

<p>Institution: University of Reading</p>
<p>Unit of Assessment: 6 Agriculture, Veterinary and Food Science</p>
<p>a. Overview</p> <p>Reading's long-standing, international reputation for agri-food research derives from sustained commitment to the research area by the University. Our reputation is for integrative, interdisciplinary research across the whole food chain; to understand how interventions can be optimised to sustain and improve the provision of safe, healthy and nutritious food for consumers. Staff in this UoA are from the School of Agriculture Policy and Development (APD) and the Department of Food and Nutritional Sciences (FNS); with particular, closely allied staff from the School of Biological Sciences. In their host Schools, staff are managed in Research Divisions that underpin our interdisciplinary research, and which constitute this submission. In APD these are: i) Biodiversity, crops and agro-ecosystems; ii) Food production and quality; and iii) Economic and social sciences. In FNS they are: i) Food and bioprocessing science; ii) Food microbial sciences; and iii) Human nutrition.</p> <p>During the present REF period, the University has strengthened its interdisciplinary science research through the creation of four strategic research Centres of Excellence (CoE) reporting directly to the Pro-Vice-Chancellor (PVC, Research and Innovation). One of these is the Centre for Food Security (CFS) which provides co-ordination for the work of this submitting unit. Delivery of CFS strategy is organised through three overlapping themes: i) Food chain and health, ii) Biodiversity and agro-ecosystems, and iii) Sustainable food production systems. These three themes overlay the school divisional structure to create strong multi-disciplinary teams in response to the needs of industry, policy makers, and society. As well as an overall Director, deputy directors have been appointed to each CFS theme and they are responsible for overseeing the objectives and promotion of their themes within and beyond the University. These appointments provide leadership experience and a basis for succession planning in the next REF period.</p>
<p>b. Research strategy</p> <p>The research strategy is to address specific societal challenges through the themes of CFS. The CFS platform facilitates greater understanding of the interaction between different components of the food supply system to deliver improvements in the agri-environment, productivity, surety of provision and human health. Foci for the strategy are developed by an annual Research Planning Process (RPP), led by the Pro-Vice Chancellor (Research and Innovation), to which plans from CFS and supporting schools are presented. CFS strategy is also informed by an External Advisory Group which adds wider context to the internal facing activities. Strategic investment (posts, studentships, and infrastructure) is directed by the CFS following the RPP. Strategy of the <i>Food Chain and Health</i> theme is to link work on agricultural processes targeted at improving product quality, with a greater understanding of consumer behaviour and human biology, to deliver health benefits for society through improved nutrition. The strategy of the <i>Biodiversity and the Agri-environment</i> theme is to link improved understanding of agro-ecology and rural environmental management to improve the ecosystem services for and from agricultural systems. <i>Sustainable Food Systems</i> links improved understanding of the whole of the food chain to increase efficiency and sustainability in terms of mitigation of environmental harm, adaptation to environmental change, and the avoidance of waste.</p> <p><i>Activities and plans of the Research Divisions in support of the CFS strategy:</i></p> <p>Biodiversity, Crops and Agro-ecosystems (BCA) comprises 37 post-doctoral scientists and academic research staff and contributes to all themes of CFS. Expertise includes crop eco-physiology, crop modelling, agronomy, horticulture, plant breeding and molecular genetics, seed science, plant pathology, entomology, ecology, population biology and biodiversity conservation. Our research enhances understanding of the interactions between climate change and food production through experimentation in modified environments, and the coupling of regional climate models, land surface models and crop production models (Wheeler). Novel empirical and genetic studies (with the John Innes Centre and Rothamsted Research) are characterising the benefits of within-field, crop and plant diversity for the resilience of production in the face of increasing weather variability (HE Jones, Lukac, Gooding). Assessment of climate change, its uncertainty, and impacts on crops is greatly facilitated by the involvement of the Walker Institute for Climate Systems Research (another of the University's CoEs), and collaboration with other UK universities (e.g. Leeds, Exeter, Southampton), and further afield (e.g. EMBRAPA, Brazil; Potsdam Inst. for Climate Impact Research; IRRI; CIMMYT).</p>

We provide better understanding of the factors influencing the quality and nutritional characteristics of crops at a range of levels, including genetic, environmental and production practices (Dunwell, Hadley, Tosi, Shewry). The interactions between genotype and environment in determining resource capture and use-efficiency are similarly explored from gene to field (Gooding, Gregory, Hammond).

We coordinate work across Europe with over twenty-five institutional partners to improve understanding of pollinator behaviour and survival to help maximise their utility for sustaining crop yield and quality, as well as wider environmental benefits (Potts, Roberts). Strong UK collaborators for much our pollinator work include University of Leeds (Prof Kunin), University of Bristol (Prof Memmott) and the Centre of Ecology and Hydrology (Dr Vanbergen). The importance of biodiversity for ecosystem service-delivery in agro-environments has been researched using trait-based approaches to examine potential responses to environmental change (Potts, Roberts, Mortimer). The understanding, quantification and utility of diversity continues to be studied at landscape, farming system and crop levels (Norris, Potts, Mortimer, HE Jones) with partners throughout the EU. Particular strengths at Reading are in the understanding of floral development (Battey, Ordidge), and in the phenotyping of flowering diversity (HE Jones, Lukac).

Advances are being made in the development of novel modelling approaches in risk assessment strategies relating to the spread of invasive diseases (Shaw). Greater precision in weed control is being developed with image-analysis systems of weed recognition and robotics (Murdoch).

Genetic conservation and exploitation is facilitated by the Division's management of the International Cocoa Quarantine (Hadley) facility, and the scientific management of the UK National Fruit Collection (Hadley, Battey, Dunwell). We are, for example, characterising genotypic and phenotypic traits for water stress tolerance in cocoa (Hadley, Daymond). The Royal Botanic Gardens, Kew, and IRRRI collaborate with our long-standing seed biology research (Ellis, Murdoch). There is increasing collaboration with East Malling Research (Battey, Gregory, Hadley, Shaw) on perennial crops, including the joint appointment of a research fellow to investigate the potential of novel crops to diversify UK fruit culture in the warming climate of southern England.

Specific targets for the next five years include:

- The study of resilience and adaptation of crop production to intensification and environmental change; in terms of tolerance, escape and diversity at molecular, genetic, plant, crop, crop-pathogen, crop-pollinator and cropping system levels. This priority builds upon many continuing and new projects in the area, for example, EC-FP7 Linking farmland biodiversity to ecosystem services for effective eco-functional intensification, £308K to Reading from 2013-2017.
- Extension of our phenotyping capability, with an increase in spatial and temporal resolution, particularly to support crop genotype-adaptation analysis and selection. This is currently the subject of significant bids to BBSRC and industry, and new posts (e.g. O'Sullivan).
- An expansion of activity in oilseed and protein crops, recognising significant gaps in the UK research base for these crops of strategic significance. This activity is being facilitated by the recent appointments of O'Sullivan and Hammond.
- Further work on vegetable and fruit crops supported by our responsibilities for the National Fruit Collection; and joint programmes and appointments with East Malling Research (EMR) as an Associated Institution of the University. Greater collaboration with EMR is the subject of a £3.5M bid to BBSRC for a 5 year Institute Strategic Programme Grant.

Food Production and Quality (FPQ) comprises 12 post-doctoral scientists and academic research staff and contributes to the *Food Chain and Health*, and *Sustainable Food Systems* themes. The division focusses on the impact of animal nutrition on production efficiency, climate change mitigation, and product quality as related to consumer health. Sustainability is addressed by improving feed conversion efficiencies to reduce nitrogen waste and greenhouse gas emissions from livestock. Research on consumer health concerns factors influencing lipid metabolism and cardiovascular disease, particularly as related to the composition of animal products. This latter work involves close collaboration with our Human Nutrition Division.

Research with the University Hospital of Wales (Cardiff) has led to better understanding of the role of dairy products in body mass index control and how this may be influenced by a person's genotype (Givens, Reynolds); and also of the chronic effect of dairy product intake and the lipids they provide on blood pressure and vascular stiffness, and which is now recognised to be an important independent and holistic marker of cardiovascular risk (Givens). We have continuing

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work to improve the poly-unsaturated fatty acid (PUFA) content of animal products for human consumption (Gibbs, Rymer).

Reading leads internationally important, collaborative research with Aberystwyth University, SRUC, and Rothamsted Research (North Wyke) on GHG emissions by ruminants (Reynolds, Humphries). Models have been developed to predict methane production as a function of nutrient supply to the gut, liver and mammary gland (Crompton, Mills). A new technique to assess amino acid uptake by the liver using isotope dilution has provided a better understanding of the factors that influence protein utilisation.

Specific targets for the next five years include:

- Further development of integrated approaches to understand the effects that milk lipids and milk protein have on vascular health, supported by a recent £783K MRC (2013-2016) grant for the sustainable replacement of saturated fatty acids in milk and milk products.
- Testing the hypothesis that milk proteins are linked to cognitive disorders such as autism. Cell line research has started with colleagues in FNS. The aim is to extend this to human studies and so increase links with the Institute for Cardiovascular & Metabolic Research (ICMR), another of the University's CoEs. The research will also extend to fat-soluble vitamins, particularly animal-derived foods as dietary sources of vitamin D.
- Development of integrated research aimed at reducing the use of human food ingredients (e.g. cereals) in the diets of food-producing ruminant animals by an increased focus on the role of forages and food chain by-products, and the effect of this on production efficiency and food composition.
- Further strengthening of our environmental animal nutrition research. A major grant (£1450K 2012-2017) from DEFRA will support studies on long term effects (e.g. whole herds over many lactations) of dietary management and genetics on animals' excretion of pollutants and productive responses.
- Further assessment of metabonomic approaches to identify characteristics of animals that could be markers of efficiency and thus be an aid to predicting pollutant output and provide targets for well-focused nutritional interventions.

Food and Bioprocessing Science (FBS) comprises 21 post-doctoral scientists and academic research staff dealing with the science of processing food for healthy human nutrition as part of the *Food Chain and Health* theme. The strategy is focussed on health attributes of food ingredients and products. Expertise in food processing allows us to develop and test the science from other divisions in real food products. Key collaborators are Hotchkiss and Cote (USDA, USA), Waldron (IFR, Norwich), Webb (Manchester University), and Sanz (Madrid).

Examples of our present research include developing a novel layer-by-layer coating approach to improve survival of probiotic microorganisms (provided by colleagues in the Food Microbial Sciences Division) in acidic media. Associated with this we have developed a novel method for visualizing pH changes within polymer matrices using confocal microscopy. Much of our work is collaborative with industry. Thus, industrially funded research (Nestlé) has established underpinning scientific links between milk quality, milk foam formation conditions and the foam quality of a product (Charalampopoulos, Grandison).

We have collaborated with scientists at the Rutherford Appleton Laboratory and the Diamond Light Source to define the interaction of puroindolines and other co-expressed proteins and peptides with model biomembrane interfaces to better understand their biological role in the defence of wheat against fungal and microbial pathogens (Frazier).

Collaboration with Newcastle and Glasgow Universities has developed a prototype for improved nutritional care for older patients in hospital. This has entailed sensory science to improve the taste of traditional meals and to show that unpalatable mouth-drying problems with oral nutritional supplements are due to binding of dairy proteins to mucosal cells (Methven, Gosney).

Fagan and Harborne strengthen our research on the effect of processing on quality and activity of plant bioactives and development of functional foods, thereby linking to the Human Nutrition Division researching the bioefficacy and mechanisms of action of such bioactives, and the development of online Processes Analytical Technology (PAT) sensors for the Food Industry. Implementation of these technologies will facilitate optimization of food manufacturing processes to ensure the consistent production of high quality and safe food products.

Specific targets for the next five years are to:

- Strengthen interactions with the FPQ division in APD to link the primary production facilities

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with the processing facilities and use this combined platform to investigate how primary production and secondary processing interact to determine food quality.

- Develop new processing science for the delivery of foods with a positive impact on cardiovascular health.
- Elucidate the relationship between processing, food structure and product functionality. A recent EC Marie Curie multi-site training network (£404K to UoR) will help support this strategy, focussing on the impact of processing on micro structure of plant based food products and thence to functionality variables such as texture, rheology and nutrient bioavailability.
- Develop new research programmes around sustainable processing and developing functional foods built around plant bioactive compounds, in particular from agricultural waste. This will be facilitated by a new BBSRC Integrated Biorefining Research and Technology (IBTI) Club grant (2012-2015; £557K to UoR) in collaboration with Rothamsted Research, to identify processes for production of high value functional products from dried distilled grains. We will also develop novel processing opportunities for plant derived prebiotics and the development of optimised food delivery systems for polyphenols.

Food Microbial Sciences (FMS) comprises eleven post-doctoral scientists and academic research staff and is particularly aligned with the *Food Chain and Health* theme. The division instigated 'prebiotic' research, developing these interventions for managing human gut microbiota. Our approaches combine product development, *in vitro* assessments and human studies, with a focus on dietary based gut microbiome intervention studies. Gut models are run as a precursor to human studies whereby certain dietary ingredients are assessed for their influence on microbiota.

We have generated novel oligosaccharides with multi-functional activity which can improve food safety, and a new prebiotic food ingredient which has powerful effects upon beneficial gut bacteria (bifidobacteria) (Rastall, Gibson). Human studies have assessed the influence of dietary ingredients on gut flora with clinical trials in conjunction with various UK hospitals (St. Mary's, Northwick Park, Royal Berkshire, York, St. Thomas') on interventions against gut mediated disorders including ulcerative colitis, irritable bowel syndrome and peptic ulcers (Gibson, McCartney, Rowland).

Capability in metabonomics (Claus, Swann) is an important component of our overall research strategy covering activities relevant to all of FNS including gut microbial ecology, host-pathogen/microbiota interactions, investigations of the metabolic state in health and disease and the impact of dietary changes. Key collaborations are ongoing with Nicholson, Frost and Barraclough at Imperial College on the gut metabonome. We also have significant strengths in microbial food safety and physiology research (Andrews, Woodward, Karatzas, Lewis).

Specific targets for the next five years are to:

- Build upon high profile sequencing projects (Human Microbiome, MetaHit) to enhance independent molecular monitoring strategies that obtain maximum information regarding gut microbiota compositional change with prebiotics and move towards interventions that are tailored specifically towards the individual's gut microbiome. This research will be partly supported by a commercial grant (Tate and Lyle, £300K) to investigate reduction of specific enteric pathogens by prebiotic and probiotic combinations.
- Apply metabolic capabilities, involving the science of metabonomics and metagenomics, to dietary intervention and observational studies, e.g. develop NMR-based profiling of metabolites in blood, urine and faeces, also enhancing our capability to assess the effects of prebiotic intervention on the gut microbiome. A grant (£160K) from the Bill & Melinda Gates Foundation will support studies to identify novel metabonomic biomarkers of gut function and health in children with chronic gut infections and malnutrition in Brazil.
- Extend our dietary intervention strategies to the gut microbiome of livestock
- Continue to research microbial aspects of food safety e.g. new detection methods, effects of food processing, transmission through the food chain, microbial pathogenesis and physiology.

Human Nutrition (HN) comprises twenty-six post-doctoral scientists and academic research staff allied to the *Food Chain and Health* theme. We focus on the cellular and molecular basis of action in humans of protective dietary compounds and the factors (age, gender, genotype) which underlie inter-individual responsiveness to diets, foods and nutrients. The Hugh Sinclair Unit, funded via the Hugh Sinclair Endowment Trust and a key component of this Division, has an exceptional reputation for conducting acute experimental physiology studies and longer term dietary intervention studies in human volunteers.

The strategy of the Division has been to consolidate our international reputation in the

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relationship between dietary fatty acids, lipoproteins and the risk of cardiovascular disease, and to expand expertise to encompass other dietary bioactives, particularly plant foods and phytochemicals. We have also extended the range of chronic disorders that we investigate to include neurodegenerative diseases and cancer, recognising that many of the pathophysiological processes are in common.

Over the last five years, research has focused on controlled dietary intervention studies in healthy or at risk subjects, and mechanistic studies in human cells to explore relationships between diet components and risk of chronic degenerative diseases. For example, in the area of cardiovascular disease, we have shown that the improvement in vascular function with fish oil fatty acids is influenced by genotype with respect to the enzyme involved in the production of the vasodilator nitric oxide (eNOS) (Williams, Jackson). Changes to the amount and type of fat in the diet have a significant impact on fasting lipid levels with differential effects according to apolipoprotein (APO)E genotype in men and women with normal lipid levels (Lovegrove). Key collaborative studies are ongoing with Minihane (UEA), Mathers (Newcastle), Sanders (KCL). At the molecular level we have been working at the interface of plant and biomedical science to understand which regions of the plant genome (in a model species related to Brassica) confer potential health benefits to humans using human cell and gut models (Wagstaff). We have explored the impact of fruit and vegetables and their component phytochemicals on cancer and cardiovascular risk, which has provided evidence for the amount and types of plant foods needed to lower risk of chronic diseases (Rowland, Lovegrove) in collaboration with Mithen (IFR, Norwich). We have characterised the effects of pre- and probiotics on immunity in an ageing population and explored the impact of increasing the wholegrain content of the diet and fish on gut health and immune function (Gibson, Yaqoob) in collaborations with Calder (Southampton). We have established cause-and-effect relationships between the intake of dietary flavonoids and improvements in neurocognitive function and highlighted plausible mechanisms by which they exert these effects through interactions with neuronal and glial signalling (Spencer).

Specific targets for the next five years include:

- Development of an integrated approach to research diet and neurodegenerative disease that will capitalise on the investments in neurosciences across the university and in the functional MRI scanner through fundamental investigations into the interactions of plant bioactives with the brain.
- Collaborating with FPQ in developing an integrated approach for researching the development and treatment of cardiovascular disease and the role of diet. This will be facilitated by the recent MRC grant listed under FPQ.
- Developing our research capacity into the role of phytochemicals and human health and risk of chronic disease. For example, a recent EC FP7 grant (£431K to UoR) will support research into the reduction by phytochemicals of nitrite in meat, which has implications for colon cancer risk.
- Extending our reputation for fundamental research on nutrient-gene interactions in human health. Building on our new capability in genetic epidemiology and our on-going work on the interaction of the ApoE genotype with dietary lipids in the area of cardiovascular disease risk and the role of the COMT genotype in bioactivity of phytochemicals, to capitalise on a major EC-funded research programme on personalised nutrition 'Food4me'.
- Development of metabonomics research to further elucidate mechanisms through which diet influences disease risk combining previous experience of conducting large scale well controlled nutritional interventions with, importantly, our extensive bank of blood, urine and faecal samples. The data sets which this will create will place us in a strong position worldwide. We plan to initiate investigations of the metabolic state in health and disease (ageing, obesity, type II diabetes, IBS, IBD, gastrointestinal cancers) and impact of dietary changes.

Economic and Social Sciences (ESS) comprises 18 post-doctoral scientists and academic researchers, supporting all three themes of CFS. The importance of human decision making and policy in determining the outcomes of the food system is emphasised. We develop econometric (Balcombe, Holloway) and experimental methodology (Bardsely, Georgantzis), and also play a significant role in the integration of natural science with policy formation. An array of qualitative and quantitative methods is employed to analyse choices and their impacts. A range of scales is covered, from the individual to the international as represented by governmental institutions. Our expertise in the economics of diet and health policy has been applied to study a range of interventions that are designed to improve the quality of the diet (Traill, Tiffin, Nocella). We have

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shown that public information campaigns are cost effective, but are often short-lived, which limits their potential usefulness in sustaining long term behavioural change. Our ESRC-funded research on fiscal interventions (fat taxes) has shown that they are cost-effective in raising revenue that could partially offset social costs of unhealthy eating, but that their impacts in reducing obesity will be limited and that there are important distributional implications associated with them.

Livestock disease-control modelling has been used to produce decision-support models at farm scale which demonstrate the benefits of disease control to farmers (Tranter, Bennett). We have also developed a method which demonstrates the broad societal benefit to be gained from improvements to the welfare of farm animals and which can be used by policy makers to help evaluate the relative merits of a host of policy initiatives impacting on animal welfare.

Understanding the key interactions between ecological and economic systems as well as analysing the effectiveness of natural resource management and environmental policies in achieving sustainable development are foci of our environmental economists (Bardsely, Bailey, Areal, Robinson). Both theoretical and empirical models have been developed to explain individuals' behaviour and collective decision making, by incorporating spatial dimensions and ecological and climatic dynamics.

We have analysed the impact of intellectual property regimes on innovation in UK agriculture in the context of the emerging role of biotechnology, and the institutional and policy changes in agricultural research (Srinivasan).

Future priorities are to:

- Collaborate with psychologists to improve our understanding of how behavioural differences between consumers can explain differing patterns of food consumption across the population. This multidisciplinary approach will underpin much of our new funding in ESS, such as a new ESRC-funded project (2013-2017; £358K) on Cognitive Biases and Behavioural Segmentation in Food Demand, and has been strengthened by the appointment of Professor Georgantzis.
- Improve our understanding of how humans behave and make choices when confronted with complex choices impinging on various aspects of environmental change.
- Better integrate economic and ecological models to improve our understanding of food system resilience.

c. People, including:

i. Staffing strategy and staff development

Academic Staff Appointments: Within the current REF period, strategic appointments have been made to strengthen our research capacity in key areas of CFS. These appointments have had strong backing at the institutional level: a number have been funded by the University's Academic Investment Project (£14M funding 2011-2017) and are additional, not replacement posts. In BCA additional appointments have been made at Lecturer (Roy, appointed in 2013), Senior Research Fellow (Hammond, 2013; Tosi, 2013) and Professorial (Gregory, 2011; O'Sullivan, 2013; Shewry, 2012) levels. Gregory is a world authority on root biology and function and contributes directly to the *Sustainable Food Systems* theme. Gregory is also Chief Executive of East Malling Research and assists in collaborative projects between our two institutions. Shewry is widely known for his expertise in cereal grain composition and structure, particularly as they relate to end-use functionality and human health. Shewry thereby enhances cross disciplinary work between APD and HN, and further links to Rothamsted Research, to support the *Food Chain and Health* theme. O'Sullivan works principally on wheat and faba bean, developing and utilising genetic resources and genomic tools for the efficient genetic dissection of agronomically important traits. Tosi is an expert on the genetic and environmental influences on grain quality in wheat. Hammond focuses on the elemental nutrition of plants, combining research into plant physiology, elemental nutrition and genetics, particularly of *Brassica* species. Roy is a joint appointment between APD and the School of Archaeology, Geography and Environmental Sciences to bring expertise in mathematical modelling of Earth Observation and other remotely-sensed data to CFS.

Professor Woodward (2012), is a leading international authority in microbial sciences, and is developing a metagenomic approach to our current research on the gut microbiome and also strengthens our expertise in microbial food safety research.

All replacement appointments are made with reference to annual research plans and are not seen as automatic like-for-like replacements. In BCA HE Jones (2009) and Lukac (2010) have been appointed to augment our strengths in *Sustainable Food Systems* for changing environments. HE Jones uses system approaches to improve the resilience of production; of

particular interest is the use and understanding of spatial and temporal diversity at levels ranging from within plants (such as flowering time) to within cropping systems such as with the use of species mixtures and composite populations. Lukac uses modified environments and modelling approaches to study the tolerance of crops and ecosystems to the stresses predicted under climate change scenarios, and also the study of climate change mitigation through an understanding of the agro-ecosystem carbon cycle. In FPQ Gibbs (2010) and Rymer (2012) strengthen the *Food Chain and Health* theme with expertise to improve the PUFA content of animal-derived products.

FMS has been strengthened by Claus (2010) and Swann (2010) who bring expertise in NMR-based metabonomic profiling to enhance our existing expertise on the gut microbiome. Food safety is augmented by Karatzas (2012) with expertise in bacterial food pathogens, and Lewis (2013) who specializes in host interactions with the indigenous microbiome. In HN we are developing our capability in the areas of nutrition and cancer and cardiovascular health: Kuhnle (2010) has worked on the European Prospective Investigation into Cancer and Nutrition, one of the largest epidemiology studies ever conducted, which facilitates our access to a valuable collection of high quality biological samples and data. Karani (2013) is a genetic epidemiologist specialising in nutrient gene interactions. He brings new expertise on large human dietary intervention studies including DiOGenes and international cohort studies such as D-CarDia and will enhance our nutrigenomics research providing novel candidate nutrient-gene loci to be further investigated using our expertise in human intervention nutrition.

Within ESS, Bardsley (2010), Areal (2011), and Robinson (2012) have been appointed to strengthen expertise in Environmental Economics. Bardsley is a behavioural economist who develops improved theories of individual and collective decision making, particularly with regard to departures from narrow self-interest as are needed to reduce greenhouse gas emissions with policies acceptable politically to democratic electorates. Areal develops models to incorporate the provision of environmental goods by farmers and spatial dependence into technical efficiency analysis using Bayesian Stochastic Frontier Analysis. Robinson uses explicitly spatial and temporal models of resource extraction to explore the intersection of people and the natural environment, in particular to protect both resource-dependent livelihoods and the natural resource base. Georgantzis (2013) is a behavioural economist, with particular expertise to link with psychology and experimental methods.

Staff Development and Training: Early career staff: are each assigned a mentor when they arrive and receive close mentoring when writing grants; have a reduced teaching and administration load to give them time to apply for grants; and are given special support by the University's Research Endowment Trust (RET) to fund experiments to gather pilot data for large grant applications. Early career staff are also given priority in the Faculty of Life Sciences postgraduate studentship competition thereby enabling them to begin establishing a thriving research group. All new teaching and research staff are required to take the Postgraduate Certificate in Academic Practice (PGCAP) which is designed to meet the CPD needs of new lecturers and is accredited by the Higher Education Academy. The programme includes elements on writing successful research proposals, writing for publication and supervising research students.

All staff prepare an annual research plan which forms part of the annual staff development review. This contributes to the school research plans and also to the identification of training and staff development needs of the individual. These needs are in part met by the University's Centre for Quality Support and Development (CQSD) which offers courses in, for example, grant and paper writing and the responsibilities of a Principal Investigator. We recognise that staff development is relevant to staff at all career stages and all staff are encouraged to make full use of the wide CQSD prospectus. We have an effective promotion procedure to recognise and reward achievement with 10 colleagues promoted to Professorial grade across the submitting unit in the assessment period. We operate a system of internal peer support in preparing and submitting grants which acts as both a support mechanism and a quality assurance check. The RET provides a strategic resource which is used in part to fund staff development activities. It does this through schemes such as the best research output prize, a travel fund, grants to fund proof-of-concept research and the purchase of equipment. In addition, RET funding has been vital to the establishment of the CFS, enabling a buyout of the CFS director's teaching and the provision of administrative and dedicated research support. RET funding to CFS has also supported the further development of links with, for example, Rothamsted Research and East Malling Research with

joint academic appointments, PhD studentships and workshops.

Concordat to Support the Career Development of Researchers: We develop early career researcher staff using the framework provided by the Local and National Research Concordats. The University was in the first cohort of UK HEIs to be awarded the HR Excellence in Research Badge from the European Commission in recognition of our research staff development systems. Our commitment begins with the appointment of the researcher and all staff involved in appointment panels are required to have undergone training in recruitment and selection. Once appointed researchers attend an induction programme which familiarises them with their host school and the wider University. Opportunities for staff training and development are also outlined and participation in the programme leading to the Staff Educational and Development Association recognised Certificate in Research Career Management is encouraged. At the outset of each project the Principal Investigator (PI) agrees a statement of objectives and responsibilities with the researcher. Progress towards the targets is reviewed at least monthly. An experienced mentor is appointed to support their induction and professional development. The mentor also provides support in developing ideas for grant applications. Mentors are charged with recognising and valuing contributions and for putting these forward for wider recognition through schemes such as the best output prizes. Researchers are encouraged to teach and supervise students at levels appropriate to their own qualification, including co-supervision of PhD students where appropriate. Such teaching and supervision is supported by required attendance at relevant training and development events.

Equality and Diversity: We recognise that family responsibilities and structural obstacles can prevent women and people from ethnic minorities fully realising the opportunities that a career in science presents. All appointment panels in the submitting unit include members of both sexes. The University provides an on-line introduction to Diversity in the Workplace which all staff are required to take. Equality and diversity is embedded into compulsory training modules for all chairs of appointment panels. Appropriate gender balance and gender awareness is regarded as essential for committees addressing issues such as health and safety, promotion and delegation of tasks. This submitting unit is particularly attentive to gender issues when considering staff rewards, whether the payment of performance lump sums or the submission of cases for increments, regrading or promotion. All relevant members of staff within the UoA are fully aware of the legal obligations concerning maternity/adoption leave, and all female members of staff are made aware, via the University's HR Department, of what leave is available. Funds are made available by the University to provide teaching cover for staff members on maternity leave from the UoA. Staff returning from maternity/adoption leave are provided with a relatively light teaching /administration load during the first term after return and are offered considerable flexibility in the hours that they work. The University's Employee Health and Well-Being policy outlines good practice concerning maternity/adoption leave and caring for young children, and is implemented within the UoA.

The University has received the Athena Swan Bronze award for its work to develop a solid foundation of policies and practices to eliminate potential gender bias and to promote an inclusive culture that values female staff. Of the schools in this UoA, FNS have the Bronze award while APD submitted an application in November 2013. Commitment to the Athena Swan process and the consequent need to identify and support staff in leading on equality and diversity is a measure of our commitment to this area.

ii. Research students

Currently, 170 PhD/MPhil students are being supervised in the six research divisions of this submission. Sponsorship comes from research councils, Government departments, EU, charities, industry, RET and overseas scholarships. Scientific synergy with other related UK and international research establishments is evident. Of particular note is the BBSRC Doctoral Training Partnership (DTP) in Food Security led by CFS at Reading in partnership with the University of Surrey, Lancaster University, University of Southampton and Rothamsted Research which provides £3.4M worth of training across the partnership. Similarly CFS at Reading, in partnership with Birmingham University and Rothamsted Research, secured a BBSRC Advanced Training Partnership in Food Quality & Health which includes funding for a number of Professional Doctorate studentships. The ATP is worth £3.2M over five years across the partnership and supports an innovative programme of industrially based training for mid-career professionals. As such it supports the development of collaborative research with both our academic partners and the businesses which second individuals to the programme. Four PhD students were secured as part of our success with the

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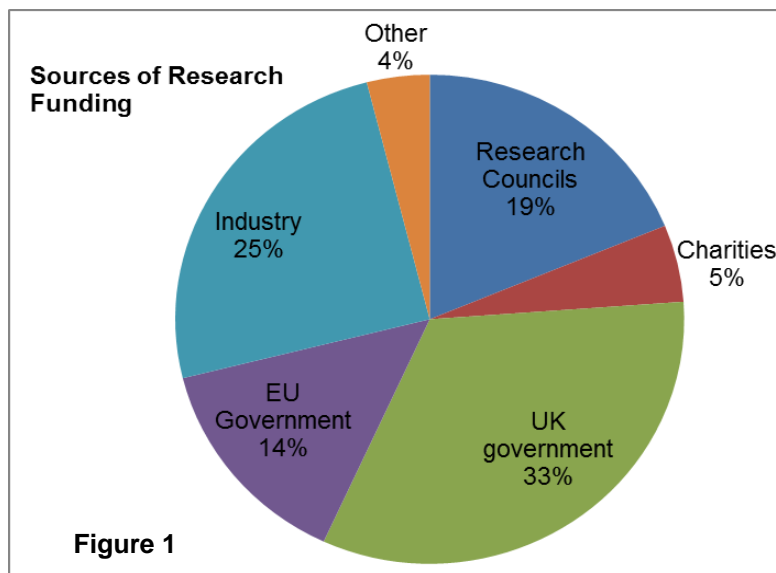
BBSRC DRINC scheme, associated with total project funding of over £2M. In addition to external scholarships, the University invests funds in support (half, leveraged industry funds providing the remainder) of 12 research students in this UoA.

Training and Support: Research students are members of the University of Reading Graduate School. As such they join the Reading Researcher Development Programme (RRDP). The RRDP offers a rich array of training sessions and development workshops for planning, promoting and supporting the personal, professional and career development of researchers. This programme maps on to the Research Development Framework adopted by the Research Councils with support from other funders and a wide range of employers. Students are also provided with subject-specific training within FNS and APD. Postgraduate students are invited to contribute to the University’s teaching and learning remit. This is primarily through practical demonstrating on selected laboratory and field-based courses, specific teaching and assessment activities, active involvement with Departmental summer schools, open days and external dissemination events. Training for this is provided by required attendance on programmes from our Centre for Staff Training and Development. Sessions designed for PhD students include: *Making a Professional Start with your Teaching, Small Group Teaching, Marking and Feedback Practice, Laboratory Demonstrating, Large Group Presentation Skills, and Planning & Running Computer Classes.*

Supervision and Monitoring: All students in the UoA are appointed two supervisors and a monitor. Where one supervisor is inexperienced they are always paired with a more experienced counterpart. The monitor’s main role is to chair the annual progress review committee (PRC) meeting which is also attended by the student and both supervisors. Prior to the meeting written reports are submitted by both student and supervisors. In addition to the PRC meetings a confirmation of registration meeting is held after 12-14 months of registration where the registration for the PhD is confirmed, or the student is re-registered for an MPhil, or registration is terminated.

d. Income, infrastructure and facilities

From 2008/09-2012/13, 72% of the unit’s research income of £36.3M came from government and industry sources (Figure 1). A further 19% was derived from research councils. This illustrates our emphasis on ‘real world’ science underpinned by excellent basic research. Our income per submitted FTE staff member of £498K over the five years contributing to this submission compares to £352k for the comparable period leading up to RAE 2008.



The facilities of the UoA represent an integrated platform for food chain research. Our farm based facilities include the Crops Research Unit with a 20 ha irrigable field site dedicated to plot work, augmented with modern field laboratories and equipment for plot-scale biodiversity assessment, phenotyping with a range of sensors and recent (2012) investments in computer image analysis, resource capture (light, N, S, C), and grain quality appraisal. Our crop science experiments to improve crop models and to investigate adaptation to climate change are facilitated by 30 controlled environment cabinets, over 2000m² of glasshouse space, and 4000m² under poly-tunnels. The University is currently investing in further crop genetics facilities, a process which has already seen £250K (2013) in new laboratory refurbishment which include modern capabilities of

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high throughput DNA and RNA extraction and quantification, rt-PCR for quantitative gene expression and high resolution melt capabilities for genotyping, and cloning of PCR fragments in *E.coli*. We are in the advanced stages of planning to invest a further £3M in new plot and controlled environment facilities (for 2015). Farm-based facilities for animal research include the Metabolism and Applied Units. The Metabolism Unit uniquely supports detailed studies of 40 large animals with surgical intervention to access the digestive tract. The NIRD Trust has provided £350k in support of new large animal open-circuit calorimeters with completion planned in early summer 2014. The current and new calorimeters enable direct evaluation of whole animal energy balances, efficiency of feed utilization, and emissions of CO₂ and methane. The Applied Unit includes 200 dairy cows that can be individually fed with a Calan gate system (the total pool of cows available to select from for such research being 550), and other facilities to individually feed and monitor cattle, sheep, and poultry. Many of the methods at Shinfield are licensed under the Animals (Scientific Procedures) Act; staff have Home Office Project and Personal Licences. Three laboratories (Metabolism, Fermentation, and Chemistry and Biochemistry) support the animal science. Recent investments include: GC with electro-chemical and flame ionization detectors (ECD+FID) for fatty acid analysis; GC+MS for amino-acid analysis; an iLab autoanalyser for blood metabolites; and Liquid Chromatography with MS for tannin work.

Our food research facilities include: the Flavour Centre, providing expertise in food analysis; Sensory Science @ Reading, providing sensory evaluation expertise; and the Process Research Centre, with the largest food processing pilot plant in UK academia. Our food microbial sciences unit has been the subject of a £3M investment in the REF period. This has provided a state of the art facility for gut microbiology and food safety research. Throughout, the laboratory is fully air conditioned and includes: a microscopy suite, an anaerobic gut model fermentation room, anaerobic and microaerophilic cabinets, molecular biology apparatus (for microbial detection and enumeration) and general microbiology equipment. In 2013, a further £2.5m was invested to upgrade all Category 2 laboratories in the Food and Nutritional Sciences Department. Funds (£100K) for four flow cytometers from the University's RET now support our gut microbiology and immunology research. The Hugh Sinclair Human Nutrition Suite has all the facilities required for human studies including clinical input, nurses, trained phlebotomists, catering facilities, and equipment for collection, storage and analysis of biological material. The Unit facilitates approximately 1000 volunteer visits per year, and has access to a range of cutting edge, genomic, proteomic and other high throughput analytical techniques. It is fully compliant with the requirements of Human Tissue Act. The Unit has six clinical rooms for volunteer use including two rooms devoted to vascular function assessment and well equipped laboratories. The unit has received significant infrastructure investment of over £1M during the REF period from BHF, Wolfson Foundation, Garfield Weston Foundation and Weston Charitable Trust. This has allowed expansion of the unit, with the inclusion of two further fully equipped clinical rooms, two specialised research nurses and the development of a vascular suite dedicated to the determination of vascular function, a key cardiovascular risk predictor, using up to five different cutting edge techniques. We have also invested in the latest DEXA scanner, which allows determination of bone density and body compositional analysis. Associated laboratories contain equipment for detailed cell studies, analysis of biological samples (blood urine, faeces, hair) and food analysis. For ESS we have recently invested in high throughput computing facilities including two PowerEdge M620 Blade multi-processor servers running MATLAB, GAUSS and R. This has improved capability for the use of Bayesian Markov Chain Monte Carlo (MCMC) algorithms for the estimation of large demand systems, hierarchical models for non-market valuation, stochastic frontier models and spatial econometrics. It has also enabled the environmental economists to conduct more ambitious research in economic models that require numerical optimisation. The University supports a number of cross faculty facilities. Two are of particular relevance: the Chemical Analysis Faculty (CAF) and Centre for Integrated Neuroscience and Neurodynamics (CINN). The CAF has been the subject of a £4.5M investment of University funds. It is a state-of-the-art instrument suite that undertakes leading NMR spectroscopy, Mass Spectrometry, X Ray Diffraction and Scattering, Optical Spectroscopy and Thermal Analysis; the facility also incorporates existing facilities for electron microscopy (SEM, TEM), X-ray microanalysis (EDX, WDX), spectroscopic imaging (Infra-red, Raman), visible light microscopy and scanning probe microscopy (AFM). The CAF has contributed NMR based metabonomics to various human trials that have opened up a functionally based understanding of gut bacterial modifications by diet. This

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has been applied to various clinical situations (e.g. Metabolic Syndrome, Autism) and healthy persons of various ages. The facilities in CINN include a 3-Tesla Siemens Trio research-dedicated functional magnetic resonance imaging (MRI) scanner; two high-density electroencephalography (EEG) systems; a high resolution MRI-compatible audiovisual stimulus display systems, with integrated high-speed eye tracking; a MRI- and EEG-compatible transcranial magnetic stimulation (TMS) system; and MRI-compatible bioelectric physiological recording system. CAF and CINN receive a direct grant of >£660k p.a. from the University to maintain these world-class facilities to the highest standards.

Research Governance: Research governance within the University is overseen by the PVC for Research and Innovation who chairs the University Board for Research and Innovation (UBRI). The University Code of Good Practice in Research lays out the principles by which research is to be conducted at the University. It applies to all those who conduct research at the University and is revised annually. Heads of Schools are responsible for the research conducted within their Schools. Investigators are also charged with implementing the Code as it applies to their research projects. All staff are made aware of the Code of Good Practice during their induction. The code is based on principles of: Excellence; Honesty and Integrity; Co-operation and Openness; Accountability; Training and Skills; and Safety. A policy of internal peer review prior to grant submission coupled with open outputs on our Institutional Repository (CentAUR) contribute to ensuring that the principles are upheld. The ethical scrutiny of research projects is seen as an integral part of the procedures for Governance and Quality Assurance of Research and is the responsibility of the University Research Ethics Committee (UREC). Within each School that contributes to this UoA the Director of Research is responsible for ensuring that all research that falls within the remit of the UREC is given the appropriate level of scrutiny. An annual audit is conducted by UREC to ensure compliance.

e. Collaboration or contribution to the discipline or research base

As a leading centre for interdisciplinary research we help shape the national and international research agendas in food security. A particularly relevant development is that of the RCUK Global Food Security programme for which we have been actively engaged in workshops, scoping and developing research calls (Tiffin, Williams, Traill, Gregory). Additional contributions to RC progression of the food security agenda are wide-ranging: Wheeler sits on BBSRC Council while Williams is a member of the BBSRC Food Security Advisory Panel. Gregory chaired the BBSRC Review of Crop Science Research and O'Sullivan continues our provision of core members of BBSRC Committee B, following previous service by Shaw. Yaqoob is a member of the BBSRC DRINC Steering Committee. Norris served as the Biodiversity theme leader for NERC while Wheeler is a member of the Living With Environmental Change Partners Board. In addition, the majority of staff in this UoA act as peer reviewers for the UK Research Councils.

Our roles in helping form Government policy with regards to food security are significant and extensive. Wheeler is Deputy Chief Scientific Adviser at DfID. Both Wheeler and Williams are members of the Government Chief Scientist's Food Research Partnership together with Tiffin serving on its Resilience sub-committee. At DEFRA Robinson is a member of the Economics Advisory Panel, Norris is a member of the Natural England Science Advisory Panel, Bennett is on the Farm Animal Welfare Committee, and Traill has contributed as a member of Council of Food Policy Advisers. Additionally, at the Food Standards Agency: Givens is on the Advisory Committee on Animal Feeds; Gregory chairs the Advisory Committee on Novel Foods and Processes and Shewry is on the committee; Tiffin is a member of the Social Science Research Committee. Lovegrove contributes to committees at the Department of Health, notably on the Scientific Advisory Committee on Nutrition, but also as a member of the Carbohydrates Working group and the National Diet Nutrition Survey program. In Europe, Givens is a member of the European Food Safety Authority sub-panel on food from GM animals, and internationally, Rowland, Rastall, Gibson and Yaqoob have served on International Life Sciences Institute panels.

Our expertise across the whole food chain is widely acknowledged within industry and our relationships with commercial enterprises ensure that our research is directed towards impact. To develop these relationships we regularly hold workshops in association with other academic institutions and industrial partners. The latter include Syngenta, Bayer, Astra-Zeneca, Unilever, Nestlé, Wyeth, Kellogg's, Friesland Dairyfoods, Johnson & Johnson, Danone, Proctor and Gamble, Arla Foods, Pfizer, Kraft and Mars. Our links to Industry are further strengthened through participation on industry advisory boards: Rowland advises Dean/Whitewave Foods (USA),

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McCormicks Herbs (USA), European Natural Soybean Association and the Alpro Foundation; Williams sits on the Pepsico UK and Ireland CEO External Advisory Board; Gibson advises Clasado (UK), Kellogg's (USA), Geneden (USA), General Mills (USA) GSK (USA) and Fugeia (Belgium) and Woodward is an advisor to the British Poultry Council and the British Pig Executive.

Our levels of engagement with external bodies addressing food security enable us to be responsive to national and international priorities. Our work with funders includes membership of grant panels: Shewry is Chair Rank Prize Nutrition Committee; Niranjana and Hadley are assessors for the Technology Strategy Board; and Mueller Harvey is an advisor to the European Research Council Advanced Research Grants Life Sciences Panel. At the British Nutrition Foundation, Williams is Vice-President, Givens is a member of the Science Advisory Committee, McCartney served on the Task-force for Development and Williams, Rowland and Gibson are governors. Gibson is President and founder member of the International Scientific Association for Probiotics and Prebiotics. Potts has contributed to the work of number of international organisations concerned with pollination services including chair of the International Commission of Plant-Bee Relationships Pollination Working Group and as Advisor to the US National Academy of Sciences. Our commitment to the academic community addressing food security is illustrated by:

- Editorship of a number of journals, including Journal Human Nutrition and Dietetics (Lovegrove); Journal of Food Engineering (Niranjana); Journal of Forestry (Lukac); Journal of Animal Ecology (2000-2009, Norris); Animal (Givens); Journal of Agricultural Sciences (Reynolds); European Journal of Nutrition (Rowland); Nutrition & Ageing (Spencer).
- Contributions to other educational and research establishments, including Governorship at the Royal Agricultural College (Ellis); Visiting Professorships at Universities of Ulster (Rowland) and Malaya (Gooding); Advisor to Crops for the Future Research Centre, Malaysia (Wagstaff); Advisory board member of the Danish Centre for Advanced Food Studies (Grandison); Hon Visiting Fellow, Department of Public Health & Primary Care, University of Cambridge (Kuhnle).
- Further contributions to learned societies, including President of the International Society of Food Engineering (Niranjana); President of the Agricultural Economics Society (2012-13, Traill); Chair of the Royal Horticultural Society Science Committee (Gregory); Chair of the Royal Society of Chemistry Food Group (Frazier); membership of the Royal Society Working Group on biological approaches to crop production (Dunwell); membership of the Agricultural Economics Society executive committee (Srinivasan, Areal).

The esteem with which our scientists are regarded is evident in a number of fellowships and awards including: Order of the British Empire (Williams); Nutrition Society Gold (Williams) and Silver (Spencer) medals; Fellowship of the Society of Biology (Ellis, Gregory, Norris); Fellowship of the Royal Agricultural Society (Gregory); Fellowship of the Association of Nutrition (Williams); Fellowship of the Institute of Food Science and Technology (Kennedy); Fellowship of the Institute of Agricultural Management (Bailey).

Finally, agri-food research has been central to Reading's development, ever since the establishment of its founding institutions in 1892. During the assessment period, important advances have been made to further our leadership in the discipline. Principally we have developed CFS to optimise our strategy and collaborations across the arena, and to better inform and to respond to the international and national agendas. Our approach addresses directly the significant weaknesses identified in UK research and development to respond to the major challenges facing the global food system as identified in the *Foresight Report on the Future of Food and Farming* (2011) from Department for Business, Innovation & Skills (BIS). We respond to the aims of the (UK) Agricultural Technology Strategy of the Office for Life Sciences including: sustainable intensification of agricultural production; developing solutions for Global Food Security; increasing engagement with business; increasing collaborations for international development; and to sustain a workforce with the necessary skills to meet the undoubted challenges. Similarly we continue to respond to the industry-led *Feeding the Future* (2013) report that identifies the need for: better approaches to improve the resilience of food production; a greater understanding of the interactions between crop and environment processes; and better training for researchers, practitioners and advisors.

The development of CFS has been underpinned by very significant investments in new staff, equipment and infrastructure; advances that can be utilized within, but importantly also beyond the University in a collaborative spirit to ensure that relevant future societal needs can be met.