efforts bring together expertise from microbiology, industry and engineering, so that the development of advanced robotics, 3D printing and automated systems considers appropriate cleaning and sanitation programmes to mitigate the threat of biofilms. These measures must build on cleaning practices already employed throughout the food industry.

DETECTING POTENTIAL FOOD SAFETY THREATS

1 Genome sequencing

Detecting the presence of pathogenic (harmful) microorganisms in food is a crucial step in understanding and managing food safety. Detection technologies help us proactively identify potential risks to public health and are also used to investigate outbreaks of foodborne disease.

Over recent years, genomic technologies such as WGS have exploded in popularity due to their speed and effectiveness in investigating outbreaks of foodborne disease (**BOX 2**). While this technology was once very expensive and only carried out by a limited number of laboratories, WGS is now more cost-effective and can be undertaken with minimal training, making it more practical for the food industry. Portable WGS devices are now being used to research foodborne pathogens.[13] In the near future it is highly plausible that WGS devices will work off a mobile phone battery and so could be used virtually anywhere. As this technology becomes increasingly accessible, however, it is important that users are sufficiently trained to interpret the data they produce.

2 Big data and artificial intelligence

Whilst WGS can produce vast amounts of data, the link between the presence of a particular microorganism and the potential risk to public health is still not fully understood. However, this gap in understanding may be answered through the use of artificial intelligence (AI), in particular through machine learning (**BOX 3**).

Researchers and industry are also applying genomics and big data approaches to pre-empt food contamination at even earlier stages, by identifying the

microorganisms that make up a 'normal' food microbiome. In 2015, IBM and Mars established the Sequencing the Food Supply Chain Consortium (SFSCC), which is gathering data on the microbiomes of various ingredients throughout the food supply chain.[16] Detecting a shift from a 'normal' microbiome in the food chain may then reveal potential food safety issues, such as contamination. In 2017 the SFSCC announced that it was applying this approach to the dairy industry in the USA.[17]

Genome sequencing and approaches using big data and AI hold significant potential to transform public health strategies to prevent disease and rapidly respond to outbreaks. However, this research is fuelled by the use of data-sharing networks and collaborations, particularly at the international level. Academics and public health scientists in the UK currently play a key role in

BOX 2: Whole Genome Sequencing (WGS) in the UK

WGS technologies 'read' the DNA of an organism, providing a high degree of information that can reveal subtle differences. For instance, scientists use WGS to differentiate between different types of *E. coli* to understand how harmful they may be.

Regulators and public health bodies use this highly detailed information to trace outbreaks of foodborne disease to their source, often in collaboration with neighbouring countries. For example, in 2014 Public Health England (PHE) utilised WGS to rapidly identify an outbreak of *Salmonella* food poisoning, tracing the bacteria to a single egg producer based in Germany and the Czech Republic.[12]

BOX 3: Machine learning approaches to foodborne disease

Machine learning is an application of artificial intelligence (AI) where a computer programme learns automatically and as a result improves its ability to perform a specific task when using large amounts of data. The programme may then be used to analyse datasets that would otherwise take a human researcher a long time to work with.

In 2018, researchers at the Wellcome Sanger Institute contributed to the development of a machine learning tool that can detect whether emerging strains of *Salmonella* bacteria are more likely to cause food poisoning or invasive bloodstream infections.[14] More recently, researchers in the USA used machine learning to predict whether the source of an outbreak of *Salmonella* poisoning would likely be related to poultry, pigs, cows or wild birds.[15]

international projects such as ENGAGE (funded by the European Food Safety Authority) and the Global Microbial Identifier (an international consortium).[18]

Cross-sectoral networks and open data sharing platforms will incentivise closer collaboration between industry bodies, trade organisations, public sector bodies (e.g. PHE, FSA), research funders, institutes and universities. However, for data sharing to be streamlined and effective it is important that there is agreement on the types of data (and metadata) that can be gathered and shared. Furthermore, commercial concerns and Freedom of Information considerations must be taken into account (in relation to sensitive data from industry and public bodies).

3 Blockchain and food safety

The use of distributed ledger technology (DLT), for example blockchain, is rapidly gaining traction in the agri-food sector where it is predicted that by 2025, 20% of the top 10 global grocers will be using blockchain for food safety (**BOX 4**).[19] Global giants such as Nestlé, Unilever and IBM already use blockchain to improve traceability and transparency in food supply chains. In addition, the United Nations World Food Programme is piloting the use of blockchain technology to make food aid distribution more efficient.[20]

The use of blockchain technology carries some potential benefits for microbiological food safety:

- It could promote the standardisation of data across the food industry, which would support the work of regulatory bodies. In 2018 the FSA piloted the use of blockchain technology in the meat industry to collate and standardise data from farms, abattoirs and veterinarians.[21]
- Integrating detection technologies such as genome sequencing with blockchain systems allows automatic uploading of data, boosting transparency and circumventing potential data tampering risks.[22]
- Potential to reduce 'information asymmetry' across food supply chains (when knowledge and data is not shared equally between different stakeholders).[23]

Blockchain will play an increasingly significant role within the food industry over the coming years. However, the usefulness of blockchain technologies will depend on the quality of the data going in. Routine inspection, audit

BOX 4: What is blockchain?

A 'blockchain' is a database that collates blocks of information, linking them with an encrypted signature (**Figure 2**). Blockchains are used as a form of digital ledger, allowing different stakeholders to share and check information in a secure, traceable manner. Blockchain technology in the food industry may be used to provide a single point for farmers, manufacturers, regulators and consumers to access data, such as a product's origin and authenticity.

The use of blockchain in the food industry is gaining momentum in part for its potential to rapidly identify which batches of food products to recall in the case of a foodborne disease outbreak.[22] It also has the potential to provide customers with more information at the point of purchase.

Figure 2: *Blockchain can collate records throughout the food chain, allowing consumers and regulators to access information in a secure, transparent manner.*

and analysis efforts will remain the most important method of ensuring that food industry practices are safe and that the data provided by stakeholders are of the highest quality.[24]

Eventually, AI approaches may be applied to data in a blockchain, where smart algorithms can watch for patterns that may indicate an issue with a particular batch of a food product. However, algorithms would need to be able to take account of a significant amount of complex information, such as how microorganisms interact with different environments and food materials, changes in storage time and temperature and whether the intended consumers are within a vulnerable group (e.g. hospital patients). The design of such algorithms must therefore be conducted with the input of microbiology expertise, if emerging potential food safety risks are to be identified accurately.

Overall, it is crucial that industry stakeholders and regulators consult food safety scientists, including microbiologists, to understand the realistic opportunities, benefits and limitations of applying blockchain technologies in the context of food safety.

COMBATTING CONTAMINATION

While the detection of potential pathogens is an important facet of maintaining food safety, the central thread of ensuring microbiologically safe food is reducing or removing pathogens and preventing the spread of pathogens and their toxins. Public debate on food safety over recent years has focused on the use of disinfectants in the food industry, such as chlorine-based decontaminants,[25] fuelled by concerns that they could be used to mask poor animal welfare and hygiene practices. This highlights the importance of balancing an objective scientific approach to food safety with other values-orientated judgments.

Minimising the risk of microbial food contamination relies on multiple strategies, which include the use of physical, chemical and biological treatments within the context of what consumers perceive as necessary. Decontamination procedures in the UK are always assessed by scientists to determine the potential public health risk, as part of the wider context of the 'precautionary principle'. When used appropriately, disinfectants should pose a minimal threat to consumer health, although it is important that consumer perceptions of their use are taken into account.

4 Food processing

A significant amount of research takes place in the food industry and in academic laboratories, where researchers are developing innovative methods to decontaminate food, including the use of electric fields,[26] radio frequencies [27] and 'cold' plasma.[28]

One innovation with high potential involves the use of bacteriophages (or 'phages') – viruses that selectively infect bacteria but do not infect humans or animals. The application of phages has been gaining popularity in healthcare as a potential therapy for antibiotic-resistant infections.[29] In the food industry, phages may be utilised to control animal disease [30] and to decontaminate chilled ready-to-eat products such as salmon.[31]

Phages have been 'Generally Recognised as Safe' by the US Food and Drug Administration and have been used in the US food industry since the mid-2000s.[32] **Nevertheless, one potentially significant hurdle facing the use of phages in the UK is public acceptance of bacteriophages in the food chain. Public messaging must be clear in order to avoid misunderstanding**. Lessons could be learned from food irradiation: a FSA survey in 2012 revealed that 51% of respondents were

uneasy about the technology,[33] although only 34% had heard of it previously. Nevertheless the European Food Safety Authority confirmed it as safe after a review in 2011.[34] Recently, experts in science communication have taken to describing bacteriophages as 'friendly viruses' or 'friendly phages'.[35] In the USA, focus groups have been reported to consider phages as 'green' alternatives to chemical preservatives, and phages have also been accepted as organic and halal.[32]

5 Food packaging and storage

Many British adults are aware that food systems have a significant impact on the environment as indicated by a 2017 survey, in which two-thirds of adults agreed that the pattern of food production and consumption is a key contributor to climate change.[36] In recent years the

ubiquitous nature of plastic packaging has fallen under intense public scrutiny, as evidenced by inquiries from two select committees in UK parliament.[37]

Nevertheless, innovations in plastic packaging and the wider food supply chain have played a key role in the globalisation of food, as they reduce the potential for contamination by pathogens and spoilage microorganisms. Alternative approaches will need to deliver similar (and higher) levels of protection for the consumer whilst remaining environmentally sustainable. Numerous research projects are currently aimed at investigating new biodegradable packaging,[38] edible cling film [39] and sustainable cold-chain storage.[40] Researchers are also looking at ways to minimise contamination and spoilage in packaged food, such as generating ozone inside a package (which degrades over time to oxygen) [41] and packaging that releases oils that kill microorganisms.[42] The food industry is also investigating 'smart packaging' solutions including labels to inform consumers of remaining shelf life and whether food has warmed to an unsafe temperature.[43]

As with other food manufacturing techniques, it is crucial that consumers are informed in an accessible and transparent manner about the science behind what they are buying. For instance, 'smart packaging' can mean either 'intelligent packaging' (external indicators and labels) or 'active packaging' (interacts with food and its environment, for instance by generating preservatives and antimicrobials).[44]

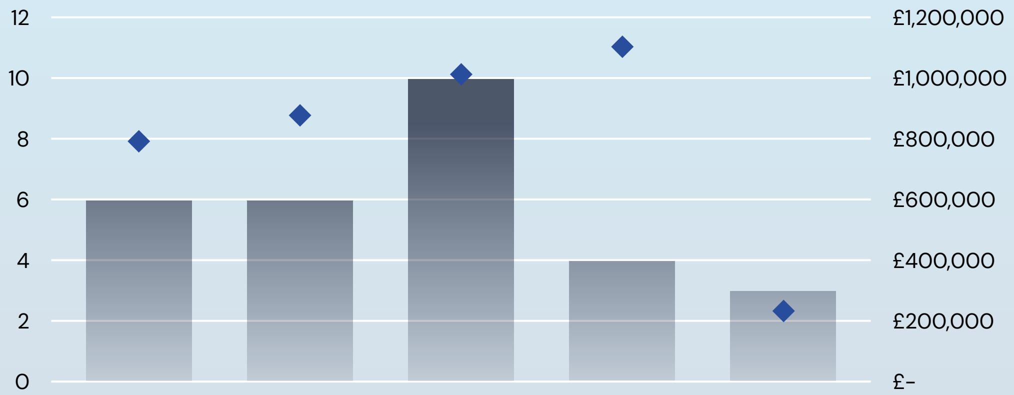
If the public is left uninformed about how these technologies work, concerns may arise about packaging interfering with food.[45] A cautionary tale can be found in the example of public concern over the use of triclosan (an antibacterial chemical) in many household products, including toothpaste and food packaging. Following reports of triclosan being found in the environment and human breast milk, retailers were pressured into withdrawing products that contained or were impregnated with the antibacterial substance.[46]

CONVENIENT FOOD: CONSUMER ACCESS IN THE FUTURE

The way in which food makes its way to the public is constantly evolving, with convenience of access featuring as a high priority.[47] This trend will affect how food is manufactured with the potential for industry in the future to become more decentralised, driven by consumer demands for local and traditional produce and enabled by advances in technology and big data.[48] With smaller factories producing food for local populations, this approach may be more environmentally friendly, reducing food miles and wastage.

Food deliveries are also evolving. Non-supermarket delivery methods (e.g. vegetable boxes, Hello Fresh™ and Amazon Fresh™) have seen a modest increase in popularity from 2% to 4% since 2012.[49] Companies such

INNOVATE UK-FUNDED PROJECTS RELEVANT TO MICROBIOLOGICAL FOOD SAFETY IN FOOD MANUFACTURING AND PROCESSING



	Detection	Decontamination	Packaging	Storage	AI and Blockchain
# active projects	6	6	10	4	3
Grant money	£796,346	£880,428	£1,018,748	£1,110,132	£236,981

Figure 3: *Innovate UK-funded projects relevant to microbiological food safety in food manufacturing and processing (active as of 20 May 2019). Source: gov.uk (Note: some grant award amounts were not listed. Innovate UK and ISCF projects were identified by searching descriptions for the words 'food', 'agri' or 'crop').*

as Amazon are now looking to take a leading role in food safety innovation.[50] Driverless vehicles and other autonomous delivery systems (e.g. drones) are expected to make on-demand deliveries of food a viable option for many consumers in the coming years.[51]

As the food supply chain increases in complexity with many more ways for consumers to receive food, the risk of contamination will change and regulators will need to adapt to meet new challenges. As discussed earlier, big data and AI approaches will play a role in streamlining food safety regulation, provided that opportunities are provided for the open sharing of data between industry, regulators and other relevant stakeholders. **Further, local environmental health officers and other regulatory officials must be given sufficient support to understand changing food processing and purchasing trends, how these impact on microbiological risks in their local area and the technologies that are used to control these risks. This translates to a need to strengthen and maintain the UK skills base in food microbiology to keep up with the fast-evolving consumer environment.**

SUPPORTING INNOVATION IN FOOD MANUFACTURING

Innovation in the application of food safety science relies heavily on collaboration between researchers in industry and academia, and so benefits greatly from focused funding opportunities that bring these sectors together. Data from the UK government indicates that Innovate UK funds activities across many different aspects of microbiological safety in food manufacturing and processing, from early detection of threats to the safe packaging and storage of food (**Figure 3**).

Nevertheless, food safety research and development (R&D) is often supported solely through private sector funding. The UK government has indicated its commitment to support the food industry and '*secure the UK's position as a global leader in sustainable, affordable, safe and high-quality food and drink*',[52] promising £90 million of new funding through the 'Transforming Food Production' Industrial Strategy Challenge Fund (ISCF) programme. Despite this, the food industry's interest in food safety R&D is not reflected by this fund, as **only 28 of the 567 active ISCF projects**

relate to food (totalling £5.9 million of investment), and none of these focus specifically on food safety in manufacturing. However, it should be noted that some ISCF-funded projects may in future impact on food safety in the UK (e.g. disease detection and sustainable plastic packaging).

Food safety innovation in the UK needs to be a priority for the UK government, considering its stated commitment and the creation of the Food and Drink Sector Council.[53] **The UK government must explore ways to place the UK as a global leader in food safety research, including through ISCF initiatives.**

To achieve this we recommend that the Food and Drink Sector Council liaise with the wider science community, bringing together researchers and practitioners from the food industry, learned societies, professional organisations, the academic sector, public health organisations and research funders.

Contributors

Applied Microbiology International (AMI) is the oldest microbiology society in the UK, representing a global scientific community that is passionate about the application of microbiology for the benefit of the public. Our members work to address issues involving the environment, human and animal health, agriculture and industry.

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