FUTURE DIRECTIONS IN RESEARCH RELATING TO FOOD SECURITY

A CONSULTATION BY THE BIOTECHNOLOGY AND BIOLOGICAL SCIENCES RESEARCH COUNCIL (BBSRC[1]) ON BEHALF OF THE RESEARCH COUNCILS[2]

We invite you to submit your views on the future priorities for research relating to food security[3].

This consultation seeks views on research relating to the production, supply and consumption of food both for UK needs and more widely in an international context of global food security. **We have identified topics that could form priorities for future research and potential barriers to delivery, and are seeking views from interested bodies and individuals on these and on related aspects of food security**. Taking into account the responses to this consultation, we aim to develop a 'road map' to set out the research that will be needed to address the challenges of ensuring future food security, including both long-term research and work with more immediate impact. Research could be supported by the Research Councils, by other public or private sector research funders in the UK or through cooperation with other bodies overseas.

Responses from all interested parties are welcome. We encourage academic departments, institutions and other bodies to submit single coordinated responses. Please state whether you are responding as an individual or on behalf of an organisation; if the latter, please provide brief summary information or web link about the organisation you represent.

Please note that BBSRC may publish responses, or a summary, and that information provided in response to this consultation will be dealt with in accordance with the access to information regimes[4].

Responses should be sent to arrive by close of business on **17 July 2009**; earlier responses would be appreciated. Responses by email are preferred: please send to foodsecurity@bbsrc.ac.uk.

For enquiries about the consultation[5], to submit responses by post or to request printed copies of this consultation document, please contact:

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[1] The Biotechnology and Biological Sciences Research Council (BBSRC) is one of seven research councils sponsored through the UK Government's Department for Innovation, Universities and Skills. The Council's mission is to fund internationally competitive research, to provide training in the biosciences, to encourage opportunities for knowledge transfer and innovation and to engage the public and other stakeholders in dialogue on issues of scientific interest. See www.bbsrc.ac.uk/science for further information.

[2] The Research Councils work together through RCUK – see www.rcuk.ac.uk for further information.

[3] For a definition of food security, see paragraph 3.

[4] These are primarily the Freedom of Information Act (2000), the Data Protection Act (1998) and the Environmental Information Regulations (2004).

[5] This consultation is being conducted as far as practicable in accordance with the guidelines for BBSRC consultations, available at www.bbsrc.ac.uk/organisation/policies/reviews/consultations.

SUMMARY OF CONSULTATION QUESTIONS

Please see the later sections of this consultation document for the context and discussion around these questions. Please address as many questions as you wish. Please keep answers as concise as possible.

Q1. Are the challenges outlined in paragraphs 8 to 20 the most important drivers and wider considerations as the background to food security? What other considerations or drivers should be taken into account?

Q2. What, if any, additional overarching issues need to be taken into account when formulating priorities for research relating to food security?

Q3. Please comment on the research targets for crop production – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Q4. Please comment on the research targets for livestock and fish production – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Q5. Please comment on the research targets for agricultural practice – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Q6. Please comment on the research targets for food safety – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Q7. Please comment on the research targets for nutrition, food quality, processing and manufacture – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Q8. Overall priorities for research
Considering all the research targets outlined:
(a) Which should be the most important overall priorities?
(b) What (if any) additional research targets would make a real difference?
(c) Does the UK have sufficient facilities/ infrastructure to deliver the research, and if not, what are the additional needs? (for example, see para 35 and 38)
(d) In which topics could UK research make the greatest impact in improving food security for developing countries?

Q9. Knowledge transfer
(a) How should the translation of research into practical application for food security be best supported? (you may wish to consider separately the needs of the UK and those of developing countries)
(b) What new funding mechanisms for knowledge transfer and translational research would be beneficial?
(c) How can relevant industries be encouraged to invest more in R&D?

Q10. Training, skills and career paths

(a) What important areas of expertise and what levels of skills related to food security are in short supply (please provide evidence if possible), what are the causes of the shortages and how best should these needs be met?

(b) What areas are most urgent to address, and on what basis should investment in training and skills be prioritised?

Q11. Coordination across funders

(a) How should coordination of research related to food security be improved (in the UK and internationally)?

(b) What overseas models for funding and coordination should the UK consider adopting?

(c) What will be the most important opportunities to maximise the effectiveness of UK research spending through coordination with activities overseas?

Q12. Regulatory framework

In what ways does the regulatory framework in relation to food production and supply present barriers to improving food security, and how best might any such barriers be overcome?

Q13. Public engagement

How can we best capture the views, aspirations and concerns of stakeholders, including different interest groups across society, and ensure that these contribute to developing a food security strategy?

Q14. What additional barriers (beyond those outlined) may prevent the successful implementation of a strategy for research to improve food security, and how might such additional barriers be overcome?

Q15. Please provide any further comments on any issues that are relevant to this consultation.

FUTURE DIRECTIONS IN RESEARCH RELATING TO FOOD SECURITY: TOWARDS A ROAD MAP FOR FUTURE RESEARCH FOR A SECURE AND SUSTAINABLE FOOD SUPPLY

A CONSULTATION BY BBSRC ON BEHALF OF THE RESEARCH COUNCILS

MAIN MESSAGES

- Global demand for food is expected to increase by 50% by 2030 and to double by 2050. Supply and effective distribution must increase sustainably to meet this demand, while minimising negative environmental impacts and enhancing the provision of ecosystem services. Research will be essential for meeting the challenges.
- Food security is a wide-ranging issue that is not simply about food production or national self-sufficiency: it is global in scope, and made more complicated by climate change. Social, political and economic factors are important and funders must work together to address such wider research needs.
- The Research Councils support research and training in a wide range of disciplines underpinning food security, with major strengths and capability in UK universities and research institutes. The Councils have identified food security as one of the main strategic priorities for future funding.
- Food security presents long-term challenges; meeting these will involve multiple research funders, including the Research Councils, Defra, devolved administrations, FSA and DfID, and will require effective collaboration between public and the private sectors. Coordination across funders and providers in the UK and internationally needs to be improved.
- Translation of research into commercial practice will be critical, as will the creation of effective partnerships to enable exchange of knowledge and development of skills in the uptake of new scientific findings, and the provision of the necessary infrastructure for research.
- To respond successfully to the food security challenges of 2030 and beyond we need to invest now in significantly increasing the UK's research effort and in meeting current and future skills needs, otherwise it will be too late.
- An urgent and sustained increase in investment is needed to address the above challenges by exploiting and extending the capacity of the UK's world-leading strengths. This will require long-term programmes in research and training, underpinned by investment in agricultural research infrastructure that has been eroded over the past 20 years in universities and institutes.
- Research will need to focus on applying the latest science to increasing crop and animal productivity globally while minimising negative environmental impact (including reducing greenhouse gas emissions and improving the efficient use of water, energy and other inputs), reducing losses from pests and diseases, enhancing food safety and quality for improved nutrition, and reducing waste throughout the food supply chain. Research will also be needed on issues around land tenure, food markets, supply and distribution, regulation, consumption, and affordability.
- This consultation seeks views on potential research priorities relevant to food security, and on barriers to the effective delivery of research and its translation into practice.

INTRODUCTION

1. This consultation is intended to help develop a strategy for research supported by key funding partners in relation to food security: it will lead to a 'road map' for future research needs. Global food security is a long-term research challenge over the coming decades; the road map will focus initially on the next 5-10 years and we envisage that it will be updated as progress is made and opportunities arise. The world faces major challenges in needing to feed a growing population in the context of global environmental change. The supply and effective distribution of food must increase, and such increases will need to be sustainable. The negative environmental impacts of food production and consumption need to be controlled and minimised (including greenhouse gas emissions, use of water, energy and other inputs, and conversion of forests and the other habitats to agriculture), while enhancing the delivery of ecosystem services from agricultural land (including carbon sequestration, water management and creation of suitable conditions for the conservation of biodiversity).

2. BBSRC and the other Research Councils have identified food security as one of their main priorities over the coming years. Building on current strengths, and working with other research funders, there is a significant opportunity for the UK to be a world leader in this area but a step-change in investment and coordination of the main funders is required if we are to make a real difference by 2030.

BACKGROUND AND DRIVERS

Definitions and scope

3. Food security is broad in scope and is not straightforward to define or measure. The FAO has stated[6]: "*Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life*." In an analysis in 2006, Defra compiled other definitions[7], and identified common themes that need to be satisfied for food security to be achieved. These were:

   - **Availability** – including the volume of food, as well as reliability of its production and issues of provenance and diversity
   - **Access** – including transport and food distribution systems
   - **Affordability** – especially relevant in developing countries, but of increasing concern worldwide when food prices rise
   - **Nutrition and quality** – the composition of food, but with links to affordability
   - **Safety** – "In rich countries, people are more likely to die of food poisoning than of starvation."
   - **Resilience** – the ability of food systems to withstand disruptions
   - **Confidence** by consumers and the media, and avoiding 'food scares'

4. Thus food security is not simply about agricultural productivity, nor national self-sufficiency. It also entails ensuring that food that is safe and of appropriate nutritional and physical quality is available and accessible to people in the right places at the right times. The long-term food challenges will not be solved by technology alone, but will also require better understanding of relevant political, economic, social and cultural

[6] FAO (1996) *Rome Declaration on World Food Security and World Food Summit Plan of Action*. World Food Summit 1996, Rome.
[7] *Food Security and the UK: An Evidence and Analysis Paper* (Defra, 2006) - definitions in Annex B of the paper

contexts. Collaborative inter-disciplinary research programmes are needed to address wider issues including, for example, global trade, regulation, food supply chains, packaging and transport, and other social and economic aspects such as cultural and behavioural factors affecting food supply, choice, consumption and waste.

5. Further background and analysis of food security issues can be found in the Cabinet Office report *Food Matters*[8] (2008) and a Defra analysis paper[9] (2008).

6. BBSRC, the other Research Councils and funding partners will work together to deliver an overarching programme in food security research, knowledge transfer and translation into practical application. The main focus for BBSRC research (given its scientific remit) will be on agriculture and food, encompassing the production of crops and animals (farmed animals, aquaculture and fisheries) and tackling pests and diseases within sustainable systems of land and natural resource management, as well as biological aspects of food processing and manufacture, food safety and quality and the interactions of diet and health. ESRC research will focus on issues such as international markets and supply chains, reducing waste and increasing efficiency, consumer behaviour and confidence, poverty reduction and sustainable development. It is anticipated that the NERC focus will be around the environmental aspects of food security. Other funders will address topics within their respective research areas, and all will need to work together to facilitate research across the boundaries of their remits.

7. Research on food security has interfaces with existing cross-Research Council multidisciplinary programmes[10], notably Living with Environmental Change, Energy, Global Uncertainties, and Ageing: lifelong health and wellbeing, as well as with the priorities of relevant government departments and activities by the Office for Strategic Co-ordination of Health Research (OSCHR). The aim will be to complement rather than duplicate existing activity. (See also the later section and consultation question on coordination across research funders.)

Demographic and environmental change

8. Demand for food is increasing because of population growth, urbanisation and increasing affluence in the parts of the developing world. The world's population is projected to increase from 6 billion to 9 billion by 2050, including an expected doubling of the population of Africa from 1 billion to 2 billion. For the first time, more people are living in cities than in rural areas, and economic growth and increasing wealth are leading to greater demand for food, especially in Asia, and particularly for animal products in countries where diets have been traditionally vegetarian. Overall demand for food is expected[11] to increase by 50% by 2030 and by 100% by 2050.

9. Climate and other environmental changes driven by increasing human populations and economic development pose fundamental challenges for humankind. While demand for food is rising, the area of land suitable for food production is liable to decrease (through pressures from other uses) and in any case cannot currently be increased substantially without undesirable environmental impacts that would result in the loss of wildlife habitats and biodiversity, and exacerbate climate change by releasing carbon currently sequestered in forests and in soils under uncultivated land. In some countries, there is also growing competition for the available agricultural land from biofuel production, as well as increasing use of arable crops for animal feed. In

[8] *Food Matters* (Cabinet Office, 2008)
[9] *Ensuring the UK's Food Security in a Changing World* (Defra, 2008)
[10] Cross-Council programmes: see http://www.rcuk.ac.uk/research/ccprog/default.htm
[11] FAO, summit on World Food Security, Rome 2008

addition, farming currently accounts, often wastefully, for 70% of the world's use of fresh water that is abstracted globally for human use, but future population growth and urbanisation are likely to make more pressing demands than agriculture on water supplies that are increasingly limited in some regions. This competition for natural resources can in turn exacerbate local and regional instability: water security can be expected to rank alongside energy and food security among leading challenges for the future.

10. Global climate change can be expected to threaten food production and its supply, for example through changing patterns of rainfall, increasing incidence of extreme weather and changing distribution of diseases and their vectors. Fisheries are also potentially at risk from climate change through ocean acidification (as well as from over-fishing). Global stocks of some staple foods have declined (partly as a result of policies to reduce 'food mountains'), and spikes in food prices (such as those seen during 2008) may become more frequent if rising demand cannot be consistently matched by supply.

11. The Green Revolution of the 1960s introduced new technologies and advances in crop improvement that transformed agricultural productivity in parts of Central America and Asia, but much less successfully in Africa. The government Chief Scientific Adviser, Professor John Beddington, has commented that to meet the rising demand for food: "*What we need is a new and greener revolution, like the one we saw in the developing world in the 1960s, but which tackles both food security and climate change*". This new "greener" revolution must reconcile increased agricultural productivity with environmental sustainability, in order to maintain food production in balance with other vital ecosystem services. Compromises will be needed in efforts to meet potentially conflicting requirements of productivity and environmental goals.

12. Environmental change will offer **new opportunities** (as well as threats to production), for example by extending the geographic range for some crops. Temperate regions including the UK have the potential for playing a more important role in global agricultural production, with the benefit of fertile soils and more moderate predicted climate than some other regions that are currently major food producers. Europe could potentially increase its exports of food.

Other challenges in relation to food security

13. **Environmental impact**: food production and the supply chain can have wide-ranging positive and negative impacts on the environment. Negative impacts include escalating water and land use, soil erosion and degradation through loss of fertility or desertification, loss of biodiversity, and intensive use of energy (for production, notably for fertiliser manufacture, and for supply, especially in transport and refrigeration) with associated greenhouse gas emissions. By contrast, agricultural land can manage water quality and flood risks and act as habitats for wildlife, while agricultural soils are major carbon sinks. The challenge is to enhance both food production and environmental benefits while minimising environmental harm. Negative environmental impacts will need to be minimised, particularly as the demand for food rises and the climate changes.

14. **Pests and diseases** present further challenges to the production and supply of food – from crops and from farmed animals and aquaculture. Threats include new and emerging pests and diseases, and the spread of existing ones to new regions because of climate change. Increased use of chemical inputs to address these problems will be limited by regulatory requirements, the need to avoid potential adverse environmental impacts, and the greater costs of producing fertilisers and pesticides because of rising

energy prices. Exploitation of natural resistance to pests and diseases, and tolerance of environmental stresses, will be important for sustainably increasing yields or for expanding the area that can be used for agricultural production under adverse or variable conditions.

15. **Efficiency of resource use:** while land and water in particular will become increasingly scarce, it will also be important to improve the efficiency with which other resources are utilised, including nitrogen, energy and other inputs to agriculture and all stages of the food supply chain.

16. **Reducing waste** is a major challenge: at the same time as enhancing yields and improving efficiency, there is a pressing need to find new ways of reducing waste throughout the food supply chain. Post-harvest losses are estimated to be currently 40% worldwide, with waste occurring in storage, during transportation and processing, from the retail sector and by consumers.

17. **Nutrition and its health impacts** are an increasingly important challenge, in terms of providing adequate diets for the developing world, and also to tackle the epidemic of obesity and diet-related illnesses, particularly in more developed countries. Current trends of increasing obesity must be stemmed, and diets in the UK and other western countries improved (in terms of appropriate intake of calories, fats, sugar and salt, and increasing the consumption of fruit and vegetables) if we are to avoid an ever-increasing burden on the health services. Cultural, economic and social pressures determining food choices are an important component of these complex problems, in addition to psychological factors underlying diets and biological responses to food.

18. **Food safety** remains a concern: despite the progress made in recent years in reducing the incidence of food poisoning in the UK, there are still an estimated 765,000 cases each year[12], at huge cost to the health service and the economy in general. Climate change may present increased future threats to food safety through rising temperatures, drives to reduce the huge use of energy in refrigeration, and from potentially new sources of food-borne illnesses.

19. **Supply chain efficiencies**: more effective and equitable means of distributing food are required to address food security. However, increasing distances between where food is produced, processed, packaged, sold and consumed increases energy usage, waste and greenhouse gas emissions. Better understanding is needed of supply chain factors, dynamics and interdependencies in order to increase overall supply.

20. **Economic challenges** include those related to international trade, aid for developing countries in support of their agriculture, and the need to improve the infrastructure of food supply in many parts of the world; instability of food supply and trade, leading to price fluctuations; and rising energy prices and potential energy insecurity (given the intimate dependence of food production and supply on energy input). As well as these global dimensions it is important to recognise that the food supply chain represents a major component of the UK economy, creating wealth and providing employment across diverse sectors from farms and their suppliers to supermarkets and the catering sector. Maintaining the competitiveness and vigour of the UK agriculture and food supply industries presents numerous challenges.

Q1. Are the challenges outlined in paragraphs 8 to 20 the most important drivers and wider considerations as the background to food security? What other considerations or drivers should be taken into account?

[12] *Annual Report of the Chief Scientist 2007/08* (Food Standards Agency, 2008)

Meeting the challenges – the need for research

21. The challenge of food security is, in short, to produce and supply sufficient food that is safe and nutritious for the growing world population, but using the same or less land, water and other inputs (such as fertilisers and pesticides) and without increasing emissions of damaging greenhouse gases or other adverse environmental impacts. New science will be crucial to address the many complex issues surrounding future food security, both nationally and globally.

22. The UK has an excellent research base in basic and strategic biological (including biotechnology) and environmental science underpinning agriculture, fisheries and food, and in other relevant topics such as process engineering, as well as economic and social research. Major facilities and centres of expertise at research council institutes are key parts of the national capability, as are strengths in the university sector. We need to bring the nation's scientific resources to bear on issues related to food security, for the benefit of the UK and internationally.

RESEARCH PRIORITIES FOR FOOD SECURITY

23. The following research targets have been compiled taking into account discussions at a BBSRC-led workshop on food security held on 19 February 2009 in London, attended by over 50 delegates drawn from universities, research institutes, relevant industrial sectors, research councils and government. The topics range from those with a particular UK focus to wider issues of European or global relevance, and with timescales from short (with potential impact within a few years) to much longer (likely to require sustained research effort over many years).

24. For each section, we would welcome views on the research targets and especially on **which should be the top priorities** for action (consultation questions follow within each section). An indication of the **time scale** within which your top priorities might realistically be achieved would be welcome. You may wish to indicate short, medium and long-term priorities.

25. The targets as currently set out are largely bioscience-focused (reflecting their origins in a BBSRC-led workshop); as well as comments on these, we would welcome suggestions for important aspects that should be added when considering the wider context of other relevant research disciplines and at the interfaces of bioscience with other topics. These suggestions will help to frame a proposed multidisciplinary and cross-funder research programme.

Overarching issues

26. Integrated and systems-based approaches are needed to develop coherent research strategies and joined-up policies for addressing the many important and interrelated problems in a holistic (rather than fragmented) way. It is important to be clear about the desired outcomes and related questions, with reference to end-user needs and societal views in order to decide and prioritise research targets (taking into account input that is independent of researchers). Economic, social and political considerations need to be integrated into scientific and technological challenges from the outset.

27. It is important to recognise that both synergies and conflicts may be found between different requirements (e.g. food production and environmental considerations). Where requirements prove to be in conflict, these should be explored fully to achieve an optimal balance.

28. The UK should decide which research topics it can best address for maximum impact and should focus on those. We should take account of, but avoid attempting to compete with, major programmes overseas. A focus on a small number of objectives that are readily articulated can be helpful in communicating with a wider audience.

29. Research needs to be effectively coordinated across different funders and (where appropriate) internationally – see also the section on coordination.

30. Effective translation of research into practical applications will be critical – see separate section later. Clear links and partnerships between public and private sectors are essential at both national and international level.

31. There is a need to instil a sense of urgency among policy makers but also among the research community, given the long lead-time for some research (for example, development of new crop varieties can typically take around 10 years). To meet the scale and pace of the rising demand for food, major programmes of focused research must be put in place without delay.

Q2. What, if any, additional overarching issues need to be taken into account when formulating priorities for research relating to food security?

Crop production

32. Research will be needed on crops for the UK and other temperate regions and also for the developing world. The main target crops for the UK would include wheat and other small grained cereals, oilseed rape, potatoes, horticultural and other 'minor' crops, forage crops and pasture. Research targets include:

    a. Enhancing crop productivity with optimised efficiency of resource use (water, nitrogen, other nutrients); reducing reliance on fertilisers that are derived largely from fossil fuels; making more efficient use of chemical inputs through precision application and controlled release.
    b. Major scientific challenges such as raising photosynthetic efficiency through engineering C4 metabolism, and introducing nitrogen fixation to cereals or other non-legume crops.
    c. Enhancing resistance to pests and diseases, and research on weed control. Advances will require improved knowledge of the biology and genetics of the host and pathogen or pest and (importantly) their interactions. Technologies will include new biological control, genetic approaches (both conventional breeding and genetic modification) and novel chemical treatments. Breeding should ideally anticipate future problems (e.g., to pre-empt the emergence of new insect pests that may spread with climate change).
    d. Research to sustain effective use of herbicides, insecticides, and fungicides in the face of evolution towards resistance. This will require work on molecular mechanisms as well as at the population level, and the exploitation of genomics for the identification of novel targets for the control of weeds, pathogens and invertebrate pests.
    e. Enhancing tolerance of abiotic stresses (e.g., drought, salinity, flooding, ozone, UV, high and low extremes of temperature, especially at critical stages such as flowering); research is needed especially on the effects of combinations of such stresses.
    f. Reducing post-harvest losses from pests and diseases.
    g. Exploiting the potential of genomics (of model plants, crops, microbes, pathogens, pests, beneficial organisms) – the pace is accelerating with

advances in sequencing technologies. Effective management and sharing of genomic (and other "omic") data will become increasingly important, enabling data mining, novel analyses and integration of different types of biological information, leading to improved ability to select genotypes efficiently.

h. Mathematical and computational approaches – leading to improved ability to predict outcomes and provide tools for decision-making in managing agricultural systems. Modelling of production systems to reduce inputs and greenhouse gas emissions and maximise outputs; development of practical management tools based on predictive models. Mathematical modelling will be important for disease epidemiology.
i. Making best use of genetic diversity: to develop new cultivars of current crops and to explore the potential of new crops for adapting to the predicted climate, including rising carbon dioxide and temperature. For example, with warmer summers, grain maize may become feasible as a crop more widely in the UK. But varieties need to be bred for regional conditions and cannot necessarily transfer readily between countries (e.g., wheat varieties are sensitive to day length and are therefore adapted to particular latitudes).
j. Improved understanding of polyploidy could give significant advances. Biomarkers for traits such as taste, texture and nutritional content would accelerate crop breeding.
k. Making more effective the transfer of knowledge from advances gained using model species into practical application in crops.
l. Improving energy efficiency in horticulture (for heat and light, also water use).
m. Enhancing nutritional composition (e.g., enhanced vitamin and mineral content in cereals).
n. Research on bees and other beneficial insects with roles in pollination or biological control – especially to address threats from diseases.
o. Soil science/microbiology and root-soil interactions, including how to improve nutrient flows to support plant growth; also root diseases. Phosphorus can be limiting: there are opportunities in rhizosphere research.
p. Shortages are reported in the availability of specialist research expertise in areas such as agronomy, plant physiology, pathology and general botany, plant-soil interactions, weed science and entomology /pest biology. There is a pressing need to train and recruit the next generation of researchers, and succession problems are evident already (see also later section on training and skills).
q. Bioenergy crops, while not directly a food issue, are an important consideration as they can impact on food production through competition for land, water and other resources, and can indirectly affect prices of food crops. There is potential for increased use as energy sources of co-products from food crops, and harvesting from woodland.
r. Regulatory issues include those surrounding genetic modification and the use of agri-chemicals (including regulatory changes further restricting the use of some that are currently widely used).

33. Please see also later sections for more on issues of knowledge transfer, training and skills, coordination, regulation and public engagement.

Q3. Please comment on the research targets for crop production – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Livestock and fish production

34. There are arguments on health and environmental grounds to reduce overall meat consumption in the western diet, but global demand for meat and dairy products is predicted to increase greatly. Research targets include:

    a. Identifying possible changes in processes that would help to reduce adverse impacts on the environment e.g. reducing greenhouse gas (methane, nitrous oxide) emissions from livestock and manures – using nutritional and genetic approaches to improve efficiency of production (conversion of plant biomass to meat) and to reduce waste. We need better knowledge of the gut, especially rumen biology.
    b. Managing the threat from and impact of animal diseases, including both current and newly emerging or exotic diseases, and spread of disease from and to wild animals. Risks from animal diseases are increasing with climate change and increased movement of animals and people. Disease avoidance and mitigation should be starting points.
    c. New zoonotic diseases are a particular threat, and horizon scanning for potential new diseases is needed, involving international co-operation.
    d. Detection and treatment of sub-clinical diseases that can have major impact on productivity and welfare.
    e. Integrated approaches to reducing disease through genetic selection for immunity combined with vaccine development (where there may be opportunities for international sharing of effort), epidemiology and improved knowledge of host-pathogen interactions.
    f. Methods to distinguish animals that have been vaccinated against disease from those that are infected with or have been exposed to the disease; also sensitive diagnostics to allow earlier detection of disease.
    g. Mathematical modelling will be important to enable prediction of disease outbreaks and to optimise interventions (e.g. vaccination, restrictions on movement).
    h. Ensuring animal welfare under future climates (e.g., increasingly variable and extreme weather) and/or altered production methods: research needs include developing objective measures of well-being in animals.
    i. Animal breeding for improved yield and quality – including fish breeding (relatively under-developed at present). Breeding and knowledge transfer is efficient in the poultry sector (less so for others) but there may be risks from a narrow genetic base.
    j. Lower-intensity livestock farming in economically marginal areas underpins some of the most important landscapes and ecosystems from a biodiversity perspective across Europe (referred to as High Nature Value farming systems). Research is needed on such farming systems and on social, economic and cultural aspects such as the public's desire for landscapes based on livestock farming (especially dairy and sheep). A framework is needed for placing value on such considerations and on adverse environmental impacts (e.g., greenhouse gas emissions) – as distinct from costs of production.
    k. Tackling the loss of UK upland grazing land through ingress by bracken.
    l. Aquaculture is expected to increase in importance as a source of protein (in both temperate and tropical regions), but research is needed to increase the diversity of species that are farmed, and to devise alternative sources of fish meal (to avoid feeding wild-caught to farmed fish) – alternatives could include

plant-derived fish oils, and marine algae. There is also potential for ranching fish in larger areas in the deep oceans.

m. Exploring more diverse sources of animal protein, especially fish but also other species. Cultural traditions and consumer taste preferences will need to be tackled.
n. Research is needed on the regulation and governance of fish and livestock production.
o. Shortages in areas of specialist expertise are reported, including ruminant nutritionists and veterinary pathologists (see also later section on training and skills).

35. The availability in the UK of research facilities for large animals (and especially for animal diseases) is of great concern. There is a need to develop a sustainable infrastructure that enables research on pathogens and their hosts and provides the necessary protection against the threat of serious disease outbreaks – the UK needs facilities and research to support prevention, surveillance, diagnosis and treatment of animal diseases. A recent report[13] has identified facilities that are strategically important resources underpinning the delivery of land-based research in the UK.

36. Please see also later sections for more on issues of knowledge transfer, training and skills, coordination, regulation and public engagement.

Q4. Please comment on the research targets for livestock and fish production – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Agricultural practice

37. In conjunction with research on crop and livestock production, there is a need for developing improved land management and other agricultural practices that enhance productivity while minimising adverse environmental impacts and optimise the provision of ecosystem services. Research targets include:

a. Practices that enhance the conservation of biodiversity in agricultural and associated ecosystems
b. Practices for maintaining the structure and fertility of soils, avoiding erosion and compaction
c. Making most efficient use of water, energy and chemical inputs (e.g. precision farming technologies, integrated crop management)
d. Bringing into cultivation more land that is currently marginal in terms of the viability of agricultural production, while minimising detrimental effects on biodiversity
e. Improving farming practices in developing countries to reduce damage to ecosystems
f. Delivery of ecosystem services, such as carbon sequestration and flood management from agricultural landscapes
g. Land management that balances local/national/global needs – practices must be adapted to local conditions
h. Impacts of changing climates, natural resource availability and energy costs on agri-food systems
i. Social and economic research on demographics of the farming community

[13] BBSRC/HEFCE study of land-based facilities and resources (May 2009)

j. Management of agricultural waste.

38. There is a need to sustain strategically important facilities and infrastructure for research on land management and agricultural practice, just as there is for animal research facilities (see also previous section – para 35 and reference[13]).

Q5. Please comment on the research targets for agricultural practice – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Food safety

39. Food security entails the provision of food that is safe for consumers. Research targets include:

    a. Maintaining microbiological food safety throughout the supply chain – entailing better understanding of the sources of infection (from the farm, during processing, and manufacture, in catering and the home), improved detection methods. In the UK, reduction of the incidence of *Campylobacter* infections is a particularly pressing need.
    b. Improving food safety in the catering sector and in the home; especially in times of financial constraint there may be a tendency to compromise on food safety, while changes in domestic practices (such as increasing use of ready meals) can have implications for food safety.
    c. Managing risks arising from climate change, e.g., from new food sources or production methods or altered practices through supply chains (reduced use of refrigeration, smaller scale decentralised manufacturing driven by transport costs)
    d. Re-evaluation of irradiation as a safety measure, and associated questions of regulation and consumer acceptability
    e. Developing active labelling and packaging; hybrid processing (e.g. vacuum/ microwave) offers potential to improve food safety and reduce waste
    f. Infection of crops with e.g. fungi/bacteria impacts on the supply chain and can have food safety consequences (e.g., fungal toxins)
    g. Improved understanding of food allergens in order to predict and reduce their incidence
    h. Developing better ways to predict when food is safe to consume
    i. Food safety implications of using waste as an energy source
    j. Responding to likely increases in emerging pathogens e.g. *E. coli* O157; also viruses likely to be important e.g. SARS, avian flu
    k. Improving knowledge of opportunistic pathogens and impact arising from demographics (e.g. more older people susceptible to *Listeria*), and changes in food processing/manufacture.

40. Please see also later sections for more on issues of knowledge transfer, training and skills, coordination, regulation and public engagement.

Q6. Please comment on the research targets for food safety – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Nutrition, food quality, processing and manufacture

41. The provision of nutritious food in forms that are desirable to consumers is an essential component of an adequate and secure food supply: the food processing and manufacturing sectors play a central role in the supply chain. As well as the nutritional content of food, its physical structure is also important, along with its taste, in determining its attractiveness to consumers and the bioavailability of nutrients. Nutrition and the interactions of diet and health form a major research area, and also have important linkages with other research topics such as animal and crop breeding, where evidence from human intervention trials will inform and help to shape research programmes.

42. Research targets across the broad topics of nutrition, food quality, processing and manufacture include:

    a. Providing healthy diets from available food sources (in both developing and more developed countries).
    b. Tackling the causes of the obesity epidemic and associated ill-health: this will require nutrition research but also social and economic studies of consumer perceptions, attitudes and behaviour in determining food choices (see also points **l** and **m**, below).
    c. Increasing production will be necessary but not sufficient: “food into mouths” is an important measure. It will be necessary to achieve enhancements and improve efficiency throughout the supply chain, using life cycle analyses to identify where improvements will have most impact.
    d. Nutrition studies to understand the particular needs of certain populations and in the context of changing demographics, e.g. an increasingly ageing population may require or prefer different types of food. It is important to understand the scientific basis of what constitutes a healthy diet and the dietary causes of health inequalities across the population.
    e. Exploiting the potential of genomics, for example for studying gut biology including metagenomics of the gut microflora.
    f. Exploring the potential to use plants to supply nutrients to substitute for animal sources, e.g. producing omega fatty acids in plants, exploiting algae and novel plant sources, and understanding the implications for nutrition of novel foods including nutraceutical products.
    g. Research on how (e.g.) salt and fat can be reduced without negative impact on the desirability of the food to the consumer, or on food safety.
    h. Quality (taste, texture) is as important as quantity – in developing countries as well as in rich countries. New foods (e.g. new crop varieties) must have acceptable quality or they will not be adopted.
    i. Research to underpin new food processing, packaging and storage using less energy (e.g. without refrigeration), to reduce the adverse environmental impacts of food manufacturing.
    j. Reducing waste throughout the food supply chain – from farm to fork, including food production, processing, manufacture, retail, catering and in the home.
    k. New technology to enhance traceability of food through the entire supply chain, which is likely to increase in importance for consumers.
    l. Social and economic as well as biological research to understand consumer perceptions (e.g. of acceptable food quality such as the colour of meat, or desirable taste and texture) and the factors underlying patterns of consumption and waste. For instance, how do factors including the cost and palatability of foods influence preferences and choice; how we can encourage individuals to adjust to a lower amount of meat in their diet? Interactions of diet and lifestyle

need to be better understood: it is important that changes to the food supply chain do not encourage increased consumption.

m. Understanding and informing consumer behaviour is critical – more research is needed to understand the biological/ psychological processes of behaviour change and to better explore ways of influencing customer choices. Currently little scientific information influences the public; social drivers, family and culture, and marketing and advertising have more impact. There can be conflicting messages about food and what we should eat, and we need to find ways of conveying information more effectively to the consumer. There is a need to show that nutrition research underpins healthy eating and public health, and is not concerned only with the development of new products. A challenge for the policy community and retail sector is to persuade consumers of the need to move towards a lower energy food supply chain and to reduce waste.

n. Shortages of specialist research expertise are emerging and the research base has been eroded, with few UK academic labs currently active in food science or research and training related to food manufacture. Capacity needs to be rebuilt (see also section on training and skills, below).

43. Please see also later sections for more on issues of knowledge transfer, training and skills, coordination, regulation and public engagement.

Q7. Please comment on the research targets for nutrition, food quality, processing and manufacture – which are the most important and/or most urgent priorities, and what other important topics should be added (including wider social and economic considerations)? For the top priorities, please indicate time scales if possible.

Overall priorities for research

Q8. Considering all the research targets outlined:
(a) Which should be the most important overall priorities?
(b) What (if any) additional research targets would make a real difference?
(c) Does the UK have sufficient facilities/ infrastructure to deliver the research, and if not, what are the additional needs? (for example, see para 35 and 38)
(d) In which topics could UK research make the greatest impact in improving food security for developing countries?

BARRIERS TO DELIVERY

44. This section aims to outline some potential barriers to the effective delivery of research and its implementation and to seek solutions to overcome them.

Knowledge transfer and translational research

45. The translation of basic research through to application by the agriculture and food industries, policy makers and non-governmental organisations will be critical: the flow of knowledge needs to be improved. Innovation and effective two-way flow of information is needed at all stages and among all relevant partners. The Research Councils and other funders have in place a range of schemes to promote knowledge transfer and to engage with industry, policy makers and other end-users. But additional activity will be needed and possible new funding mechanisms to encourage such interactions should be explored. It will also be important to find new ways to build effective partnerships with sectors such as retail and with the diverse range of organisations working in the developing world.

46. A key issue for the agricultural sector is the need for improved mechanisms and funding for applied research to translate underpinning science into farming practice. Furthermore some type of (public) extension service (as previously provided by ADAS) is needed. Similar issues exist in other countries.

47. Plans by the Technology Strategy Board (TSB) to establish activity in the broad area of sustainable agriculture and food supply may offer new routes to translation. The Research Councils and other funders will need to work with TSB to ensure that opportunities are fully explored.

48. It is important to address intellectual property (IP) issues – companies need to cooperate on pre-competitive research (through "open innovation"). It can be difficult to gain IP in the agri-food sector, except on plant varieties or new processes. Hence the food industry tends to do relatively little research and is also highly fragmented – this is markedly different from sectors such as pharmaceuticals or aerospace. Alternative (public) sources of research funding are needed, coupled with public-private partnerships. Innovation is especially important in applied research, linking basic research to introduction into practice.

49. In relation to crop breeding, major research expenditure over long time scales may be required, for relatively low returns. Mechanisms are needed to promote the generation of new (pre-competitive) germplasm in the public sector that can be taken forward into commercial breeding programmes. Initiatives such as Crop Genetic Improvement Networks can be useful to bring together public and private interests, but IP ownership needs to be clear and agreeable to all parties.

50. Translation of research into policy is a further important aspect of knowledge transfer. Key policy customers in government for research related to agriculture and food supply include DEFRA and the devolved governments, DECC, DfID, FSA and Department of Health. It will be important for the Research Councils to continue their close working with relevant government departments to ensure that translation of the outcomes of research into policy is as effective as possible (see also **Coordination**, below).

Q9(a) How should the translation of research into policy and practical application for food security be best supported? (You may wish to consider separately the needs of the UK and those of developing countries)
(b) What new funding mechanisms for knowledge transfer and translational research would be beneficial?
(c) How can relevant industries be encouraged to invest more in R&D?

Training, skills and career paths

51. An issue related to knowledge transfer is the shortage of specialist research expertise in topics (as outlined in earlier sections) such as agronomy, plant pathology and weed science, plant breeding, whole plant/animal physiology, veterinary pathology, entomology, mycology, plant virology and food science. In addition, skills in translation of research into practice appear to be lacking. Issues behind the emergence of vulnerability in the availability of such 'niche' areas of expertise of skills shortages are often complex (with problems of both supply and demand, and at various levels from school leavers to senior postdoctoral researchers) and can not be addressed solely by any single research funder. Training in modern technologies (such as genomics) tends to be aligned to biomedical topics rather than food-related areas. Employment opportunities in some areas of applied research in the commercial sector have reduced, and career paths or progression for high-skilled individuals are often unclear. Undergraduate courses and some whole departments in agriculture and food subjects

in UK universities have closed from lack of demand from students, and yet some employers report recruitment difficulties. Food science / nutrition are currently not classified as 'science, technology, engineering and mathematics' (STEM) subjects and therefore departments do not receive the same recognition. In other areas, the name changes of undergraduate degrees may make it difficult to know whether an area of training is in decline, or has simply been re-labelled to make it more attractive to prospective students.

52. There is a need to explore ways to encourage the uptake of subjects with identified shortages, which will need to be tackled through cooperation across research funders and training providers, including the universities, and in consultation with employers. Career paths and progression will also need to be addressed, together with steps to increase the employment opportunities in the private sector for applied scientists. We need to inspire a new generation of researchers to see topics relevant to food security as sufficiently important and rewarding to be attractive as a career.

Q10(a) What important areas of expertise and what levels of skills related to food security are in short supply (please provide evidence if possible), what are the causes of the shortages and how best should these needs be met?
(b) What areas are most urgent to address, and on what basis should investment in training and skills be prioritised?

Coordination across research funders

53. There are clear opportunities and a need to work across funders, both among the research councils and more widely with government departments and other stakeholders, including industry, but improved coordination is needed. The Government Chief Scientific Adviser, Professor John Beddington, is leading the development of a cross-government Food Research Partnership and research strategy, and it is anticipated that the road map that will result from this consultation will contribute to that wider process. As the major UK funder of agri-food related research, BBSRC plans to take a leading role in coordination across other funders, including building on existing relationships with other research councils, Defra and the devolved administrations, DfID, FSA and the Technology Strategy Board.

54. Activity must not be constrained to the UK, since many issues are international or global. In addition to working with DfID, there will be further opportunities for international coordination and potential joint funding, building on previous successes in joint activities with European agencies and more widely around the world, including private sector funding sources.

Q11(a) How should coordination of research related to food security be improved (in the UK and internationally)?
(b) What overseas models for funding and coordination should the UK consider adopting?
(c) What will be the most important opportunities to maximise the effectiveness of UK research spending through coordination with activities overseas?

Regulatory framework

55. Earlier sections have included reference to some regulatory issues. The regulatory framework for agriculture and food is increasingly international. For example, proposed changes to EU licensing of chemicals may mean that some pesticide and fungicide treatments that are currently widespread in the industry will no longer be allowed, without any obvious replacements being available. There may be

opportunities for biological approaches to fill such gaps, but these are likely to become viable only on a longer time scale than is needed. Furthermore, the regulatory framework for agrichemicals may not necessarily be suitable for assessing biological agents.

56. New regulatory issues that may arise in relation to food production and supply will need to be identified and taken into account at an early stage. In relation to genetic modification, issues arise because of the high weighting given in European regulations to the process rather than the trait or product itself.

57. Regulatory requirements differ around the world, and greater international cooperation and harmonisation would ease the introduction of new processes and products. Issues can arise from differences in national priorities and differing interpretation of international regulatory frameworks.

Q12. In what ways does the regulatory framework in relation to food production and supply present barriers to improving food security, and how best might any such barriers be overcome?

Public and other stakeholder engagement

58. Food security is of clear public and media interest, with actual or potential concerns over numerous issues such as good provenance, food quality, safety, animal welfare, the rural environment, wider environmental and international development agendas, and new technologies including genetic modification, nanotechnology applications in the food industry, and food irradiation. Early and on-going public dialogue is needed around the acceptability of solutions that could be offered by the application of new technologies in relation to the challenges surrounding food security.

59. The Research Councils actively pursue public engagement through a variety of mechanisms and incorporate expert advice on societal issues into their planning processes. But debate – and further research – around perceptions of risk and benefits would be valuable.

60. Genetic modification (GM) in particular remains a sensitive topic that needs to be tackled carefully. While it is not currently feasible to commercialise genetically modified crops in Europe, it is essential that research can be carried out, including field trials to evaluate the effectiveness of particular modifications and their environmental impact[14].

Q13. How can we best capture the views, aspirations and concerns of stakeholders, including different interest groups across society, and ensure that these contribute to developing a food security strategy?

Q14. What additional barriers (beyond those outlined) may prevent the successful implementation of a strategy for research to improve food security, and how might such additional barriers be overcome?

Q15. Please provide any further comments on any issues that are relevant to this consultation.

[14] BBSRC's position on GM research is set out at http://www.bbsrc.ac.uk/organisation/policies/position/public_interest/genetic_modification.pdf

ABBREVIATIONS

ADAS	Agricultural Development and Advisory Service
BBSRC	Biotechnology and Biological Sciences Research Council
DECC	Department for Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DfID	Department for International Development
ESRC	Economic and Social Research Council
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FSA	Food Standards Agency
GM	genetic modification
IP	intellectual property
KT	knowledge transfer
MRC	Medical Research Council
NERC	Natural Environment Research Council
OSCHR	Office for Strategic Co-ordination of Health Research
STEM	science, technology, engineering and mathematics
TSB	Technology Strategy Board