Research in Agriculture and Food Security

Strategic Framework

BBSRC
bioscience for the future

The Biotechnology and Biological Sciences Research Council

BBSRC is the UK's leading funder of academic research and training in the non-clinical life sciences in universities, institutes and centres. We fund internationally competitive research to improve the fundamental understanding of the biological systems upon which all human life depends. Our research spans the microbial, plant and animal kingdoms, from molecules to cells to whole organisms and populations. We also provide training in the biosciences, drive knowledge exchange and innovation, and enable public engagement around issues of societal importance.

The BBSRC Research in Agriculture and Food Security Strategic Framework was first published in July 2017.

Images: istockphoto.com unless otherwise stated

Research in Agriculture and Food Security Strategic Framework

Agriculture and food security (AFS) is an area of key economic and societal importance to the UK and globally, and a strategic priority for BBSRC[1]. The aim of this Strategic Framework document is to expand on, and provide further details of, BBSRC's strategic priorities in AFS. It provides researchers and wider stakeholders with BBSRC's key AFS research and innovation priorities, identifying areas where the Council will focus efforts and expects to deliver the most impact over the next five years.

This document is intended as a helpful reference for those wishing to understand the focus of BBSRC's AFS strategic prioritisation. It does not represent a change in BBSRC remit and BBSRC will continue to support a broad portfolio of AFS research. However, the Strategic Framework recognises that BBSRC cannot do everything to address the global AFS challenges and must prioritise its efforts.

The UK's strengths in plant, animal, human and microbial sciences will be essential for developing the new knowledge and innovations in agri-food that will deliver benefits to the UK and globally. BBSRC's investment in excellent bioscience provides a strong foundation from which to address the many challenges facing the agri-food system. BBSRC will continue to prioritise support for a breadth of frontier bioscience[2] underpinning AFS priorities.

BBSRC's AFS remit covers arable, horticultural, forage and non-food crops, farmed animals (livestock, poultry and aquaculture), agricultural systems including soil, and the related food chains.

John Innes Centre

Rothamsted Research

The strategic importance of AFS research

The challenge

Global demand for food is rising, driven by factors such as population growth, increasing affluence and changing diets. At the same time, there is increasing competition for land and fresh water, putting added pressure on production and the wider environments within which food is produced. Climate change is also increasing the uncertainty of ensuring food supply, for example, through more extreme weather and increased pressure from pests and diseases. The global population is projected to grow from 7.3Bn in 2015 to 9.5Bn in 2050[3]. At least 60% more food production is needed by 2050 to feed the world's population[4] and this must be in the context of minimising the impacts of agriculture on the environment. There is a need for more sustainable production of a sufficient, safe and nutritious food supply to deliver future food security.

Agriculture and food make a vital contribution to the UK's prosperity. The agri-food sector employs 3.9M people and contributes £110Bn Gross Value Added to the UK economy[5]. There are clear opportunities for research to deliver significant improvements to the agri-food system and provide further economic benefit to the UK, through increased productivity, improved quality and safety, and increased trade and exports. Food is a global commodity, and in 2016 the total value of food and drink exports from the UK was over £20Bn[5].

The Global North and Global South[6] face many similar challenges in agriculture such as climatic variability, pests and diseases. The need to end global hunger, achieve food security and improve nutrition is an urgent issue. Enabling countries to secure a sufficient and stable food supply, reduce poverty and stimulate economic development are important sustainable development goals[7]. Some countries in the Global South are likely to be hardest hit by climate change compared with the UK, and climate change is already affecting harvests globally. Partnership working with researchers in the Global South is needed to address global AFS challenges, including reducing the risks of pests and pathogens

Adam Staines

and ensuring secure supply chains. Addressing these challenges will also require research collaborations between the UK and the Global North.

The UK is a world leader in AFS research. Over the next 20 years there is strong potential for the UK to strengthen and consolidate this position through continued and new strategic partnerships, and for UK-developed innovations in food and farming to have a global impact. Step changes in biological understanding of crops and farmed animals, novel innovations and new disruptive technologies will help address the agri-food challenges globally, while also benefiting the UK economy by opening up new markets for exports.

Wheat genetics research

Globally, wheat is the largest crop-based protein source and the value of wheat production in the UK alone is over £2Bn per annum[8]. Long-term BBSRC investment in wheat genetics research has contributed to improvements in global wheat production. The research has underpinned £445M potential gross yield benefits per year delivered by UK plant breeders[9], through key discoveries such as the factors controlling flowering time, dwarfing, disease resistance, bread making quality, and recombination, as well as synteny.

BBSRC is investing in Designing Future Wheat (DFW), a fully integrated national wheat research programme bringing together expertise from a range of research institutions and universities. DFW will facilitate future breeding trait selection and develop novel wheat resources in a readily accessible and referenced form to the wider community. The programme has been designed by working closely with industry and overseas partners such as the International Maize and Wheat Improvement Centre (CIMMYT) and through links to the global Wheat Initiative programme.

BBSRC's role in AFS research

BBSRC investment in AFS

BBRSC has a central role in supporting the research, capability and skills that are needed to address the challenges facing agriculture and food security. BBSRC is the UK's largest public sector funder of AFS research and has invested over £1Bn over the last ten years. In 2015/16 alone the research spend totalled £124.9M, representing 38% of BBSRC's overall research investment. Just over half of BBSRC's AFS research is delivered by strategically-funded institutes[10] through a variety of competitive funding routes. The institutes provide globally-acclaimed critical national capability and expertise, and enable BBSRC to invest in long-term, mission-driven strategic research in the AFS area.

BBSRC investments in AFS research also link closely to other BBSRC strategic priorities. For example, non-food crops are an important component of Industrial Biotechnology and Bioenergy[11]. Understanding human nutrition, and livestock and zoonotic disease are important components of Bioscience for Health, highlighted in BBSRC's *Bioscience for Health Strategic Research Framework*[12] and the *BBSRC Research in Food, Nutrition and Health Strategic Framework*[13]. Data handling and novel technologies are key components of the cross-cutting Exploiting New Ways of Working enabling theme[1].

Research opportunities

The latest frontier bioscience[2] provides an opportunity to tackle some of the long-term research challenges that have potential to produce a step change in agriculture and food security. BBSRC is encouraging a whole food-systems approach to explore these opportunities, building on the UK's excellent plant, animal, human and microbial sciences research base.

New enabling tools and technologies are opening up previously intractable questions to investigation. The completion of whole genome sequences for crop and farmed animal species combined with new breeding techniques means that whole genome manipulation is now possible. New technologies are enabling phenotyping and metabolic analysis, more rapidly and efficiently.

Data science approaches can help to understand complex agricultural systems, and there is clear potential for agricultural informatics to improve the management of crops and farmed animals in the field and as a decision support tool for farmers. The scale of the agri-food challenges provides many opportunities for BBSRC-funded research to make significant discoveries that will drive future innovation and societal impact.

Many of the challenges facing agriculture are complex and cannot be solved by bioscience alone. If researchers are to succeed in making substantive advances, interdisciplinary approaches will be needed. Partnership and collaboration will also be vital, with opportunities for the best UK researchers to work and train with their counterparts in other countries and within UK industry.

Improving the quality of oats

A multi-funder LINK project has used genomics research to develop novel strategies for the breeding and selection of winter and spring oats. The project developed enabling technologies for the identification of specific genes and molecular markers associated with agronomic qualities, yield, economic competitiveness and quality traits. The research has enhanced the use of oats as a profitable component of sustainable arable production for human and livestock consumption, and for industrial end uses.

Working in partnership

The importance of addressing the challenges facing agriculture and food security is recognised by Government, other UK public funders, and industry. BBSRC's AFS Strategic Framework is closely aligned with other relevant strategies in this area. By enabling a world-leading UK agri-food sector, BBSRC-funded AFS research will make a vital contribution to the delivery of the UK's Industrial Strategy[14] and the UK Bioeconomy Strategy[15]. BBSRC is also working closely with Innovate UK to support the UK's agricultural technologies (agri-tech) strategy[16], ensuring that knowledge and insight from the UK's excellent science base is translated into benefits for society and the economy at home and abroad.

The focus areas described in BBSRC's AFS Strategic Framework will help deliver wider government and stakeholder priorities. These include addressing the future needs in the provision of research, capability and evidence in animal and plant health[17,18], supporting the food and farming industry[19,20,21], slowing the spread of antimicrobial resistance[22], promoting nutrition and healthy eating[23], and addressing food safety[24]. BBSRC works closely with others to achieve impact in these areas, including the Department for Business, Energy & Industrial Strategy (BEIS), the Department for Environment, Food & Rural Affairs (Defra), the Food Standards Agency (FSA), the Department of Health (DoH), the Department for International Development (DFID), and the devolved administrations.

BBSRC cannot achieve its vision for AFS research alone. BBSRC will work in partnership with other national and international funders to deliver its AFS priorities, both through coordinated activities and bilateral / multi-funder programmes. Several areas of AFS research are part of the interface between BBSRC and other partners, with continued opportunities for collaborative efforts within UK Research and Innovation. These include the agri-environment, nutrition, food engineering, remote sensing and space technology, economics of food systems, consumer behaviour, global food cultures, and the role of design in agri-food. The UK's main public funders of agriculture and food-related research are already working together to facilitate multidisciplinary approaches that cut across the remits of the funding partners, for example, through the Global Food Security programme[25].

Lameness in sheep

Research supported by BBSRC and Defra has enabled UK farmers to reduce the prevalence of lameness in UK sheep from 10% in 2004 to 5% in 2013. Over ten years, the research has saved UK farmers £700M and prevented 7.5M sheep from becoming lame.

International collaboration

BBSRC actively aligns relevant research it funds with that of other European countries through the Joint Programming Initiative for Agriculture, Food Security and Climate Change (FACCE-JPI; comprised of 22 member countries). FACCE-JPI achieves this through joint funding of new research (e.g. in Climate Smart Agriculture) and bringing together existing research and communities through Knowledge Hubs or Networks (e.g. MACSUR).

The Pirbright Institute

Delivering impact from BBSRC investments in AFS research

It is essential that BBSRC works to maximise the benefits from the research it invests in. The knowledge and understanding arising from excellent AFS research has potential to deliver academic impact though significant scientific advances, both across and within disciplines. By addressing the global AFS challenges, there is also strong potential to realise wider economic and societal benefits, within the UK and globally.

To deliver the maximum impact from AFS investments, BBSRC will continue to engage with industry and policy stakeholders across the whole food chain, and ensure effective knowledge exchange between the research community and end-users. BBSRC will also continue to support the skills and capabilities that underpin AFS research and the agri-food sector, and enable public engagement around issues of societal importance.

AFS research underpins a variety of user and business sectors, including farmers, producers, processors, suppliers and retailers. There is a need to ensure that the UK's agriculture and food industries can benefit from and are able to exploit the research that BBSRC supports. This requires consideration of the specific challenges experienced by the sector, for example, fragmented supply chains, the length of time to market, traditionally low levels of industry R&D investment, and regulation. UK industries operate in a competitive global R&D environment and there are significant and diverse market opportunities for new innovations.

There is clear potential for the UK agri-food sector to contribute to economic growth and public good. Future innovations in agri-food research will be driven both by technology 'push' and market 'pull', and it is essential that UK academic researchers understand the needs of users, industry and policy makers. BBSRC will continue to encourage engagement between academic researchers, industry and other stakeholders through a variety of mechanisms. BBSRC will build on our strong relationship with Innovate UK and the Agriculture and Horticulture Development Board (AHDB) to drive a culture of open innovation that enhances impact through the free flow of knowledge between private and public sector research.

Rothamsted Research

BBSRC's network of Research and Innovation campuses also contributes to the delivery of innovation and impact in AFS. The campuses are centred on a critical mass of excellent bioscience, strategically funded by BBSRC, and create environments where interactions between world-leading researchers and business can occur.

Roslin Innovation Centre

The Roslin Innovation Centre is a new development in partnership between the University of Edinburgh, Scottish Government and BBSRC. The Centre will provide flexible laboratory and office space for companies and business collaborators in the animal and veterinary sciences. It will enable opportunities to develop and adopt new and existing technologies, products and services to increase agricultural productivity — addressing food security and poverty in the Global South, while enabling the UK to sustain and expand its own livestock industries.

Public good benefits

BBSRC's investments in AFS research are helping to address issues of public concern, while also ensuring the long-term productivity and sustainability of the sector. Cross-funder initiatives addressing insect pollinators, and tree health and plant biosecurity, are informing policy and practice in these areas. For example, the research has helped inform the UK's National Pollinator Strategy.

John Innes Centre

Capitalising on the UK's excellent research base requires continued support for essential infrastructure, facilities, national capabilities, data and resources, as well as the training of researchers to support the agri-food research base. Advances in AFS research and technology mean that the skills required to support the sector are changing rapidly. The sector requires individuals with interdisciplinary skill sets and who are able to apply their expertise in academic, commercial and policy settings, and translate new scientific knowledge into improved agricultural practice. This will include collaborations with other disciplines to help address AFS research challenges.

There is a need to address existing and emerging gaps in areas of vulnerable skills and specialist expertise within the UK agri-food research community[26]. There is also a need for more succession planning to ensure that the UK is well-positioned for the next 20 years of AFS research. BBSRC will continue to support the training of the next generation of researchers through a variety of mechanisms, working in partnership with academia and industry. BBSRC will support training and capacity in the UK to enable working on the challenges affecting the agri-food system in the Global South. BBSRC will also build capacity in those countries through partnership working.

AFS research has the potential to positively impact on lives and economic prosperity in the UK and around the world. To realise those impacts research must be engaged with, and responsive to, the needs, views and values of society and should take account of a wide range of perspectives. This needs to be coupled with open and honest communication of the research, along with its implications, processes and products.

AgriFood Training Partnership

BBSRC's AFTP programme is helping to realise opportunities for new knowledge and technology to transform the agri-food industry. Covering the full agri-food chain, the AFTP brings leading UK institutions in agricultural and food research together with industry practitioners. It provides specialist high-level skills training which will help exchange cutting-edge knowledge from the research base to industry, enabling the UK agri-food sector to respond resiliently to food security challenges[48].

Global Challenges Research Fund (GCRF)

GCRF is a £1.5Bn fund announced by the UK Government to support cutting-edge research that addresses the challenges faced by the Global South through deploying the UK's world-class research capability. BBSRC is partnering with four other Research Councils to support multidisciplinary Foundation Awards for Global Agriculture and Food Systems, recognising that the complexity of the research requires collaborative effort from a range of disciplines. The £16.7M investment will address a number of different threats to the sustainable production of safe and nutritious food, including tackling pests and diseases, improving food safety and nutrition, and the sustainability of agricultural soils and the wider farming landscape.

BBSRC priorities for AFS research

BBSRC's vision for AFS research

BBSRC's vision is to encourage a whole food-systems approach for agriculture and food security research, to deliver productive, resilient and sustainable food and farming.

BBSRC will continue to encourage research that will enhance UK and global food security by providing knowledge and evidence to farmers, food producers, processors, retailers, consumers and governments. This knowledge will enable them to respond and manage the challenges facing the UK food system and related global issues, including those confronting the Global South.

Given the nature of the current strategic challenge and drivers, over the next five years BBSRC will focus efforts on AFS research and innovation that broadly achieves the following:

- takes an integrated approach across the food system
- enables food and farming systems to be more sustainable and resilient
- supports the improvement of crops and farmed animals, including health and welfare
- increases the nutritional quality and safety of food
- reduces waste on farm and in the food system
- enables better exploitation of genetic diversity and more predictive approaches to determining crop and farmed animal phenotype from genotype
- enables and supports smart technology and precision approaches to agriculture.

BBSRC's focus areas

The Strategic Framework is divided into six focus areas:

- Sustainable agricultural systems
- Crop and farmed animal health
- Food safety and nutrition
- Reducing waste
- Understanding and exploiting genomics
- Precision agriculture and smart technologies

The focus areas naturally overlap and are integrated. In particular, the last two focus areas are cross-cutting and relevant to all other areas. Details of each focus area are provided on the pages that follow.

Summary of BBSRC's focus areas for agriculture and food security research

Sustainable agricultural systems

To meet future demand for crops and farmed animals, agriculture must be sustainable and resilient

The challenge

There is a global need to produce more crops and farmed animals sustainably and resiliently, from the same or a smaller area of cultivated land and with lower inputs. This must be achieved while minimising adverse impacts of agriculture on biodiversity, soil, water or the atmosphere, and in the face of a changing climate and threats from emerging pests and diseases.

- UK natural assets were valued at £1.6 trillion in 2015 and are increasing in value[27]
- More efficient use of water and improvements in soil health can lead to average crop yield increases of 79 %[28]
- Agriculture accounts for 70 % of global fresh water use and 10 % of the UK's greenhouse gas emissions[29]

Research opportunities

A sustainable agricultural system is dependent on a range of ecosystem services, but research to understand the complex interactions between crops/farmed animals and the environment is challenging. Research is required to enhance productivity and nutritional quality of crops and farmed animals, while improving resource use efficiency and enabling better environmental, economic and societal outcomes.

There are opportunities to improve understanding of the interactions between the biology of crops and farmed animals, their environments and management. These include how different elements of the agri-ecosystem interact, and how they affect production, other ecosystem services and functional biodiversity. Research is needed to inform new and improved strategies to increase resilience to abiotic stresses, pests and diseases, while protecting and enhancing performance and quality.

Opportunities to enhance agriculture's relationship with the natural environment include breeding for traits associated with efficiency, and developing agronomic practices that optimise resource inputs while minimising negative impacts. Research can also help to reduce reliance on monoculture and current rotation systems, with opportunities to enhance crop health and production through understanding of the soil microbiome and other beneficial organisms.

There is clear potential to advance research through integrated, systems approaches (agronomic, genetic/breeding, ecological), the use of new tools and technologies (phenotyping, sensors, whole organism sequencing and other 'omics techniques), the use of experimental farm platforms, and working at multiple scales (lab-field-farm-landscape).

Increased sustainability and efficiency will make a critical contribution to improving the long-term economics of farming businesses, while enhancing ecosystem services.

Achieving Sustainable Agricultural Systems (ASSIST)

ASSIST is a long-term research programme which aims to develop and assess the effectiveness, impacts and robustness of novel agricultural systems and technologies to advance the understanding of sustainable intensification. It combines multidisciplinary expertise from BBSRC and the Natural Environment Research Council (NERC) supported research centres, with links to policy makers and the farming industry. By bringing together expertise in management of natural resources and crop production, the programme will examine the impacts of intensification on the wider environment and develop synergistic farming systems that contribute towards environmental sustainability.

BBSRC's focus

Research is required to enhance productivity (including nutritional quality) in harmony with other ecosystem services. To achieve this, BBSRC will focus more efforts in the following areas:

Addressing the complexity of the challenges by utilising multi-scale and systems approaches to agri-ecosystems

Research must focus on integrating the biology of crops and farmed animals with their management in different agri-environments. This requires interdisciplinary, systems-based approaches at multiple scales (lab-field-farm-landscape). Sustainability should be researched in parallel with production in 'real world' conditions, including consideration of the impacts on productivity and other ecosystem services. Modelling these findings will help to understand the potential trade-offs within the agricultural system and develop a predictive approach to assessing vulnerabilities and impacts.

Delivering improved agricultural performance and sustainability through enhancement of the soil microbiome

Agricultural soils are an important research target, given their broad potential to enhance performance. Understanding the role of the microbiome in the soil ecosystem and crop production is key, with a particular emphasis on understanding soil-crop-microbe interactions, soil management techniques, and restoring the nutrient balance of soil for optimal food production.

Improving on-farm efficiency and long-term sustainability through more effective resource use

The efficient application of resources and their use by crops and farmed animals is crucial to maintaining yields and managing long-term ecological impacts. Water, nitrogen and phosphorous are important targets for research, with an emphasis on optimising their uptake and use in different agri-environments and management regimes.

Improving the resilience of the agricultural system though increased understanding of the effects of abiotic stresses

Understanding how the agricultural system performs under abiotic stresses is needed to enhance future productivity. Multidisciplinary, systems-based approaches are needed to improve the resilience of agriculturally-important species, taking into account multiple stresses (e.g. drought, flood, heat and cold, increased salinity and high winds). Research is also required to understand the effect of increased resilience on performance, quality and other elements of the agri-ecosystem.

Research addressing these challenges will build on the recent strategic collaborations between BBSRC and other funders – in particular NERC, Defra and the Economic and Social Research Council (ESRC).

Examples of BBSRC investment that are addressing this challenge area

- A £2.5M partnership between academia and industry (SUREROOT) is developing grasses and clovers with improved rooting systems for sustainable livestock systems.
- The Sustainable Intensification Research Network (SIRN) is facilitating multidisciplinary, systems-based research and supporting the integration of research communities.
- AnaEE (Infrastructure for Analysis and Experimentation on Ecosystems) is an EU research infrastructure dedicated to the experimental manipulation of ecosystems.
- BBSRC, NERC and India's Department of Biotechnology have invested in Centres in Agricultural Nitrogen, which are pursuing the production of high crop yields with lower inputs of nitrogen fertiliser.

Crop and farmed animal health

Healthier crops and farmed animals are essential to a safe and productive food and farming system

The challenge

An essential aim in managing any agricultural system is to maintain the long-term health and welfare of the crops and farmed animals. Crop and farmed animal pests and diseases are major contributors to inefficiencies in agricultural production and pose serious and continuing threats to food security. This challenge is also linked to farm animal welfare, zoonotic diseases and anti-microbial resistance.

Climate change, globalisation and trade are creating new problems by contributing to the spread of pests and pathogens, and impacting on welfare. Current control regimes are under threat from widespread resistance, as well as a changing regulatory landscape. For some emerging and under-researched pest and pathogens, there is a lack of existing control options.

- The global annual costs of losses due to plant diseases is US$220Bn[30]
- UK sales of veterinary medicines for farmed animals are over £290M per annum[31]
- At least 75% of emerging infectious diseases of humans have an animal origin[32]

Research opportunities

There are significant societal and economic drivers to better manage existing and new threats to crop and farmed animal health (including livestock, poultry and aquaculture). Research underpins the development of new tools and strategies to prevent, control and potentially eradicate the pests and pathogens that cause disease within the farming system.

Research is needed to improve understanding of the biology of pests, pathogens and weeds, alongside knowledge of vector and host biology. There are opportunities to improve understanding of the mechanistic interactions between pests/pathogens, vectors and their hosts, particularly in seeking to respond to the challenge of increased resistance to chemical controls. In this context, a new generation of novel insecticides, herbicides and anti-microbial agents is also needed.

The development of novel crop and farmed animal varieties which are healthier and more resistant to infection can build increased resilience into farming systems. Improvements to epidemiological modelling and disease detection have the potential to better understand risks and inform effective decision making. Combined with the development of novel protection agents and alternative approaches, there is substantial scope to maintain the health of the farming system.

Crop and farmed animal disease is a global challenge. Not only does it influence the efficiency of in-country production, but it also has significant implications relating to the transmission of exotic pests and diseases. International collaboration in this area has the potential to improve production efficiency and reduce risks to the UK farming system and consumers.

Gary Naylor Photography

Antimicrobial resistance

Antimicrobial resistance (AMR), especially resistance to antibiotics, is a growing global problem. The Research Councils have been working with UK Government partners to foster collaboration between diverse disciplines, share information across the public and private sectors, and acquire new insights into the emergence and spread of antibiotic resistant bacteria. One of these multi-million pound research investments is investigating whether the pig microbiome provides a reservoir of AMR genes that may both receive and donate genes, in particular when the microbiome is under antimicrobial selective pressure. The research will provide the groundwork to inform future antimicrobial stewardship in animal and human health.

BBSRC's focus

Research is required to protect and enhance crop and farmed animal health, and animal welfare. To achieve this, BBSRC will focus more efforts in the following areas:

Developing novel breeding targets and management strategies by understanding how pests/pathogens interact with their hosts

Knowledge of how key pests/pathogens interact with crop and farmed animal hosts in the farm environment, alongside the host traits for disease resistance and resilience, are essential for developing strategies to manage disease threats. Research in genomics, host-pathogen interactions, and innate immunity, also needs to be embedded into breeding programmes to generate new resistant or more resilient varieties.

Tackling resistance by understanding the underpinning biology of agriculturally-relevant pests, pathogens and weeds

The resistance of pests and pathogens to chemical control (e.g. pesticides, anti-microbial agents) is one of the greatest threats to agriculture. There is a need to understand the underpinning biology which leads to resistance, and the transmission of resistance genes in key agriculturally-relevant pests, pathogens and weeds. Multidisciplinary approaches are needed to deliver a new variety of chemical agents, rapid on-farm diagnostics, alternative control mechanisms, and improved management practices.

Improving control regimes by developing novel approaches to farmed animal health and crop protection

Research is needed to improve and identify alternative control approaches that will address existing and emerging threats, including new control regimes, diagnostics and predictive modelling. Vaccination can provide an effective control method for animal diseases, but new platform technologies are needed to make more effective vaccines. Immune stimulation of hosts and the role of the microbiome in maintaining health are also key research areas. Other important targets are to understand the effectiveness and environmental impact of biocontrol methods, controlling vectors of disease, and the impact of management practices (including animal welfare). Research addressing this challenge area will need to be supported by effective surveillance, epidemiology, modelling and data science (including 'The Internet of Agri-Things'[18]), as well as new detection tools and technologies to enable integrated pest management approaches.

BBSRC's focus in this area is informed by a number of Government strategies including the Vision and High Level Research Strategy for UK Animal and Plant Health Research to 2020 and Beyond[18], and the UK Government's AMR strategy[22]. BBSRC's Veterinary Vaccinology Strategy is also relevant to this focus area[33].

Examples of BBSRC investment that are addressing this challenge area

- BBSRC has funded relevant networks to foster multidisciplinary research including the Veterinary Vaccinology Network, the Animal Welfare Network, and the Networks in Vector Borne Disease Research.
- A Strategic Longer and Larger grant is investigating the molecular basis, evolution and farming practices that can lead to multiple herbicide resistance in black grass.
- Researchers working closely with industry are developing durable blight resistance in potatoes.
- Zoonoses and Emerging Livestock Systems (ZELS) is a cross-funder initiative with Research Councils, DFID and DSTL, which uses global expertise to address some of the critical challenges posed by zoonotic diseases.

Food safety and nutrition

In managing the future food system we still need to ensure food remains safe and nutritious

The challenge

Improvements to the productivity and sustainability of farming must not be at the expense of the safety or nutritional quality of the food produced. Global food systems have generally been developed for calorie production and processing quality, focusing especially on yield improvements. There has been less emphasis on food safety or the nutritional needs of humans or farmed animals. This is a global challenge with relevance to the Global North and South, particularly the effects of under-nutrition on long-term health and the possible food system trade-offs required to deliver nutritional needs.

- In 2015, the global market for health-promoting foods was estimated at US$130Bn[34]
- The annual cost to UK health service due to food related ill health is £6Bn[35]
- The cost of *Campylobacter* to the UK economy is £538M annually[36]
- Mycotoxins cost the global agri-food sector billions each year[37]

Rothamsted Research

Research opportunities

There are many opportunities to improve the nutritional value of staple foods and feeds and to develop novel functional foods that can promote health. Public funders, primary producers, manufacturers and retailers are all investing in relevant research, providing excellent opportunities for collaboration and joint working. In the context of improving nutrition, it is also important to understand how changing farming practices affect nutrient levels in crops and farmed animals.

Research is also needed to improve food safety. There are many aspects of food which make it potentially unsafe for human consumption, including zoonotic pathogens, toxins produced by microbial contamination, and the presence of toxic products or allergens in the final food product.

Pathogens such as *Campylobacter, Salmonella* and pathogenic *E.coli* have complex pathologies and negatively impact the food system. Continued research effort is needed to understand these pathogens and their interactions with the host, and to identify food system modifications and interventions which can mitigate their effects.

The food system is affected by a range of toxins and infectious agents. Some come from the farmed animal sector (e.g. shellfish toxins and prions). Others are affected by the changing climate, new crop phenotypes and farm management practices (e.g. mycotoxins). Understanding the connections between the genotype/phenotype of crops or farmed animals, how these are affected by the environment, and any consequential links to the sources of toxins and infectious agents is key to making the food system resilient and safe.

The Quadram Institute

The new Quadram Institute in Norwich builds on BBSRC strategic investments in the former Institute of Food Research and across the wider Norwich Research Park, in partnership with the University of East Anglia and the Norfolk and Norwich University Hospital. Its vision is to integrate multidisciplinary bioscience and clinical excellence to deliver new understanding of interactions between food and the gastro-intestinal tract and their implications for health, production of safe and nutritionally enhanced crop-based food and accelerated innovation and commercial exploitation by UK industry.

BBSRC's focus

Research is required to maximise the nutritional value of food and to minimise any harmful pathogens and toxins. To achieve this, BBSRC will focus more efforts in the following areas:

Delivering health benefits for humans and farmed animals by integrating novel crop and nutritional research

Diet is an important determinant of human health and longevity. Research is needed to enhance the nutritional composition and bioavailability of key nutrients in food. Manipulation of crops or crop-based foods can help deliver increased levels of key nutrients and fibre, and complement other interventions (e.g. fortification, reformulation) to meet the many nutritional requirements of farmed animals and humans globally. This will require crop scientists and nutritionists to work together.

The gut microbiome of humans and farmed animals is an important research target because it interacts with food and whole diets to potentially influence health. The mechanistic interactions between food/feed and the microbiome are not well understood, and there are opportunities for new knowledge in this area to inform the breeding of a new generation of crops to benefit microbiome health.

In addition, tackling the parallel and related challenges in farmed animals and humans offers increased potential to deliver impact from the research. The combination of changes to genetics and phenotype, and the introduction of novel feeds has influenced the gut microbiome of farmed animals and potentially impacted on the prevalence and severity of food-borne pathogens. Understanding this effect and creating novel crops or feed additives to mitigate them is an important challenge.

Making food safer by reducing the levels of pathogens in primary production and along the food chain

There are opportunities to exploit fundamental knowledge in microbiology to understand food-borne pathogens, their transmission and how they can be controlled and eliminated. The role of the gut microbiome of farmed animals in food safety is also an important research target.

Improving human and farmed animal health by reducing toxins and infectious agents in the food system

A variety of toxins and infectious agents can negatively affect the food system, including mycotoxins, shellfish toxins and prions. Research is needed to understand the mechanisms and wider biological factors that contribute to these threats, and to develop biological interventions for their control. This includes research to understand the authenticity and traceability of food, where it relates to potential impacts on food safety.

Other BBSRC priorities in nutrition are described in BBSRC's Food, Nutrition and Health Strategic Framework[13] and the cross-council Vision for Food, Nutrition and Health research[38]. BBSRC's Veterinary Vaccinology Strategy[33] is also relevant to this focus area.

Examples of BBSRC investment that are addressing this challenge area

- Safer low-acrylamide varieties of wheat and potato have been identified by a BBSRC-funded collaboration with the food industry and retail sector.
- Through joint funding activities, BBSRC is working closely with FSA and Defra to address *Campylobacter* – the UK's biggest cause of foodborne illness.
- The commercialisation of Beneforté broccoli demonstrates the industrial potential from research on nutritional enhancement.
- Researchers have demonstrated how oil from genetically modified (GM) oilseed crops could replace fish oil as a primary source of the beneficial Omega-3 fatty acid EPA.

Reducing waste

To feed the global population we need to reduce the waste in food production

The challenge

Yield improvements alone are unlikely to meet the rapidly increasing global demand for food. Currently about one third of food produced across the whole food chain is wasted. Tackling the issue of pre-consumer food waste will be essential to improving productivity and resilience of the UK food system and will generate positive impacts for food security and the agri-economy. As many food chains are global in nature, this issue is not restricted to the UK and it poses an important challenge for food security in the Global South.

- Globally over a third of food produced is wasted each year - 1.3Bn tonnes[39]
- The UK wastes over 15M tonnes of food and drink per year, at a cost of over £20Bn[5]
- 51 % of UK food wasted is pre-consumer (i.e. not in the home)[40]

Research opportunities

Although there have been extensive investments in understanding and mitigating the consumer behavioural aspects of food waste, less attention has been given to addressing the associated biological issues – both on the farm and throughout the food chain. There is an essential role for bioscience research in reducing pre-consumer waste and maximising value and efficiency of the food system.

A significant proportion of pre-consumer waste relates to the inherent physiology of the produce, poor control of post-harvest biology, and the efficacy and appropriateness of the control systems applied. There are a wide variety of contributing biological factors and potential targets for intervention which provide excellent opportunities for novel research. The research challenges are of significant importance to policy makers and the global food and farming industry.

A major challenge is ensuring that as much as possible of the food produced is harvested. This requires continued research into the factors controlling flowering time and pre-harvest maturation to support more effective prediction and better control of harvesting windows and seasonality.

Maintaining post-harvest physiology and food quality is also vital to ensuring that high-quality food reaches consumers. There is clear potential to harness underpinning plant science in order to understand and manipulate key traits such as robustness, regularity, blemishes, size and shape. A better understanding of the fundamental processes of post-harvest physiology will help to reduce microbial spoilage, pest damage and contamination (including by mycotoxins), contributing to a safer and more resilient food system.

In addition, there are opportunities for biologists to engage in the development of multidisciplinary solutions to enable improved storage and shelf life. Research is needed to understand the effects of packaging and the immediate food environment on aspects such as dormancy, ripening and contamination.

Brassica, rapeseed and vegetable optimisation (BRAVO)

Oilseed rape and brassica vegetable crops have a combined UK market value in excess of £1Bn, but suffer yearly losses of up to £230M, primarily due to increasingly unfavourable and unpredictable weather patterns. The BRAVO programme aims to combat these crop losses by unravelling the processes that control key aspects of plant development, including inflorescence growth, flowering, fertilisation and seed production. This knowledge will be applied to develop more resilient varieties of brassica crops that can achieve superior field performance while reducing yield loss and industry wastage. The project brings together the expertise of leading UK plant scientists together with representatives from the oilseed and horticultural industries.

BBSRC's focus

Research is required to help maximise the efficiency of food production and reduce waste. To achieve this, BBSRC will focus more efforts in the following areas:

Enabling more effective prediction and better control of harvesting windows by understanding the underpinning developmental biology of crops

Novel biological approaches to manipulating primary production systems are required to meet the needs of producers, retailers and consumers. An important area of focus is the use of crop science research to control dormancy, flowering time, maturation biology and senescence, with the aim of enabling more effective scheduling and control of seasonality.

Optimising uniformity and physical traits by exploiting crop genetics

Improved control of physical traits and uniformity relating to grading, storage and transportation can make an important contribution to reducing waste within the food system. Research exploiting the latest crop genetics, cell biology and novel tools will lead to better control of seed and fruit development, and ultimately improved post-harvest physiology and quality.

Reducing the risks of spoilage by understanding and managing the relevant biological processes

The level of waste within the food system can be reduced by better management of the relevant biological process that affect spoilage. BBSRC investments in microbiology have produced substantial fundamental knowledge that can underpin efforts in this area. Further research is needed to understand and control spoilage organisms, reduce toxin contamination and manipulate natural resistance to post-harvest microbes and pests. This also provides an opportunity to tackle related challenges in food safety.

Minimising losses within the food system by understanding and controlling the fundamental biology that influences food storage and shelf-life

There are many challenges associated with minimising losses during storage and extending product freshness and shelf-life. Research is needed to understand the links between physiology, microbiology, and the food environment. There are opportunities to develop interventions to improve food quality and reduce contamination, including the development of innovative solutions such as biopackaging.

In considering the above focus areas, BBSRC will place particular emphasis on horticultural crops and potatoes. This reflects the proportionally high levels of wastage, the high-value nature of the produce, and the level of industry and policy interest.

The above focus areas are complementary to BBSRC's Industrial Biotechnology and Bioenergy priorities[11] around the reduction, recovery and re-use of inedible co-products from food-related bio-wastes and residues.

Examples of BBSRC investment that are addressing this challenge area

- Through a joint funding activity with India's Department of Biotechnology, BBSRC is investing in the development of bio-based packaging to improve the shelf-life of fresh food.
- Joint BBSRC and industry investments are supporting the development of novel potato varieties which are resistant to bruising and have improved processing quality.
- Sustainable Shelf Life Extension (SUSSLE), a joint BBSRC project with Defra and the food industry, reduces microbial contamination of food products, improving safety and shelf-life.

Understanding and exploiting genomics

Exploiting genomics will be essential to enable the next generation of crops and farmed animals

The challenge

To meet the future needs of the food and farming system, it will be necessary to understand and exploit the genomics revolution in crops and farmed animals. Historically, genomics research in a limited number of key species has delivered incremental improvements to yield. There has been less research effort to exploit wider genetic diversity for broader societal benefit, including traits related to resilience, sustainability, resistance, nutritional quality and higher produce quality. We also need to better understand the links between genotype and the phenotype in real farm environments.

- Historic gains in the yields of many cereal crops are now reaching a plateau[41]
- 75 % of the world's food is generated from only 12 plant and five animal species[42]
- The genetic diversity of the world's food supply is threatened by climate change[43]

Research opportunities

The understanding and exploitation of genomics will be critical to the development of the next generation of crops and farmed animals. As part of this, it will be necessary to understand in a more predictable way how the knowledge obtained from genomics approaches can be translated into beneficial phenotypes, in real world environments.

It is now technically possible and affordable to conduct whole genome studies across multiple varieties. The ability to access whole genomes and the wider genetic diversity across different varieties opens up opportunities for breeding programmes that were not previously available.

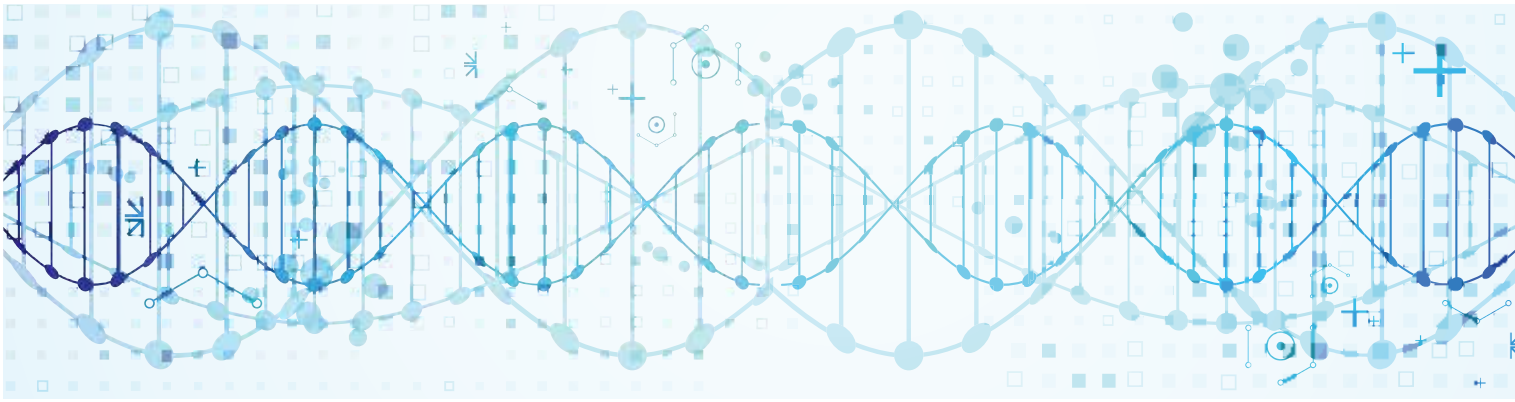
A whole new suite of technologies will be required to help access and exploit the genetic diversity, as well as new tools to transfer traits of interest into key species (e.g. gene and genome editing). This will require research to understand the genomic control processes such as recombination and the post-meiotic control of genes.

New tools and technologies will be required to automatically measure phenotypes. There is a need to rapidly determine the complete range of phenotypic properties in field and on farm, and effectively handle the large amounts of associated data. Researchers will need to make evidenced and biologically-relevant linkages between these data at single and multi-gene levels.

Ultimately, research should enable predictive biology that can identify the genes and wider background genome needed to deliver required phenotypic properties. This must be achieved while avoiding any unintended consequences such as reduced yield or lower resilience.

Agri-food genomics

BBSRC is a long-standing investor in technologies supporting genomics and next generation sequencing of whole genomes. BBSRC has worked with other funders and industry to support the sequencing and annotation of key genomes including farmed animals (pig, chicken), cereals (wheat, oats, barley) and many horticultural species (potato, tomato, strawberry, brassicas, cabbage, and mushroom). These investments have underpinned further studies in elite lines and to assess broader diversity for novel genes. For example, research to assess the Multi-parent Advanced Generation Inter-Cross (MAGIC) populations of elite wheat germplasm addressed timely questions regarding the composition of the wheat 'pan-genome' and the ways in which this knowledge can be used for wheat genetic improvement.



BBSRC's focus

Research is required to exploit the genomics revolution in crops and farmed animals in a predictable way, and translate this knowledge into beneficial phenotypes for real-world environments. To achieve this, BBSRC will focus more efforts in the following areas:

Developing the next generation of improved crops and farmed animals by accessing and utilising greater genetic diversity

The ability to undertake whole genome studies across a number of varieties suited to different environments is key to identifying new genes that can confer beneficial traits. This includes the analysis and interpretation of high coverage genomes, alongside understanding the genomic variation in underutilised varieties, less-used breeds, orphan crops and progenitor lines.

Enabling greater control of breeding by understanding and manipulating the biological mechanisms which control access to genes

It is essential to understand the fundamental genetic control processes which affect breeding and phenotypic control. In particular, further research is needed to understand the mechanisms that control recombination and access to genes (e.g. polyploidy, epigenetic regulation). Novel breeding technologies are also required to access wider genomic diversity and allow for the greater control of gene flow (e.g. genome breeding[44]).

Identifying and exploiting multiple beneficial traits through understanding the links between genotype and phenotype

Research is needed to develop a better understanding of existing genomic data and complex crop and farmed animal phenotypes of future strategic importance (e.g. resilience, pest or disease resistance, safety and nutritional quality, and consumer-based traits). Exploiting the links between target species and model systems will contribute to this goal. An important focus will be to access under-researched traits for public good, while maintaining yield and the profitability of the food and farming system. BBSRC will prioritise those traits which have the potential to deliver the greatest benefit and support the other AFS Strategic Framework focus areas.

Enabling rapid and accurate measurements of phenotype in real-world environments

New phenotyping tools and enabling technologies are required to support innovative agri-food research. For crops, it will be important to assess phenotypes within the field using a variety of flexible technologies including above and below ground imaging. For farmed animals, it is essential to conduct whole animal phenotyping, including internal and macromolecular properties which underpin wide concerns such as gut health, fertility and welfare. The automation and data management tools required to link phenotype data to genotype and environment are critical.

Examples of BBSRC investment that are addressing this challenge area

- Researchers are investigating genomic selection in collaboration with a major poultry breeding company whose activities underpin 50% of the world's marketed chicken.
- Seeds of Discovery (SeeD) is an international project bringing together improved diversity data on genotype and phenotype in key crops.
- Researchers are working with plant breeders to release the natural variation modulating meiotic crossovers and produce superior varieties with favourable agronomic traits.
- BBSRC is a key partner in the preparatory phase of the European Infrastructure for multi-scale Plant Phenomics (EMPHASIS), which will support the analysis of genotype performance under diverse environmental conditions.

Precision agriculture and smart technologies

Pioneering technological approaches can enhance bioscience research and revolutionise future farming

The challenge

Combining excellent bioscience research with novel engineering and technological solutions has the potential to revolutionise the agri-food sector. Smart technologies to detect, measure, automate, predict, compute and evaluate on farm, linked through intelligent networks ('The Internet of Things'), can create new insights to complex biological questions that have been unattainable to date. New knowledge and the translation of these approaches may ultimately transform future farming practices and help address the many global challenges facing the agri-food sector.

- Precision farming and engineering was estimated to be worth £1Bn to the UK economy in 2016[45]
- In 2015, US$661M was invested globally in precision agriculture technologies[46]
- Agricultural robots and drone technologies are already a global market of US$3Bn in 2016, growing to US$10Bn by as early as 2022[47]

Research opportunities

Technological innovations or technology transferred from other sectors are likely to have a major role in shaping the farms of the future. A digital agricultural revolution provides an opportunity to make significant gains in productivity and sustainability within the food system. By collecting real-time data in field and on farm, and integrating this with a variety of other data sources (e.g. climate data, economic data), it will be possible to develop robust scientifically-informed decision making tools for researchers, the agri-food industry and beyond.

There is a need for bioscientists to collaborate with other disciplines (e.g. engineers, technologists, mathematicians and computer scientists) to co-design enabling and disruptive technologies. These developments will initially enable researchers to detect, monitor and measure relevant biological data more accurately in the field and on farm, and in real time, with consequential impacts to the wider industry.

There are many aspects of the food system which could benefit from the application of novel technological solutions and linking data across systems, and there is a substantial global market for such innovations. Opportunities include reducing environmental impacts by the precise and timely application of inputs, improving animal welfare through early detection of stress, or the development of new husbandry approaches. Other areas include the ability to understand whole organisms in the field (e.g. new high-throughput phenotyping or multiple phenotypic indicators linked to genotypic and environmental data, and rapid detection of pests and pathogens). In developing innovative solutions, it will be critical for researchers to understand the needs of farmers and the wider agri-food sector.

In both the UK and in the Global South, the cost and availability of labour, and rapid generation of novel crops and farmed animals, will drive more high-tech solutions and automation across the agri-food sector. This will require new technologies and digital understanding of the underpinning biology.

Saturn Sense Hydrofeed

A BBSRC and Innovate UK funded project with Saturn Bioponics Ltd assisted in the development of a new in-line sensing technology for real-time management of the nutrient composition within intensive hydroponic, aeroponic and aquaponic farming. The multidisciplinary approach addresses challenges in horticultural production. It is reducing the UK's requirement to import and offering producers a flexible production facility to meet changing consumer preferences and sustainability goals.

Rothamsted Research

BBSRC's focus

New approaches are required to maximise developments in the biosciences and translate novel technologies to agriculture and food systems. Key challenges include the rapid early detection of pests and pathogens, reducing food waste through product quality improvements, below and above ground crop measurements, and reducing inputs including improving water and nutrient use. BBSRC will focus more efforts in the following areas:

Developing precision farming by embedding smart engineering technologies in agri-food research and innovation

Multidisciplinary working is needed to create innovative agricultural solutions which are challenge led, partnering knowledge of biology and technology. Precision farming technologies are needed to tackle challenges in agriculture both within the context of current farming systems (e.g. sensors, UAVs, agri-bots, imaging, satellites, phenotyping) as well as for potential future farming systems such as vertical farms (e.g. lighting solutions, hydroponics, closed-loop farming systems).

Supporting the development of digital and predictive tools to improve decision making

Predictive farming is an under-explored area of food system research, but offers substantial potential for improving farm management, informing breeding strategies and scientifically-validated guidance for intervention. There are opportunities for the measurement and interpretation of real-time in field/on farm data to model future outcomes, and this knowledge can then inform the development or improvement of digital-based decision support tools.

Revolutionise future farming by developing and utilising novel technologies

Innovative tools and technologies linked to a deep understanding of biology will be critical for enabling new approaches to farm management and food production. There are opportunities to develop smart technologies for bioscience to enable the agri-food industry to explore new and novel approaches to food production, such as fully automated farms, nutrient recycling, hydro- and aquaponics, vertical agriculture, and growing food in extreme environments. Enabling new places to grow food also provides an opportunity to tackle related challenges in reducing waste, sustainability and providing accessible and safe food.

Novel technologies and improved data management cut across all aspects of BBSRC's AFS Strategic Framework, and are also relevant to BBSRC's enabling theme of Exploiting New Ways of Working[1].

Examples of BBSRC investment that are addressing this challenge area

- The multidisciplinary AUTOPIC project has developed a prototype robotic vehicle that is capable of harvesting soft fruit at a commercially acceptable rate.
- Researchers are developing a cow health monitor early-detection system for metabolic and infectious disease in dairy cattle.
- Researchers are helping predict pests and diseases of crops by developing an integrated phone app which uses crowd-sourcing aligned with meteorological data.
- Research has demonstrated that remote sensing imagery can be used to estimate ecosystem services on farmland.

Notes and references

1. BBSRC Strategic Plan: The Age of Bioscience. www.bbsrc.ac.uk/documents/strategic-plan-pdf/
2. Frontier Bioscience. www.bbsrc.ac.uk/research/frontier-bioscience
3. United Nations Department of Economic and Social Affairs / Population Division. World Population Prospects: key findings and advance tables, 2015 revision.
4. World Agriculture Towards 2030/2050. The 2012 Revision. www.fao.org/docrep/016/ap106e/ap106e.pdf
5. Department for Environment, Food & Rural Affairs. Food Statistics Pocketbook 2016. www.gov.uk/government/statistics/food-statistics-pocketbook-2016
6. For the purpose of this document, BBSRC considers the Global South countries to be those listed as recipients of Official Development Assistance on the OECD Development Assistance Committee (DAC) list. www.oecd.org/dac/stats/daclist.htm
7. Sustainable Development Goals. https://sustainabledevelopment.un.org/
8. Agriculture in the United Kingdom 2015. www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2015
9. Economic Impact of Plant Breeding in the UK. www.plantbreedingmatters.com/economy.php
10. The BBSRC strategically-funded institutes are: the Babraham Institute; the Earlham Institute; the Institute of Biological, Environmental and Rural Sciences; the John Innes Centre; The Pirbright Institute; the Quadram Institute; the Roslin Institute; and Rothamsted Research.
11. BBSRC priority in Industrial biotechnology and bioenergy. www.bbsrc.ac.uk/research/biotechnology-bioenergy/
12. BBSRC Bioscience for Health Strategic Research Framework 2015-2020. www.bbsrc.ac.uk/documents/bioscience-for-health-booklet/
13. BBSRC Research in Food, Nutrition and Health Strategic Framework 2015-2020. www.bbsrc.ac.uk/documents/1503-fnh-strategic-framework/
14. UK Industrial Strategy. www.gov.uk/government/policies/industrial-strategy
15. UK Bioeconomy Strategy. www.gov.uk/government/consultations/uk-bioeconomy-call-for-evidence
16. UK Agricultural Technologies (agri-tech) Strategy. www.gov.uk/government/collections/agricultural-technologies-agri-tech-strategy
17. Animal and plant health in the UK: building our science capability. www.gov.uk/government/publications/animal-and-plant-health-in-the-uk-building-our-science-capability
18. A Vision and high-level Strategy for UK Animal and Plant Health Research to 2020 and Beyond. www.bbsrc.ac.uk/documents/1601-animal-and-plant-health-report-3/
19. Food and farming industry. www.gov.uk/government/policies/food-and-farming-industry
20. Feeding the Future. www.nfuonline.com/assets/61673
21. Feeding the Future, Four Years On: A review of innovation needs for British Farming. www.nfuonline.com/assets/93387
22. Antimicrobial Resistance (AMR). www.gov.uk/government/collections/antimicrobial-resistance-amr-information-and-resources
23. Obesity and healthy eating. www.gov.uk/government/policies/obesity-and-healthy-eating
24. Food Standards Agency, Food We Can Trust. www.food.gov.uk/sites/default/files/FSA%20strategy%20document%202015-2020_April%202015_interactive%20%282%29.pdf
25. Global Food Security programme. www.foodsecurity.ac.uk
26. BBSRC and MRC review of vulnerable skills and capabilities. www.bbsrc.ac.uk/about/reviews/consultations/1501-vulnerable-capabilities-report/
27. The natural choice: securing the value of nature. www.gov.uk/government/publications/the-natural-choice-securing-the-value-of-nature
28. Save and Grow: A policymaker's guide to the sustainable intensification of smallholder crop production. www.fao.org/docrep/014/i2215e/i2215e.pdf
29. Agricultural Statistics and Climate Change. www.gov.uk/government/uploads/system/uploads/attachment_data/file/552438/agriclimate-7edition-12sep16.pdf
30. Chakraborty S and Newton AC (2001). Climate change, plant diseases and food security: an overview. Plant Pathol 60:2-14 doi:10.1111/j.1365-3059.2010.02411.x
31. NOAH annual review 2015/16. www.noah.co.uk/wp-content/uploads/2016/08/NOAH-Review-2015-16-HR.pdf
32. World Health Organization. A brief guide to emerging infectious diseases and zoonoses. www.searo.who.int/entity/emerging_diseases/topics/Zoonosis/en/
33. BBSRC Veterinary Vaccinology Strategy 2015-2020. www.bbsrc.ac.uk/documents/1506-veterinary-vaccinology-strategy/
34. Functional Foods Market Analysis By Product (Carotenoids, Dietary Fibers, Fatty Acids, Minerals, Prebiotics & Probiotics, Vitamins), By Application, By End-Use (Sports Nutrition, Weight Management, Immunity, Digestive Health) And Segment Forecasts, 2014 To 2024. www.grandviewresearch.com/industry-analysis/functional-food-market

35. Rayner M and Scarborough P (2005). The burden of food related ill health in the UK. J Epidemiol Community Health 59:1054-1057. doi:10.1136/jech.2005.036491

36. Veterinary research in the UK: a snapshot. www.rcvs.org.uk/publications/veterinary-research-in-the-uk-a-snapshot/

37. Schamle DG and Munkvold GP (2009). Mycotoxins in Crops: A Threat to Human and Domestic Animal Health. The Plant Health Instructor. doi:10.1094/PHI-I-2009-0715-01

38. A Cross-Council vision for Food, Nutrition and Health research. www.bbsrc.ac.uk/documents/1503-crosscouncil-fnh-booklet/

39. Global Food Security Programme. Food waste within global food systems. www.foodsecurity.ac.uk/publications/food-waste-within-global-food-systems.pdf

40. WRAP. Understanding out of home consumer food waste.

41. Grassini P, Eskridge KM and Cassman KG (2013). Distinguishing between yield advances and yield plateaus in historical crop production trends. Nature Communications 4:2918. doi:10.1038/ncomms3918

42. Food and Agricultural Organization of the United Nations. What is happening to Agrobiodiversity. www.fao.org/docrep/007/y5609e/y5609e02.htm#bm2

43. Food and Agriculture Organisation of the United Nations. Coping with Climate Change: The Roles of Genetic Resources for Food and Agriculture. www.fao.org/3/a-i3866e.pdf

44. Genome breeding is defined as taking a whole genome approach to the breeding pipeline and not focusing on breeding for single traits.

45. Agri-Tech Industrial Strategy: Evaluation Scoping Study and Baseline. www.gov.uk/government/uploads/system/uploads/attachment_data/file/536388/bis-16-18-agri-tech-industrial-strategy-evaluation-and-baseline.pdf

46. AgTech Investing Report Mid Year 2016: https://research.agfunder.com/2016/AgFunder-Agtech-Investing-Report-Midyear-2016.pdf

47. Agricultural Robots and Drones 2017-2027: Technologies, Market Players. www.idtechex.com/research/reports/agricultural-robots-and-drones-2017-2027-technologies-markets-players-000525.asp

48. AgriFood Training Partnership. www.aftp.co.uk

www.bbsrc.ac.uk