

BBSRC HIGH-LEVEL FOOD RESEARCH STRATEGY 2007-2012

1. The Biotechnology and Biological Sciences Research Council (BBSRC) is the UK's principal funder of basic and strategic biological research. To deliver its mission, BBSRC supports research and research training in universities and research centres throughout the UK, including BBSRC-sponsored institutes; and promotes knowledge transfer from research to applications in business, industry and policy, and public engagement in the biosciences.
2. BBSRC funds non-clinical basic and strategic biological research and has a role in underpinning the strategic objectives of stakeholder industries, including those in the agriculture, pharmaceutical and food sectors. The food sector includes those industries responsible for primary production, food production and food quality. The UK public is a major stakeholder in the outputs of government-funded research, and the relationship between diet and health is an important area for food research in the BBSRC remit. This document is produced to inform both stakeholders and the research community.
3. Curiosity-driven ("blue skies") research has been a limited driver for food research; many of the objectives of food science and technology relate to the requirements of the food industries or consumer benefit. Often these requirements are met by relatively low technology solutions due to lack of more sophisticated approaches in food production, food processing or food safety, or have been related to issues of understanding human nutritional needs and dietary effects on health. Unlike other areas of activity, this has not driven major technological advances in basic science. The industry base does not have a major UK research capacity.
4. Increasing societal pressure to understand the relationship between diet and health and for low environmental impact of food production, processing and delivery has increased the opportunities for curiosity-driven food research. New technologies arising from other parts of the research base are providing new tools to undertake this research.
5. Food research covers a wide range of disciplines. The variety and complexity of plant and animal foods, manufactured food products, consumer behaviour, and dietary requirements of individuals to promote optimal health present major research challenges. Multidisciplinary approaches are required to investigate and improve the quality and nutritional value of raw materials and to address the challenges generated by different processing technologies required to give a range of safe and nutritious products, and by the variation in age, health and genotype between individual consumers. Some of these challenges require fundamental studies at the limits of current knowledge. This document sets out some of the problems and issues that are relevant to the BBSRC research community.
6. With its active involvement in research at different stages of the UK food chain, the BBSRC is uniquely placed to contribute to improving the health of the UK population by provide expertise needed to provide safe and nutritious plant and animal foods and a better understanding of the mechanisms underpinning diet-health interactions.

INDUSTRY CONTEXT

7. Food supply is controlled by a set of interconnecting industries, from the farm, via ingredient and raw material suppliers, to food manufacturers, and hence via the retail

and catering businesses to the consumer. Food research addresses strategic objectives at various points in this chain.

8. Despite the social and economic importance of an effective and efficient food industry, and the large number of companies engaged in food production in the UK, the industry has limited capacity to conduct its own research. In total the sector spent £258M on R&D in 2004. Within the food industry most product development proceeds incrementally, and, except for the very large multinationals, large research centres do not exist. The industry is well served by the food research associations, Campden & Chorleywood Food Research Association and Leatherhead Food International, which carry out mainly applied research, but there is scope for improved linkages with centres of academic excellence coupled with mechanisms to disseminate the results of research back to the industry. Substantial opportunities for innovative research exist across the food supply chain.
9. Historically, food research has focused on the delivery of ingredients and of foodstuffs and on the flavour and texture of food. Recently the relationship of diet to health has assumed increasing importance in response to consumer interest and impending EU legislation on health claims.
10. The food industry still has requirements for research in processing to ensure good organoleptic properties of healthier foods (e.g. tastier low-fat, low-salt foods) and delivery of bioactive compounds in food.
11. The agri-food sector plays a key role in delivering high quality staple foods and raw materials. The lower energy requirements associated with sedentary lifestyles require raw materials and processed foods which maintain micronutrient intake with a lower energy diet.
12. The public sees the role of government research funding to improve the safety and nutritional quality of food and to tackle food-related health problems. The September 2005 MORI study of public attitudes to Research on Diet and Health, based on a small sample of BBSRC-funded projects, indicated that the priority research areas for the public were protection/prevention against illness, tackling obesity and the nutritional quality of foods; of lesser importance were improvement to the taste, colour and texture of food. There was, however, little public understanding of the role of research in the UK economy and the potential economic and institutional benefits of research into diet and health.

POLICY CONTEXT

13. BBSRC-funded research into the supply of food materials, dietary requirements and food safety has significant links to and impact on the policy of several government departments, mainly the Department of Environment Food and Rural Affairs (Defra), the Food Standards Agency (FSA), the Department of Health, and the Scottish Executive Environment and Rural Affairs Department (SEERAD). The underpinning scientific research to meet policy needs is already acknowledged in the attendance of Defra and FSA at the Agri-Food Committee and Defra at the Animal Science Committee, together with their funding through the Government Partnership Award scheme.

BBSRC-FUNDED RESEARCH IMPACTS

14. Food is a product of primary agricultural industry (growth, harvesting), food manufacture (storage, processing) and delivery (storage, packaging, retail). It is also the starting point (substrate) for nutrition and human health. Food research covers food both as a product and as a substrate.
15. The food chain can be divided into several distinct but overlapping parts. One such categorisation of the food chain is:
 - Primary production and supply
 - Processing and manufactured products
 - Food safety
 - Food choice
 - Diet and health
16. Impacts on **primary production and supply** are largely through the application of the recent advances in plant science research to crops, in order to increase production, to reduce plant disease, to provide high value products with low intensity inputs of fertilisers and biocides, to produce crops with novel properties, and to reduce waste. Of particular importance to food research are the post-harvest properties of crops for storage and processing. Advances in animal breeding, husbandry and health have made major contributions to the improvement of food animal quality and welfare. For both crops and animals, their nutrient and bioactive non-nutrient composition are important in their impacts on human health.
17. **Food processing for quality** is of increasing importance. There is a demand to produce cheap convenient food which has low salt, sugar and fat content, but retains good flavour and texture. This is a technological challenge. Alterations in the properties of raw materials as well as innovation in processing technologies may be required to satisfy this demand.
18. **Food safety** is a major issue in public health. The incidence of *Salmonella* and *Campylobacter* infections is estimated to be under-reported at least 10-fold and a basic knowledge of food hygiene in the public is lower than a generation ago. Major potential or actual infections such as BSE in cattle, *Salmonella* in eggs, *E. coli* O157 in cooked meats have ensured that food-borne illnesses have remained a high-profile area of research for the last two decades. Changes to food composition and chemistry may also affect its safety.
19. The role of **diet in improving and maintaining human health** is now a highly politicised area of research. For example, the UK has the highest levels of obesity in Europe and there has been considerable debate about the contributory role of cheap convenience foods. BBSRC-funded research can contribute to understanding the relationship between diet and health, ranging from the psychology of food choice to the effect of dietary constituents on human physiology, and can inform the development of Government policy. Of particular importance and relatively poorly understood is the direct effect of diet on the health of the GI tract. In the food chain, the step about which possibly least is known is the interaction of foodstuffs with the GI tract, particularly the variation between individuals in nutrient assimilation and food allergies. Ultimately, this determines the acceptability and nutritional quality of foods at an individual level.
20. BBSRC should undertake basic food research to elucidate mechanisms that explain the relationship between diet and health, and should undertake strategic research,

preferably in association with the agri-food industries, to address the production of safe and nutritious foods. Some areas for consideration are given below.

CURRENT BBSRC RESEARCH PRIORITIES AND FUNDING

21. The Agri-Food Committee (AF) is the main grant-awarding committee of relevance to food research, but the Engineering and Biological Systems (EBS), Plant and Microbial Sciences (PMS) and Animal Sciences (AS) Committees also have remits that cover aspects of food science and technology.
22. The current Themes and Priority Areas of these Committees of relevance to food research are:

Themes

- Sustainable Agricultural Systems (AF)
- Food Quality (AF)
- Control of Food-borne Pathogens (AF)
- Diet and Health (AF)
- Integrative Animal Physiology (AS)
- Mechanisms of Immune Function and Disease Pathogenesis (AS)
- Neuroscience and Behaviour (AS)
- Biochemical Engineering (EBS)
- Metabolic Engineering (EBS)
- Mechanism of Plant Growth and Development (PMS)
- Biochemistry and Physiology of Microorganisms (PMS)

Priority areas

- Genes to Food Products (AF)
- Food Metabolomics (AF)
- Food-borne Pathogens and the Environment (AF)
- Genotypic Variation and Responsiveness to Diet (AF)
- Diet and Vascular Health (AF)
- Control of Infectious Disease (AS)
- Genes to Physiology (AS)
- Integrating Physiology (PMS)
- Exploring the Potential of Metabolomics (PMS)

23. In addition, the recent BBSRC Initiative "Innovation in Crop Science" addressed many of the issues of bringing recent advances in plant science to crop plants for agricultural sustainability.

Funding

24. Current funding on food research by BBSRC comprises 181 project grants totalling £55.7M. The majority of these (140 grants) are from the Agri-Food committee, but the split by value is 62% AF, 21% GDB, 11% AS, with the remainder split between BCB, EBS and PMS. About 19% of the grant funding goes to BBSRC institutes (mainly IFR and IAH).

In this analysis the following areas of research were classified as being relevant to food research:

- *Post-harvest production, packaging, etc*
- *Materials research and properties of food including starch*
- *Food-borne zoonoses*

- *Effect of diet on human health, eg obesity; effect of maternal nutrition on foetus development*
- *Some aspects of gut immunology*

For the purposes of funding analysis, the following areas of research were excluded:

- *All pre-harvest research including crop, agriculture / biodiversity, pest control*
- *Plant and animal breeding including genetic modification of crops*
- *Use of food as a reward in animal behaviour experiments*
- *Effects of nutrients on tissue engineering processes*
- *Animal diseases other than food-borne zoonoses*
- *Nutrient / ion transport mechanisms in humans or animals, except across the gut*

This funding equates to an annual spend of ca. £19M.

Funding on food research undertaken by other organisations is classified in different ways and is not included here.

THE NEED FOR FUTURE RESEARCH

25. Future priorities in food research should include both "blue skies" curiosity-driven research and those of strategic relevance to the food industries. Research should cover a range from supply of raw materials, through processing and manufacture, through consumer behaviour, to physiological impacts on health.
26. Food contains *bioactive components*, which include nutrients (proteins, carbohydrates, lipids, vitamins, minerals), flavours and many other non-nutrients which act as physiological modifiers (these affect a wide range of cellular processes and some may act as stimulants or appetite suppressants). The objective of food production is to deliver these in an appropriate manner to benefit health. Once food has been ingested its interaction with the GI tract affects the supply of nutrients and bio-active non nutrients to the body, The quality, form and kinetics of metabolites that enter the systemic circulation and their impacts on physiological functions at the cellular and molecular level will have a major impact on health. Genotypic differences and epigenetic changes can influence responsiveness to diet and understanding individual variation in dietary requirements and risk will be a major challenge.
27. The future research areas necessary for application in the food industries, from primary manufacture to retail, can be broken down as follows:

Research relating to the delivery of bioactive components in food that benefit health

28. This area includes research to maximise the production, yield and delivery of nutrients and physiological modifiers that benefit health.
For example, research to improve:
 - *our understanding of metabolism in crop plants and farm animals*
 - *separation methods for bioactive components*
 - *analytical methods to measure beneficial components*
 - *efficient bioprocessing in food fermentation*
 - *our understanding of the reaction chemistries in food processing*
 - *our understanding of microbial physiology in processing environments*
 - *technologies to protect and deliver beneficial components*
 - *composition of foods to meet the low energy-high nutrient modern dietary requirements.*

Research leading to an improved understanding of what constitutes healthy food

29. This area includes research to improve the health benefits of foods and maintaining consumer satisfaction.
For example, research:
- *to understand the influence of food structure and composition on human nutrition and physiology to enable foods to be designed with precise nutritional and physiological properties*
 - *to ensure that beneficial bioactive food components are delivered to the point where they can be used. This includes, for example, active delivery of nutritional benefit to the gastrointestinal tract and post-absorptive tissues, or of flavour to the nose and mouth*
 - *to understand the basis of taste, texture and flavour at a fundamental level to enable reductions in salt, sugar and fat content without adversely affecting consumer response*
 - *to investigate the role of food constituents, particularly minor food components, on regulating energy intake through signalling satiety*
 - *to study the GI tract in order to characterise the biology underlying the interactions between nutrients, bioactive non-nutrients, the intestinal microflora and the gut.*

Understanding the effects of food and food components on human physiology, metabolism, health and behaviour

30. This area includes research to improve our understanding of the effects of food and food components on human health.
Examples would include:
- *the effect of the physical properties of food on the physiology of the gut*
 - *nutrient and bioactive non-nutrient uptake and assimilation, and systemic distribution of food metabolites*
 - *the immunology of the gut in relation to food allergens and other dietary components*
 - *the microbial ecology of the gut in health and disease*
 - *satiety signalling and the role of food components*
 - *individual genetic variation and personalised nutritional requirements.*

Tools and technologies for food research

31. This area is generic and is required to underpin a number of aspects of food research.
Examples would include:
- *imaging technologies at cellular and organismal level (inc fMRI)*
 - *high throughput methods for metabolomic studies of food plants and animals*
 - *high throughput methods for genomics and metabolomics in understanding the cellular responses to nutrients and other food bioactives*
 - *application of new methods in the analysis of food composition*
 - *development of novel technologies for assessing exposures to foods and food components*
 - *materials technology for delivery of bioactive components.*

Trained people

32. Food research is multidisciplinary. Although students may specialise in one aspect of food research, they should ideally receive training which encompasses a mixture of biological and physical sciences and engineering. The interaction between basic science and clinical aspects of nutrition is also an important interface that will benefit

from teams able to work across a range of activities from food research in the laboratory to human studies in nutrition units and clinics.

EUROPEAN FOOD RESEARCH

Framework Programme 7

33. Aside from those parts of FP7 open to all areas of research (ERC, Marie Curie, infrastructures and SME research), FP7 Cooperation Programme will fund collaborative research and networking plus ERA-Nets in 10 thematic areas.

Theme 1 Health will fund research on immunotherapy for food allergies, and has a specific area of relevance: 'Nutritional signals and the development of new diabetes/obesity therapeutic agents'.

Theme 2 Food Agriculture and Biotechnology is the focus of food research in FP7, and €106M is set aside for food, health and well being. This covers a range of topics in nutrition, food processing food quality and safety, consumer research, environmental impacts and the total food chain.

34. Areas of specific relevance for future research are:

Nutrition

- Effect of diet on mental performance
- Impact of diet on ageing
- Diet and its effect on the development of intestinal microflora and on the immune system through the entire life span
- Systems biology and bioanalytical tools for nutrition research

Food processing

- Assessment and improvement of existing food and feed technologies
- Harmonising and integrating research on food technology, safety and nutrition through commonly shared food models
- Nano-devices for quality assurance, food safety and product properties

Food quality and safety

- Exposure to food additives, flavourings, and migrants coming from the packaging: Dietary intake models
- New methods for the monitoring and control of food-borne viruses
- Food sampling strategies for risk analysis
- Protecting animal and human health from prions in food, feed and the environment

Environmental impacts and total food chain

- Post-market monitoring of GM food and feed
- Converging technologies and their potential for the food area
- Development and application of computational biology as a complementary tool to *in vivo* and/or *in vitro* trials
- Sustainability of the food chain
- Reduce contamination by mycotoxins in the food and feed chain

European Technology Platform on Food for Life

35. The vision of the ETP on Food for Life is that of sustainable safe food production throughout Europe that improves health through nutrition and allows the European agro-food industry to exploit market opportunities. An integrated 'farm to fork' approach is proposed. It is intended to promote innovation, to integrate research across the food chain, and to improve European health and quality of life through appropriate nutrition. This will be pursued through a strategic research agenda on diet and health, food quality and manufacturing, consumer choice behaviour, food safety, sustainable food production, and food chain management, with appropriate training, communication and KT activities.

PROPOSALS FOR BBSRC FOOD RESEARCH PRIORITIES 2007-2012

36. Future priorities for BBSRC-funded research in food research should build on the existing knowledge base and extend the impact of basic and strategic research in delivering high quality foods and food products and improving human health.
37. The research areas contributing to the dietary health of the nation are varied, and some lie outside the remit of BBSRC. Innovative areas of BBSRC-funded research that should contribute significantly to the objectives of the food industry, to the development of policy and to the nation's health are proposed below.

Genomics and metabolomics of food-producing organisms

38. This priority will address the intrinsic properties of crops, food animals and food-processing microorganisms to provide the evidence base for breeding crops and animals with improved properties for delivering bioactive components and for specific processing objectives. At present this would be by natural genetic processes, but the possibility of using genetically-modified crops and animals must be considered.
39. The properties of microorganisms used for dairy and fermentation bioprocesses influence the final product. The application of metabolomics to understanding the complex process of fermentation, particularly in optimising food structure and/or flavour and reducing undesirable by-products, is an important new technique to understand and manipulate microbial physiology for food processing. With the increasing understanding of such microorganisms and the availability of genome sequences, there are significant opportunities to study and improve fermentation microorganisms.

Physico-chemical structures of foods

40. The physical nature of foodstuffs is important in the technologies that need to be applied in processing the raw materials and the delivery of nutrients and bioactive non-nutrient components of food to the human body. It has become increasingly apparent that the fine structure of food at the nano- and micrometre scale is important in defining its physical, chemical and biological properties. This affects food processing, has a major impact on delivery of bioactives and is likely to regulate nutrient release in the gut, yet is relatively poorly understood.
41. An understanding of the physics and chemistry of foods requires collaboration between biologists, physical scientists, and engineers, with input from mathematicians and modellers. There is a specific requirement for materials scientists. New analytical methods for analysing desirable and undesirable constituents of foods will be

important. Having suitable physico-chemical models for foods will better enable the modification of foods to have desirable properties conferring health benefits with optimal processing conditions and costs.

42. This will include the active modification of foods to ensure better delivery of flavour, nutrients and physiological modifiers at the appropriate sites of action. A better knowledge of food structure should help develop processing protocols to reduce salt, fat or sugar contents of some foods.

The human GI tract as a biological system

43. The primary site of action of food is on the human GI tract. Via its role in taste and satiety and regulation of rates of absorption and metabolism of nutrients and fluids, the gut acts as the gate keeper in whole body homeostasis. The health of the large gut is related to its microbial ecology (commensal and pathogenic microorganisms), and to complex interactions between these microorganisms, the epithelial lining and mucosal immune defences, and to the chemical and physical properties of the gut contents (pH and ionic balance, food residues, allergens, toxins). Metagenomic techniques may be used in the analysis of the gut microbial flora, and new analytical and imaging techniques may give better information on the chemical and physical properties of the gut contents *in vivo*.
44. A full understanding of the physiology, immunology and biochemistry of the gut, including nutrient sensing, transporter regulation, musculature and endocrine and neural feedback systems, is required in order to be better able to address issues of diet and health. It is important to study gut function across the lifecourse, from infancy to old age. There are some generic properties that need to be better understood (e.g. the rate and efficiency of macronutrient and micronutrient absorption by the enterocytes, and transport into the systemic circulation, interactions of commensal and pathogenic bacteria, effect of allergens and toxins), in order that the functional components of the alimentary tract can be modeled using systems approaches. This will require the collaboration of biologists, mathematicians, engineers and physical scientists to develop theoretical models of the functions of specific sub-components of the whole system, and to test the predictions through cell, animal and human volunteer studies. This is a significant challenge and may require new methods, including imaging techniques, in order to determine the data required to populate and test the models proposed.

Diet as a modifier of development and health

45. Although there is considerable evidence and public acceptance that diet affects health and the risk of chronic disease in adults, as illustrated by public health campaigns to reduce salt intake and increase fruit and vegetable consumption, the role of diet in affecting development at critical life stages, beyond minimal nutritional requirements, seems less well understood. In particular, little is known about the detailed mechanisms whereby nutrition early in life e.g. during fetal development or infancy, can affect health and cognitive functioning decades later.
46. Evidence from animal studies suggests that epigenetic modifications introduced by dietary insults and constraints are “remembered” throughout the life-course with consequences for gene expression and cell function. Recent advances in characterization of the epigenome provide a unique opportunity to understand the molecular basis of early life programming on later health. It is also possible that early-life nutritional experience leaves an imprint through stochastic damage and/or the

long-term consequences of altered organ growth, which can affect later health and cognitive functioning.

Nutrition, metabolic regulation, ageing and health – a life course approach

47. An individual's body weight results from the sum of metabolic activities functioning under differing circumstances, and reflects complex interactions among genotype, gender, metabolic phenotype and the environment. A better understanding of these interactions and markers of dysfunction over the lifecourse are needed. There is particular need to understand the effects of childhood obesity, patterns of weight gain and differences in body fat distribution on long term health outcomes. A consensus is emerging that sleep restriction has an impact on appetite regulation and metabolic function and chronically may contribute to failing homeostasis. Maintaining metabolic homeostasis throughout the life course is likely to be key to healthy ageing.
48. Individuals in an ageing population now risk spending more of their later years in ill-health, and hence placing higher demands on healthcare provision. It is now recognized that diet can moderate the rate of ageing directly through an ability to retard the loss of homeostatic decline, but our understanding of the underlying mechanisms of ageing and how diet can ameliorate the physiological and cognitive decline into ill-health is very incomplete. Many aspects of nutrition and metabolic regulation undergo alterations with age that result from an accumulation of cellular and molecular damage. For example, age-related changes to the gut epithelium, neurons, muscle, endocrine signaling pathways and mucus secretion have important effects on many aspects of health, yet are little understood.
49. There is significant interest in the differences between individuals and the potential role of personalized nutrition in achieving and maintaining optimal health. There is considerable opportunity to determine the effects of individual genetic (and physiological) variation in response to nutrients, allergens and microorganisms. Knowledge of the extent of individual variation in response to diet (nutrigenetics) and capacity for manipulation of phenotype according to genotype, is of importance in optimizing individual health.
50. In view of the intrinsic complexity of the relationship between the gut, diet and health, there is an urgent need for systems approaches to studying nutrition, endocrinology and metabolism, including linking diet to physiological programming. It is unclear how far into the life course such programming can occur to affect the subsequent health trajectory and if such physiological programming is reversible. This will require high throughput data collection including exploitation of emerging knowledge of the epigenome and modelling of dietary effects on metabolism and development, including the biology of the GI tract, to develop predictive dietary approaches to minimize dysfunction and to optimize health.

Food microbiology and food safety

51. Microorganisms are crucially important in the harvesting, production and safety of foodstuffs. Microorganisms responsible for food production have long attracted research interests, particularly to develop more stable and more efficient strains for the dairy industry. With increasing emphasis on the reduction of preservatives in food and the environmental cost of large-scale refrigeration, spoilage of raw and processed foods may increasingly be an issue. There has been relatively little recent work on spoilage microorganisms other than those that cause problems in human health (e.g. toxin-producing or pathogenic microorganisms).

52. Although there has been a significant amount of research on the mechanisms of pathogenesis of food-borne pathogens, there has been less work on their detection and removal from the food chain. Although much of the work in hygienic manufacture is in the remit of EPSRC, biological methods for the detection and, especially, for the inactivation or early removal of pathogens from the food chain are within the purview of BBSRC.
53. The role of probiotics in altering the gut flora is a topic of increasing commercial and scientific interest. There is a role for BBSRC-funded research into the effects of probiotics and the interaction of food with the gut microflora.

Tools and technologies for food research

54. The EU expert workshop "Enabling Technologies for Nutrition Research" in September 2006 identified the engagement of individuals from the high technology disciplines and cutting edge life sciences as being important to the future of nutrition research. Such engagement would include simulation of human metabolism and the prediction of individual nutritional need, technologies (including nanotechnologies) for targeted delivery of bioactive components, new methods for chemical sensing of metabolites, and non-invasive imaging for visualisation of nutritional status and of cellular and tissue responses to particular foods or food components. There is significant opportunity for new methods from other disciplines to contribute to food research.

Training

55. As indicated above, food research requires skills from a range of disciplines. While it is appropriate that students and postdoctoral research workers train within a specific discipline, which could be outside food research, optimal multidisciplinary interactions occur when individuals have an understanding and knowledge of the disciplines in which they are not expert but with which their work interacts. This would be best achieved by training students and research staff within a food research environment.
56. The opportunities for food research to benefit from the new technologies are significant, but will only occur if experts in these technologies are developed from within the food research community or if such experts move in from outside. Food researchers need to take advantage of discipline-hopping schemes and other opportunities to bring the new techniques to their laboratories.

NEXT STEPS

57. Following consideration by BBSRC Council and Strategy Board and further consideration by the Strategy Panels, the strategy has been updated and published on the BBSRC web site. It will inform the future priorities of the relevant grant committees.
58. Comments from stakeholders, researchers and other interested parties are welcome. They should be sent to food.strategy@bbsrc.ac.uk

Science and Technology Group
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