Institution: University of Nottingham

Unit of Assessment: UoA6, Agriculture, Food and Veterinary Science

1. UNIT CONTEXT AND STRUCTURE, RESEARCH AND IMPACT STRATEGY

1.1 Unit Context

UoA6 comprises the Schools of Biosciences (SoB) and Veterinary Medicine and Science (SVMS) working together to deliver world-leading fundamental and applied research across the broad remit of Agriculture, Food and Veterinary science (Figure 1). Colocation on the Sutton Bonington (SB) campus brings advantages of shared resources, critical mass of research and support staff, and close integration, facilitating interdisciplinary cross-fertilisation of research ideas, concepts and tools. The SB campus provides world class research facilities, comprising 44 buildings with >10,000m^2 of laboratory space and 3,300m^2 of glasshouse space, world-leading platforms for imaging, molecular and analytical sciences, and integrative interdisciplinary research. The 459ha University Farm facilitates innovative livestock and crop research.

UoA6 activity has delivered key fundamental discoveries and globally-significant applied research outcomes that have transformative impacts on society. UoA6 has fostered a dynamic, inclusive and sustainable environment that values all our staff and students. This creates a shared vision to generate high quality research, and to deliver impact through engaging with industry, policymakers, and wider society. EDI is embedded throughout our culture to energise this process. The success of UoA6 during this REF period is highlighted by key achievements:

- External research income of £81.2m (£11.6m per annum); a 23% increase over the REF2014 £9.5m per annum income.
- Substantial institutional and external investment of >£17m in world class research infrastructure and strategic appointments, including: the Future Foods Beacon (£6.8m); the Centre for Dairy Science Innovation (£6.3m); the Hounsfield Centre for 3D X-ray imaging (£2.9m); and the Wolfson Centre for Global Virus Research (£1.5m).
- Publication of >2600 peer reviewed articles produced by 134 FTE REF-returned staff, achieving >33,000 citations, 18% of which are in the top 10% most cited, and 55% of which include international collaborations.
- Extensive engagement with industry, including £13.17m of industry funded research, and commercial impact evidenced in multiple impact case studies.
- Wide ranging industry and policy impacts in animal welfare, food and drink manufacturing, and agriculture, including arable, horticulture and livestock.
- Significant doctoral student training, with 515.94 FTE Ph.D. awards during the period benefiting from extensive national and international collaborations. PGRs contributed to 27% of our REF outputs.
- A gender equality step change, achieving parity at assistant professor level, and approaching parity at associate professor level (17% female at REF2014; 42% female in 2020).

1.2 Research Mission and Structure

Our research spans biological sciences at all scales from molecules to ecosystems and across all kingdoms of life (plants, animals, fungi and microbes), and is underpinned by a population of fundamental, technological, applied, translational and clinical researchers. Our research is driven and delivered with a view to promote discovery, enterprise and the advancement of the human condition through world-leading research (Institutional Level Statement [ILS] 2.1).

Our strategic research priorities are to:
(1) advance food security and improve nutrition;
(2) ensure healthy lives and promote well-being for humans, farm and companion animals;
(3) enable delivery of sustainable agriculture and food production;
(4) tackle the causes of climate change and mitigate their impact;
(5) improve clinical veterinary practice and animal welfare.

The unit's research structure (Figure 1) integrates fundamental and applied research across all agriculture, food and veterinary sciences, drawing on research centres with world-class facilities and expertise that deliver against our strategic priorities.

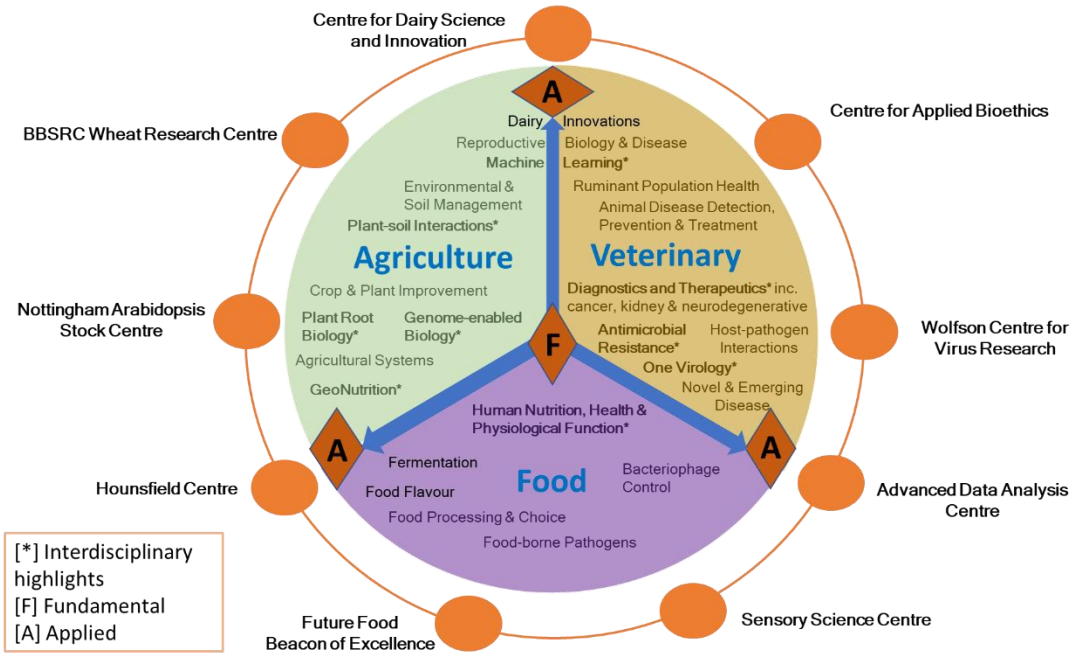

Figure 1: University of Nottingham UoA6 Agriculture, Food and Veterinary Sciences Research Structure and Facilities.

Drawing on our research strengths (Figure 1) the unit's research programmes and outputs: (a) enable production and consumption of safe and environmentally-sustainable food, through research on soil, crops and livestock, while promoting human and animal health through healthy eating; (b) improve the health and welfare of livestock and companion animals by developing novel diagnostics and disease control strategies, based on a clear understanding of disease pathogenesis. Our research and knowledge exchange contributes primarily to the delivery of four United Nations Sustainable Development Goals: SDG2 (*Zero Hunger*), SDG3 (*Good Health and Wellbeing*), SDG12 (*Responsible Consumption and Production*) and SDG13 (*Climate Action*).

1.3 Interdisciplinary Unit Focus

The interdisciplinary nature of UoA6 manifests across all research, impact and knowledge exchange operations including staffing and succession planning. Interdisciplinary research includes fundamental discovery science and applied veterinary medicine bringing together agriculture, nutrition, chemistry, physics, mathematics, computing, economics and bioethics with major breakthroughs at the interface between disciplines. Interdisciplinary research is a core part of our research strategy facilitating grant acquisition and enabling delivery of quality research and impact outputs across objects of study (e.g. plant/soil interface; animal health/welfare) and methodologies (e.g. biology/computing interface). Collaborative working is evident from our outputs: of 337 returns, the majority (57%) have two or more REF-submitted authors and 24% include staff from other University of Nottingham (UoN) UoAs. The Schools in the unit collaborate primarily in areas of research overlap (notably animal development and phage biology), and through the use of platform facilities (e.g. Hounsfield Centre and the Advanced Data Analysis Centre).

Interdisciplinary research highlights of UoA6 include:

GeoNutrition (>£11m awards: including £9m Gates Foundation; £1.3m Royal Society-Department for International Development; £540k EPSRC; £495k BBSRC GCRF; section 3.1.2) combines geochemists, soil and crop scientists, statisticians, human nutritionists, plus collaborators beyond UoA6 (Education, Sociology and History) and the institution (Rothamsted, LSHTM). This interdisciplinary food system approach has advanced international efforts to reduce micronutrient deficiencies and alleviate 'hidden hunger' in Africa (Ethiopia, Malawi, Zimbabwe), through mapping micronutrient status and development and delivery of a policy-focused web-based mapping tool.

Plant Root (>£6.5m awards) research encapsulates molecular cell and systems biology, crop science, microbiome, soil and bio physics, image analysis and mathematical modelling, and includes collaborations in Mathematics, Engineering and Computer Science. Funding resulted in the creation of the **Hounsfield Facility**, the world's first centre for X-ray microCT imaging for plant and soil sciences (section 3.3.4). Plant root research also intersects with plant-soil interactions which generated £2.8m of large awards (section 3.1.2) and led to fundamental discoveries including root adaptive responses in soil and how ethylene acts as an early warning signal for roots to avoid compacted soils. This had direct application to breeding crops with greater resilience to soil compaction.

Precision Livestock Health and Welfare (> £3m awards) brings together research in animal health, behaviour and welfare, data science, mathematics, signal processing, image analysis, nutrition and population genetics. The group's work has long standing collaborations with global technological companies such as Intel, HPE and BT to develop technological solutions for monitoring health and welfare on farms. Activity in this area is facilitated by access to the **Centre for Dairy Science Innovation, a state of the art facility for dairy research.** Research led to development of novel technological algorithms for cattle drinking behaviour as indicators for health and welfare, early detection of lameness in sheep and cattle, and novel welfare indicators of positive welfare such as play behaviour in calves. The group intersects with the infectious disease research group and the **Advanced Data Analysis Centre**.

Antimicrobial Resistance (>£5m awards: including £3.3m BBSRC; £558k International Development Research Centre; £481k RCUK cross-council funding; £411k IUK; section 3.1.2) integrates researchers in microbiology, veterinary science, mathematics, computing and economics with researchers outside UoA6 in Engineering, Sociology and Statistics. This research network has delivered fundamental understanding of antimicrobial resistance (AMR) risks, and applied mitigations for, UK dairy and Argentinian and Chinese poultry farms. AMR research has included the use of bacteriophage as an alternative to antibiotics to control Campylobacter, *E. coli* and Salmonella in livestock, and the identification of disease intervention targets for porcine *Streptococcus suis* infections in Vietnam. AMR research has benefited from the **Centre for Dairy Science Innovation** and the **Advanced Data Analysis Centre** facilities and expertise.

Controlling Tomato Fruit Texture (> £1m awards and Industrial sponsorship) draws on molecular genetics and quantitative trait loci (QTL) cloning, enzyme biochemistry, imaging, transcriptomics and metabolomics, statistical and bioinformatic data analysis and food flavour chemistry. Together these have delivered targeted genetic control of tomato softening, while maintaining good colour and enhancing flavour. These discoveries are being used in commercial practice, changing breeding strategies to target improved shelf life, taste and nutritional value.

Other areas of research strength achieving large awards and addressing national and global challenges include the BBSRC GCRF **SustainPeat** award (£595k) combining pan-institutional environmental science, modelling, economics and social science disciplines focused on understanding food, environment and socio-economic sustainability of land use in Malaysian and Indonesian tropical peatlands. National agricultural policy has drawn heavily from the UoN-led Defra **Farm Business Survey** research programme for England ([text removed for publication] across 6 institutions) in the development of the post-Brexit **Agriculture Act 2020**.

Further national, international and industry collaborations are discussed in section 4. All have fundamental research informing and integrating with strategic and applied research.

1.4 Review of Research Strategy 2014-2020

The REF2014 Research Strategy focussed on five areas:

1.4.1 Investment in capacity: 32 new members of staff (30.35 FTE) were recruited including professorial appointments and ECRs in strategic areas (section 2.2). £28.2m of internal and external funds have been invested into facilities, staff and research activities, including the Future Foods Beacon (FFB), high-throughput elemental phenotyping platform, the Centre for Dairy Science Innovation (CDSI), the Hounsfield Centre, plant and wheat research, the Wolfson Centre for Global Virus Research and an amenities building supporting staff and PGRs (section 3.4).

1.4.2 Fostering partnerships: We actively manage engagement with industry and professional bodies through our Showcase platforms, Business Development Officers and Knowledge Exchange activities. Improved awareness of our research and facilities is demonstrated by success with funding schemes such as InnovateUK (sections 1.5; 4). Research funding from 76 UK, EU and other international industry, commerce and public corporations totalled £13.17m.

Partnership is reflected in our outputs, with 1489 (59.6%) including international collaboration, 652 (24.9%) national collaboration and 223 industry collaboration.

1.4.3 Integration of multidisciplinary themes: Strategic areas/themes were established to facilitate interdisciplinary research (section 1.3). 51% of submitted outputs were identified as interdisciplinary. This has been achieved by sharing cross-disciplinary technical and scientific advances, and enhanced by the provision of platform technologies, e.g. Hounsfield centre, Ionomics Facility and High-throughput Phenotyping platforms. Seminars and meetings focused on enhancing interdisciplinary interaction have been facilitated by unit-wide support, promotion and engagement including faculty pump-priming, and FFB cross-discipline challenge events.

1.4.4 Increased research income: Research income increased from £47.3m in the previous REF period to £81.2m, from a wide range of sources, and in collaboration with external partners. This reflects our strategic decision to diversify our research funding portfolio (section 3.1) whilst concomitantly enhancing our offering to funders of our core science (BIS, UKRI).

1.4.5 PGR:Staff ratios: 515.96 FTE PhDs were awarded during the REF period (section 2.10), compared with 248 students in REF2014. The average number of PhD students per FTE staff member per year increased by ~30% from 0.41 in REF2014 (122 FTE staff and 5 year period) to 0.53 (137 FTE staff and 7 year period). This was driven through the BBSRC Doctoral Training Programme (DTP), unit funded studentships and a broader outreach to quality international students and funding. The DTP programme provides students with the opportunity to learn from, and explore their own interest in, a number of research disciplines, providing greater student support and embedding an enhanced interdisciplinary culture at doctoral training level (scholarships detailed in section 2.10.3).

1.5 Review of Impact Strategy 2014-2020

Impact strategy from REF2014 had three aims: responsive management of impact; strategic engagement with end-users and policy makers; and embedding an impact culture. During the current REF cycle, advancements have been made in:

1.5.1 Responsive Management of Impact

Two *Research and Business Development* roles were created to: establish processes to manage and record impact activities; embed external stakeholders in project design and delivery; enhance stakeholder engagement and foster an impact culture. This has informed the targeting of impact opportunities (e.g. UK Parliament calls for evidence; impact awards and prizes) and impact-related funding (see 1.5.3). These processes have allowed us to track and foster more than 50 research programmes that have made a notable impact on industry or policy, generating ICSs for this REF, and also embedding ongoing policy and industry engagement.

1.5.2 Strategic Engagement with End Users and Policy Makers

UoN Strategic Partnership agreements with corporations have led to funding into the Sensory Science Centre (Ford, Gould). External partners form part of our strategy groups, e.g. Severn Trent Water; Lindhurst Engineering; levy-board (Agriculture and Horticulture Development Board (AHDB)); and government (Veterinary Medicines Directorate (VMD), Food Standards Agency

(FSA)) advisors on strategic research grant advisory boards. Research Impact and Knowledge Exchange events have resulted in a new Knowledge Transfer Partnership (KTP) with Paragon Vets and new services rendered work (PBD Biotech). Engagement with trade associations and other bodies representing end-users has widened research capacity to benefit a broader industry base (section 4.3). Links to government have enhanced the use of research outputs in policy making (e.g. Development of UK Agriculture Act 2020 drawing on Farm Business Survey research; section 4.4). Research-informed CPD, in which research outcomes are shared externally, is described in section 4.7.

1.5.3 Embedding an Impact Culture

Success is highlighted by our innovation awards: University Federation for Animal Welfare (UWAF) young scientist to Kaler (2015); BBSRC International Innovator of the Year to Broadley and Ander (2018); European Federation of Animal Science (EAAP) outstanding contribution to Garnsworthy (2019); numerous industry innovation awards for the Actiphage® diagnostic test, including the Royal Dairy Innovation Award (Rees; 2019); RCVS Impact Award to Freeman (2019).

Investment of University managed funds, Higher Education Innovation Funding (HEIF), BBSRC Sparking Impact, BBSRC Impact Accelerator Account (IAA) awards and related impact awards, have enabled the pipeline between researchers and non-academic beneficiaries. Awards (37) totalling £544k have been made in areas from food flavour to vet diagnostics: notably one award has underpinned industry guidelines (Ray, BBSRC IAA – Safemalt); two awards have strengthened commercial links with UoN spin-out company Azotic Technologies Ltd and led to sub-contracted services work (both Fray, BBSRC IAA – Azotic); two awards have underpinned Impact Case Studies (Yon, HERMES / HEIF funds – elephants; Rees, HERMES / HEIF funds – Actiphage®). A further 10 awards are commercial in confidence. Success has been publicized via UoN Vision Magazine, press releases, websites, blogs and on social media platforms. Impact activities are recognised in staff workload allocation, appraisal systems, promotion criteria and peer recognition via publicising success.

1.6 Research Strategy 2020-2026

UoA6's research strategies align with the UoN's Institutional Level Statement (ILS), through discovery, enterprise and the advancement of the human condition. Going forwards we will continue to deliver world-changing impact through knowledge exchange and research translation to:

- Tackle global hunger and improve food security and nutrition.
- Ensure and promote healthy lives and welfare for humans, farm and companion animals.
- Develop sustainable agriculture, food production and consumption patterns.
- Mitigate the causes and impacts at the intersection of climate change, agriculture and food production.
- Integrate fundamental biology and novel technologies to guide treatment decisions in veterinary clinical practice and improving animal welfare.

This will enable us to develop knowledge and tools relevant to four of the UN's Sustainable Development Goals (section 1.2). To contribute to these goals, we will:

- Sustain a broad and vital research base across all aspects of UoA6 remit.
- Support fundamental, applied, technological, clinical and translational research, recognizing that these approaches are mutually supportive.
- Sustain an active, inclusive and responsive research culture that supports and celebrates researchers and academics at all career stages.
- Foster the link between research and teaching.
- Contribute to society and the economy through research relevant to local, national and international industry, government, non-governmental organisations, clinical practice and the public.
- Work globally, fostering equitable partnerships and contributing to the SDGs.
- Value all people, and embed Equality, Diversity and Inclusivity (EDI) into our research culture, including in staffing, promotions, collaborations and research content (section 2).

Specifically, our strategic aims will be addressed through the following actions:

1.6.1 Investment in staff

Strategic appointments and investment will be informed by our research aims, expertise requirements, EDI policies and responses to external national and global challenges, including Brexit and COVID-19. Priority appointments are planned to address national, global and economic concerns: environmental science (pollution; climate change), microbiology (infectious disease; antimicrobial resistance), biotechnology and veterinary medicine. Annual succession planning will focus on new areas for research and for sustaining existing research strengths (stem cell biology, ruminant nutrition, environmental science and microbiology). Building on the University FFB investment, we will make assistant professor appointments in crop physiology, root biology, plant-microbe interactions, gut-brain interactions and ionomics. Recent and future (2020/21) R&T appointments in areas of existing strategic strength include: cancer biology, precision livestock technologies, ruminant health, large animal pathology, anatomic pathology, clinical pathology and veterinary medicine. Appointments are planned in parasitology, reproductive biology, one health, farm animal epidemiology, computational genomics and immunobiology. Beyond 2022 a further 14 posts to farm, equine and small animal clinical research groups are envisioned.

ECR appointments through the Nottingham Research Fellowships and Anne McLaren Fellowships will transition to permanent academic positions (See ILS 2.1c; UoN investment to date of £15.4m and 95% staff retention rate).

1.6.2 Investment in PGR students: the UoA supports ~375 research students (section 2.10). We will continue to contribute to Doctoral Training Centres and Partnerships (e.g. BBSRC DTP3), with £8.7m already committed. The UoN-University of Adelaide partnership will recruit 46 dual PhD students (2020-24), substantially increasing the previous commitment (22 students; 2015-19). Local, national and international research and industrial partnerships e.g. with Nottingham Trent University, Rothamsted Research, the Research Complex at Harwell, the National Biofilms Innovation Centre, the AHDB, the Centre for Process Innovation Ltd, local SME bioindustry partners in Biocity and Albumedix, Penn State University and the Lilongwe University of Agriculture and Natural Resources (LUANAR) (section 2.10.3), will continue to be fostered.

1.6.3 Investment in facilities: We will continue to invest in research facilities and capabilities that link to, and underpin delivery of, our ambitious research aims. Immediate committed plans include plant growth facilities, including climate mirroring of field conditions (~£3m), animal facilities (~£2m), analytics (~£1m), redevelopment of virus research facilities including the CL3 laboratories within the Centre for Global Viruses Research (£1.25m, committed to external investment), and improvement of a University-wide research histology and laboratory service (£0.2m). These latter investments form part of a University centre for infection biology that will provide core laboratory facilities to undertake internationally-recognised, impactful research into global and emerging diseases.

1.6.4 Winning research funding: We will continue to build on our success in research awards across discipline specific and interdisciplinary science opportunities through actively managing the research grant submission process, and engaging directly with industry through demonstrating research impact outcomes and potential. To maximise research income success we will: support ECRs in their research careers; embed fairness across EDI characteristics; win external fellowships at all levels; promote internal and external academic collaborations; ensure appropriate inter-sectoral interactions; and optimise cost recovery. UKRI fund > 50% of our research and we aim to increase this and funding from other sources. We are trying to mitigate the impact of Brexit by diversifying our funder portfolio, as EU funding represents 8% of our income. We will build on recent success with Gates Foundation funding, other charitable organizations (Wellcome Trust), and attracting industry funding (section 4.3). We will also target international research councils as UKRI expands collaborations with the USA, Canada and Australia.

1.6.5 Working internationally: We will capitalise on our campuses in China and Malaysia, and build on existing partnerships with Cornell University, University of Adelaide, Shanghai Jiao Tong, Penn State University and LUANAR (Malawi). We aim to further engage with LMIC countries (section 4.6), including existing partners in Malawi, Ethiopia, Zimbabwe and India, and to increase funding beyond UKRI ODA. We will engage with our European partners (e.g. INRA, Tübingen, Wageningen, Agro Paris Tech, Ghent University, Lund University) to ensure continued collaborative growth, and expand our international networks (Australia, China, USA) in line with new UK trade deals and institutional strategic alliances.

1.6.6 Response to COVID-19: Our current focus has been the continuation of vital research and a phased resumption of research informed by COVID-19 safety in the labs, with staff and research students working safely to deliver current projects. Research staff and students work in laboratories on a booking/priority basis complying with facility-specific COVID-19 social distancing occupancy rules. Our **One Virology** group has been active in testing for COVID-19 in students and staff in co-operation with Nottingham University Hospitals NHS Trust. Personnel and equipment have been donated to the NHS. Our approach to COVID-19 research is both tactical and opportunistic. It includes the repurposing of anti-viral drugs, e.g. Thapsigargin for inhibition of SARS-CoV-2 leading to a patent in the REF period (PCT/GB2019/050977) and further patents and publications beyond (Chang; section 4.3.5). **Advanced Data Analysis Centre** (**ADAC**'s) leadership in the **CO-CONNECT** project is detailed in section 1.9.2.

1.7 Impact Strategy 2020-2026

UoA6's impact strategy is aligned with the ILS (section 2.2) and our research strategy. There is a strong focus on co-designing, co-producing and co-funding of research with non-academic users (e.g. veterinary profession, industry, industry bodies, government, non-governmental organisations, students and the public), fostering effective knowledge exchange, and on developing and delivering real-world solutions. Our aims are:

1.7.1 To develop UoA6's culture and capacity to deliver knowledge exchange

This will be achieved through:

- **Embedding impact and knowledge exchange** into research activity, with research officers providing structured support.
- Engaging with industry through Showcase Events, hosting guest lectures, providing honorary positions and supporting fellowship grant applications/exchanges and secondments.
- Monitoring and maintaining support for our strategic industry partners (e.g. PepsiCo, Unilever, Mars, GSK), hosting meetings that showcase research successes and collaboration options.
- Adopting a **diverse range of collaborative funding** (BBSRC CASE, KTPs, Innovate UK Agri-tech Catalyst) for translating UoA6 research outcomes into industry.
- Diversifying supervisors for research projects, embedding cross-disciplinary and international/industry partners/supervisors to enhance global research impact potential, informed by our EDI policy.
- Building an impact culture through PGRs and PDRAs training and providing opportunities for ECRs to present research and impact outcomes externally.
- Promoting the professional development of Research and Development Managers and Impact Officers supporting impact delivery and measurement.
- Acknowledging and valuing colleagues' internal and external public engagement and outreach activities with a range of stakeholders.
- Building and rewarding a culture of open science by hosting reusable reproducible data, software and workflows.

1.7.2 To maximize the impact of intellectual property developed in UoA6

We will work with UoN professional services teams to facilitate commercial research translation by identifying and patenting novel IP, creating spin-out companies, and securing follow-on and collaborative funding. We will enable training at all levels (PGRs, academics) in intellectual property, entrepreneurship and using the UoN KE Academy. We will maintain support for regional SMEs through Innovation funding via the Food Innovation Centre (section 4.3.3).

1.7.3 To support economic prosperity and quality of human and animal life in all communities relevant to UoA6

The unit will aim to:

- Improve animal welfare, management and productivity through transdisciplinary research in data science, behaviour, and clinical practice.

- Identify and lead networks of industry partners to develop complex funding bids and solve national challenges. Plan research impact-related activities to increase engagement with stakeholders to deliver change in real-world situations, particularly overseas development projects.
- Explore innovative means to convey our research to a wider audience across Nottinghamshire, Derbyshire, Leicestershire and national and international geographies.
- Support regional societal needs in times of crisis, providing services and advice where appropriate to regional governmental organisations e.g. the NHS.
- Enhance interactions with **national and international governmental policy makers and non-governmental organisations** (e.g. Gates Foundation, DEFRA, DFID, CFO, FAO, Nottinghamshire County Council) and maximise opportunities to incorporate research outcomes in evidence-based policy development.

1.8 Mechanisms to Establish, Deliver and Review Research and Impact Strategies

Strategies established and reviewed by School Leadership Teams and research committees are refreshed every three years, reflecting national and international research priorities and external drivers (e.g. Brexit, COVID-19). Our research committees are responsible for research and impact strategy implementation and delivery. They represent researchers at school executive and university levels, review research proposals and allocate internal funding. Through their Directors of Research, the Schools co-ordinate strategic recruitment and staff appointments. Schools report to their respective Faculty Research Committees and to the University Research Board, which provide strategic oversight and support.

For strategy review, particular attention is given to (i) annual research awards (reflecting EDI and researcher stage data); (ii) outputs, internally reviewed throughout the REF cycle; (iii) impact, which is continuously monitored and evidenced. Currently there are 57 live research impacts from 52 research programmes being tracked, with 9 submitted to REF2021. Outputs and impact are assessed against EDI criteria, within our Athena Swan (AS) submissions (currently Silver SoB and Bronze SVMS), and the REF Code of Practice. No gender disparity has been found in outputs, awards or contributions to impact case studies in academic staff at the same level (Assistant/Associate/Full Professor).

1.9 Open Research Environment

Our Open Research Environment commitment is institutionally co-ordinated (ILS section 2.3). UoA6 follows the UoN's Research Data Management Policy, aligned to the *Concordat for Open Research Data* (UoN is a signatory), the UKRI Common Principles on Data Policy and the FAIR guiding principles.

1.9.1 Open access policy for publications and data

UoA6's and UoN's OA policy supports a mixed green (standard) and gold model and is implemented by the UoN Library through its publication framework. UKRI funded research is gold open access published through the UoN institutional block grant. Over 95% of our research outputs meet Green/Gold open access, with the UoN's repository (RIS) as an Open Access showcase for our published research. The University is part of Jisc's OpenDOAR, providing a portal to other UK institutions' repositories.

1.9.2 Open Sharing of Research Materials

UoA6 supports open sharing of research data, materials and products. Examples include:

- The **Nottingham Arabidopsis Stock Centre** (NASC), an openly accessible Plant Genetic Resource, coordinated with the Arabidopsis Biological Resource Center (ABRC) at Ohio State University. NASC distributed >100,000 seed stocks per year from 2013-2018 to >50 countries. NASC is held up as exemplar in the BBSRC Data Sharing Policy: version 1.22 (March 2017 update). All data, software tools and web services associated with stocks are freely available to the community. NASC has also been involved in the development of several community white papers on data sharing, as well as adopting, actualising and evangelising community standards throughout its existence.

- The EU-funded **PALE-blu** project on bluetongue virus (BTV) research, led by UoA6 has 19 partners who share stocks of BTV serotypes and data in Pirbright UK, Glasgow, UK, INRA France and Italy. These are cross-referenced between partners and include BTV reference collections. These are available online to the research community on an open sharing basis.

- **Future Food Beacon (FFB)** contributes to the Global Open Data for Agriculture and Nutrition (GODAN) that seeks to "support global efforts to make agricultural and nutritionally relevant data available, accessible, and usable for unrestricted use worldwide". The GODAN partnership additionally provides the unit with access to GODAN's academic networks.

- **Advanced Data Analysis Centre (ADAC)** is leading the MRC Clinical Research Collaboration Tissue Directory and Coordination Centre (section 3.3.6). ADAC is the nominated representative of the UK within the European Biobanking and Biomolecular Resources Research Infrastructure (BBMRI-UK) and is leading the building of infrastructure for CO-CONNECT, the £4m UK-wide initiative to support research into the COVID-19 antibody response, by connecting COVID-19 data derived from patient blood samples.

- Laboratory reagents are shared directly or *via* external organizations, e.g. Ximbio. Examples include bioluminescent bacterial strains / plasmid vectors directly shared laboratories worldwide and a mutant library of *Streptococcus uberis* (causes bovine mastitis) for further study or genome wide assessment.

1.10 Research Integrity and Ethics

The University has institution-wide research integrity and ethics policies that comply with the ***Concordat to Support Research Integrity 2019*** (the Concordat, and its policies, CC). UoA6 benefits from its Centre for Applied Bioethics research (section 3.3.9), embedding research integrity and ethical processes leadership. UoA6's CC commitment incorporates:

1.10.1 Embedding and upholding high standards of rigour and integrity (CC1) through our Research Ethics and Integrity officers (REIO) and membership of relevant Research Ethics Committee (RECs), this promotes standards and exchanges knowledge with REIOs and academics.

1.10.2 Ensuring research is conducted according to ethical, legal and professional standards (CC2): UoA RECs champion a culture of research training, integrity and good practice that embraces EDI policies. The RECs include colleagues who sit on external and / or University level RECs, with familiarity of national regulations (e.g. the Animal (Scientific Procedures) Act (ASPA); Veterinary Surgeons Act (VSA)). RECs review research projects covering research, data access and protected sites as well as human participant and animal research. Work under the Human Tissues Act (HTA) and/or human clinical proposals is reviewed by a National Health Service (NHS) REC, the NHS integrated research application system (IRAS) or the Medical School REC, School of Education REC, or Animal Welfare Ethical Review Body (AWERB). Veterinary clinical work may require an Animal Test Certificate (ATC) requiring review by the Veterinary Medicines Directorate (VMD). ASPA projects are reviewed by the University AWERB. All research projects are reviewed at the proposal stage (REC). Annual reports are submitted to the University's Research Integrity and Research Ethics Committee (URIEC) and AWERB. REC members and URIEC also follow up on proposed and ongoing projects to ensure compliance with legislation.

1.10.3 Training in Research Ethics and Integrity (CC3): is ensured via online research integrity courses for PGRs (Epigeum) and new staff. Bespoke training for PGRs includes experimental design, statistics data management and research ethics.

1.10.4 Using transparent, robust and fair processes to handle allegations of research misconduct (CC4): a clear University level policy on misconduct (updated 2019/20) is provided to all members of the University. The code of practice has clear referral, actions and reporting protocols in place. The UoA6 REIOs (Millar / Lea) promote awareness through training, publicising processes for raising issues and acting as a consultation point.

1.10.5 Supporting a culture of working together to strengthen integrity (CC5), UoA6 annually reports to the UREIC and UoA6 academics contribute to national initiatives and consultations including hosting the regional Nuffield Council for Bioethics (2014) consultation event on Research Culture in Science.

2. PEOPLE

Our dynamic, collegial and supportive environment values staff and research students in all job families and career stages, and includes dedicated ECR and PGR support systems and research leadership development. We have a strong sense of research identity and purpose, grounded in our 120-year history and commitment to tackling contemporary, national and global challenges in Agriculture, Food and Veterinary research. Our research community is fostered by our unit's dedicated campus, with its state-of-the-art research facilities (section 3.3) and indoor and outdoor communal spaces. EDI (section 2.8) is at the centre of our policies and strategies for staff and student recruitment and development.

2.1 Staff Profile

As of 31/7/20, the UoA consisted of 266 research active staff members (FTE 248.3), of whom 144 were independent REF returnable researchers (FTE 134.64) and 122 (FTE 113.66) were research staff (largely postdoctoral). These included veterinary clinical researchers. Tables 1 and 2 provide a detailed breakdown of our REF returnable staff.

Table 1: UoA6 REF Eligible staff headcount by level, gender* and ethnicity

Level	Characteristic	Female (%)	Male (%)
5	White	12 (26.7)	18 (40)
	BAME	7(15.6)	3(6.7)
	Not declared	3(6.7)	2(4.4)
	TOTAL	**22(49)**	**23(51)**
6	White	16(30.8)	28(53.8)
	BAME	3(5.8)	1(1.9)
	Not declared	3(5.8)	1(1.9)
	TOTAL	**22(42.3)**	**30(57.7)**
7	White	5(10.6)	40(85.1)
	BAME	0	1(2.1)
	Not declared	0	1(2.1)
	TOTAL	**5(10.6)**	**42(89.4)**

*Total for all levels: Female=49(34%) and Male 95(66%).

Table 2: Age Range

Level	26-35 (%)	36-45(%)	46-55(%)	55-65(%)	66+(%)
5	8(17.8)	25(55.6)	12(26.7)	0	0
6	0	11(21.2)	26(50)	15(28.8)	0
7	0	1(2.1)	24(51.1)	19(40.4)	3(2.1)

EDI analysis: postdoctoral researchers were approximately gender balanced throughout the period (57% female in 2014; 49% in 2020). Assistant professor level profile shifted from 34% female in 2014 to 49% female in 2020. At associate professor level gender balance increased from 17% female in 2014 to 42.3% female in 2020. While this level of gender equality was not achieved with professorial staff (13% in 2014 to 10.6% in 2020), our strategic support for female staff during the REF period led to approval of 5 new female professorial promotions (Coffey, Daly, Kaler, Millar, Sjogersten, effective 1/8/2020) increasing this proportion to 19%. Four staff members have declared a disability and 14 staff members identify as BAME. Our existing policies and action plans aim to deliver institutional KPIs of 50% female associate professors, 30% female full professors, and 15% BAME associate and full professors by 2025. UoA6 has administrative and technical support for research. Among 71 technical staff, 49 were female and 22 male (6 BAME).

2.2 Recruitment Policy and Evidence of Success

2.2.1 Our recruitment policy is informed by our EDI policy and has included:

- Strategic appointments supporting research vitality, with a focus on ECRs (20.7 FTE) over senior appointments (4.65 FTE).
- Sustainability appointments, primarily staff replacements (mainly retirement) with early career appointments (5 FTE).
- A focus on EDI, grounded in UoN's Building a Culture for Success competency framework (ILS 3.1), with: (i) increased use of the gender decoder in job advertisements; (ii) mixed gender balance on all recruitment panels; (iii) awareness of other EDI characteristics and active monitoring to address imbalance; (iv) recruitment training, including unconscious bias training, for all interview panellists.

2.2.2 Strategic appointments at Professor level have been made in FFB (Salt, Director of FFB), ODA research specialists (Lark), climate change (Leng), virology (Mertens), antimicrobial resistance (Bennett, Dottorini) and soil biology (Ritz). Assistant professor strategic appointments have been made in: bioinformatics (Dottorini, Blanchard); enhancing strength in plant and crop science, including in physiology (Voss, Mendiondo, Castrillo and Rasmussen transferred from fellowship to assistant professor), post-harvest processing (Bagheri), into the Wheat Research Centre (Hubbart-Edwards and Grewal; section 3.3.4) and into FFB (Fischer, Eldeghaidy, Bhosale; section 3.3.1); and building research depth in sensory science (Yang; section 3.3.8), microbiology (Nisbett, Borkar) and ruminant health (Archer, Down).

2.2.3 Sustainability appointments have been made in microbiology (Hobley replacing Dodd), food sensory analysis (Ford replacing Hort), brewing (Lawrence replacing Boulton), food structure (Yakubov replacing Wolf) and ruminant population health (Randall replacing Huxley).

2.2.4 Success of our recruitment policy is evidenced through grant awards, REF submitted research outputs, promotions of ECR staff, and EDI profiles. The 32 new recruits (30.35 FTE, 53% female, 16% BAME) have attracted £9.47m of research grant awards, with ~£3.61m from newly recruited ECRs, while Lark and Salt have generated high value income (£3.1m and £1.5m respectively). New recruits are responsible for 70 of submitted research outputs, with contribution rates of 3.9/FTE for senior recruits and 2.0/FTE for ECRs. Two newly recruited ECR staff have already been promoted to Associate Professor (Dottorini and Castrillo) following significant grant awards and production of high-quality outputs.

2.3 Management and Support of Staff

2.3.1 Staff Management Strategy: We aim to ensure that all staff are supported to deliver their ambitions, and to develop as researchers and leaders. Our strategy includes specific provisions for different groups of researchers, including funding for researchers (section 2.4), a focus on ECRs (2.5), on clinical researchers (2.6), mid-career researchers (2.7) and EDI (2.8).

Both schools have created behavioural charters that provide a framework to challenge negative behaviour. These promote a positive and inclusive working environment and provide opportunities for feedback, discussion and sharing of best practice amongst staff.

2.3.2 Annual Appraisals: all staff receive research career development guidance within the university appraisal scheme, which focusses on staff development through supportive strategic discussions and increased frequency of meetings. Managers who conduct appraisals undertake

compulsory training (e.g. in EDI, unconscious bias) and all appraisees are offered training to prepare and understand how to derive most benefit from the system.

UoA6 uses appraisal as a two-way process, focusing on personal development, in which future goals are established and, where appropriate, follow-up support identified. Staff agree goals that help them achieve personal career targets whilst contributing to their school's priorities. Meetings are complemented with specific research career guidance by local and faculty mentoring and training.

2.3.3 Formal Mentoring and Development: formal supportive actions are in place for all new appointments, including all ECRs (section 2.5) and for any postdoctoral researchers and colleagues seeking mentoring. SVMS is a member of the Faculty of Medicine and Health Sciences mentoring scheme, while SoB runs its mentoring scheme internally. Training is mandatory for mentors and potential mentees. There is a matching process before mentoring pairs are allocated. Coaching and mentoring is also available institutionally through the Leadership and Management Academy (LMA): 15 staff have received LMA coaching; 2 staff acted as coaches; 4 staff received mentoring; and 5 staff acted as mentors. The institution has also offered Wellbeing training courses, with 133 staff attendances.

2.3.4 Leadership Development: to ensure appropriate research leadership continuity, training is coordinated by the LMA, providing leadership programs aimed at early career, mid-career and senior academic, technical and professional staff, plus coaching and mentoring. There were 71 UoA6 participants in leadership development during the REF period from research fellows to senior leaders (Heads of School). Participation has both enabled and supported staff to take new leadership roles, including the Faculty of Science and Faculty of Medicine aPVCs for Research and Knowledge Exchange both from UoA6 (Z Wilson, Emes), appointments to Head of Division (Coffey), School Research Director (Fisk), deputy Head of School (P Wilson) and PGR Director (Stekel).

Staff leadership development also includes leadership succession planning including rotation of Heads of Divisions, Research Directors and REF Co-ordinators. EDI perspectives have been considered in managing these roles, including open Terms of Reference on the Schools' intranets and open (internal) recruitment. Active participation in the Impact Accelerator Program and ESRC Impact Leaders Program (Freeman, Hobson-West and Kaler) has further developed our research leadership. Participation by more established leaders (Emes) in the EPSRC funded STEMM-change reverse mentoring programme allows a senior colleague to be mentored by someone in a more junior position to themselves who has protected characteristics. This highlights the needs and challenges of underrepresented groups when making and influencing decisions.

2.4 Funding Support for Researchers

Funding support is available from Institutional, FFB (section 3.3.1), Faculty and School-level schemes. These enable: support of ECRs to establish independent research programmes; research project pump priming; support research grant preparation and writing; completion or enhancement of research papers; delivering and evidencing impact activities. FFB has provided capital investment (section 3.4) and £750k to 50 small projects, fellowships and awards, primarily in UoA6. UoN's Research Priority Areas (RPAs) (ILS section 2.1(a)) have awarded

£415k into 8 UoA6 projects. The Faculties of Science and Medicine and Health Sciences have awarded ~£90k into 13 UoA6 projects. For example, devices purchased by FFB for biomaterial characterization (£414k) supported ECR Yakubov's research laboratory, leading to >£1m of research awards (BBSRC and GlaxoSmithKline). The Agriculture and Food Security RPA secured £250k to support ECRs in collaboration with UoN's Malaysia Campus. Three post-doctoral ECRs were funded, leading to successful publication and follow-on external funding. Established researchers have also benefitted. A total of £765k for workshops, equipment, pump priming research and impact case development has led to progression of a spin out company (Seymour, plant therapeutics), an impact case (Rees, mycobacterium diagnostics) and £2.6m of project funding. This includes: £250k GCRF funding (Langley-Evans); £391k from BBSRC and CRUK (Chakrabarti); £1.5m cross-council AMR award (Stekel and Hobman); and £464k from NERC (Lomax).

2.5 Early Career Researchers

The University is a signatory to the Concordat to Support the Career Development of Researchers 2008 and holds an HR Excellence in Research award (renewed April 2020). Our policies and practices support career development of ECRs. Newly appointed ECRs work with an academic mentor, have a reduced teaching workload, and priority access to PhD studentships. Colleagues joining UoA6 are supported through specific courses on teaching, research and PGR supervision; Postdocs and research fellows sit on a range of committees to ensure representation in decision making.

The unit has successfully supported applications to the UoN Anne McLaren Fellowship (AMF) and Nottingham Research Fellowship (NRF) schemes. Since 2014 successes includes Rasmussen, Voss, Bhosale, Castrillo, Fischer, Mendiondo, Eldgehaidy, Borkar, Archer, Foster. Success in external fellowship applications includes Leverhulme (Band), BBSRC Discovery Fellowship (Bhosale), Leverhulme (Burgess), Royal Society (Bishopp), EMBO Fellowship (Mehra), Welcome Trust Seed Award in Science and a Royal Society Research Grant (Toshana Foster). Many of these fellowships have been leveraged using internal matched funding from the Schools. Di Bari has secured industry funding (McCain) for a three year research position. Building on a strong track record of supporting post-doctoral researchers and fellowships careers, Egan, Gould, Yang, Grewal, Hubbart-Edwards, Mendiondo, Rasmussen, Voss are now permanent staff members.

The University has redeployment policies supporting staff completing fixed-term contracts. All staff are contacted 3 months before contract end to arrange an exit interview covering redeployment options, career planning and CV development.

2.6 Effective Integration and Development of Clinical Researchers

Within SVMS, clinical and fundamental research is integrated seamlessly within the School divisions and research strategy to support clinical researchers. Examples of clinical and fundamental research benefiting from staff integration include: discovery of *os cordis* associated with cardiac disease in chimpanzees combining pathology and novel imaging methods (Moittié et al. 2020 Sci Rep 10:9417); identification of sex differences in pharmacokinetics and pharmacodynamics of an anaesthetic (White et al. 2017. Vet Anaesth Analg 44:865), and; the potential link of environmental contaminants to canine sperm quality and fertility (Lea et al. 2016.

Sci Rep 6:31281). Further, the Centre for Evidence Based Veterinary Medicine provides expert training and support on utilisation of research data and outcomes to clinicians in practice who are seeking the latest or a research-based consensus on a clinical problem.

2.7 Research Leave and Evidence of Success

Levels 5 to 7 R&T staff are eligible for Study Leave to further their research/teaching and this has primarily supported mid-career researcher development. Indicators of study leave success include three female professorial promotions approved during the REF period and UoA6's first BAME female professor. Other highlights include: Kaler's delivery of Innovate UK, impact and other project outputs, with professorial promotion (2020); Daly's focus on a Wellcome Trust Prime award on Zika virus and development of a diagnostic test, leading to internal funding (UNICAS, School funds) and professorial promotion (2020); Sparkes attracting British Beet Research Organization funding, two KTP awards and subsequent IUK award (£1.4m in total, £290k to UoN), plus outputs, leading to professorial promotion (2015); Stekel's support for a REF-submitted output, and internal awards that underpinned an AMR external award (section 3.1.2) and professorial promotion (2018); Rees, for her Impact Case Study (detection of mycobacteria), establishing the spin out PBD Biotech, a £25k Hermes Award, plus patent applications and research articles. Broadley's Gates Foundation GeoNutrition grant development and subsequent awards (sections 1.4.3; 3.1.2). Senior staff have also benefitted including Crout (post Head of School) and Langley-Evans (post REF2014 coordination), both leading to research awards.

2.8 Equality, Diversity and Inclusivity (EDI)

UoA6's EDI activities are aligned with the UoN's Equality, Diversity and Inclusion Strategic Delivery Plan (2019). SoB Head of School (Langley-Evans) is a member of the institutional EDI Committee and has been involved in university-wide reviews of support for disabled staff and gender and ethnicity pay gaps. Kaler is Faculty of Medicine and Health Sciences Director of EDI co-chairing faculty EDI board and joining the University EDI PVC's group to monitor progress and affect change.

2.8.1 EDI Committees and their work

Both Schools have dedicated EDI committees that ensure UoA6 embraces diversity and promotes equality and values all staff, whilst supporting them to excel. We work to develop a culture and working environment that encourages people to challenge themselves and others openly, constructively and with respect, to raise the quality of all we do together. The EDI committees' remits includes: Visibility of women; LGBT and BAME issues; career workshops; better role modelling; unconscious bias training; sabbaticals, parental leave, part-time working; decision making/risk perception; committee leadership structure; selection for interview panels, and; teaching specialist career development.

EDI committees meet quarterly and have led to or supported the following actions:

- Changes to appraisal and development conversations to improve the gender balance and other protected characteristics in awards and promotion, encouraging applications for promotion.
- Unconscious bias training as part of all staff induction.
- Promotion workshops annually to improve prospects for EDI protected groups.

- "Women in Biosciences" and "Be Yourself" poster campaigns (featuring women, from our own staff and external role models).
- Informal internal talks - "Redressing the Balance" and "Discussing What Matters".

2.8.2 Unit EDI policies

UoA6 has introduced and publicised core meeting hours (10am-4pm), breastfeeding rooms and gender-neutral toilets, and encourages staff to take maternity/adoption/shared parental leave with provision for maintaining research activity through paid 'Keeping-in-Touch Days'. University policy provides a variety of support routes back to work, including flexible working, use of accrued leave, job-share, term-time or part-time working. UoA6 is piloting 6 months additional funding for fixed term contracts that expire during maternity leave.

We have followed the processes in the UoN REF Code of Practice for determining Independent Researchers and selecting outputs.

2.8.3 Monitoring of EDI outcomes

Bi-annual (SVMS) and annual (SoB) surveys on awareness of key issues including availability of flexible working, access to training, and initiatives to support promotion are undertaken (e.g. 2019 SoB survey showed that 72% of staff felt that initiatives to open up roles on committees and key academic service roles had been successful in addressing inequality and fostering greater inclusion). Maternity and paternity leave are monitored within the process.

2.9 Promotion Policy and Evidence of Success

Promotions follow UoN's open and inclusive promotions criteria. Staff are actively encouraged to self-nominate and apply for promotions where appropriate, with promotion discussion embedded within the appraisal system. Promotion committees are vetted for EDI balance and members have undertaken EDI training including unconscious bias training. Committees are explicitly required to address EDI issues.

UoA6 runs annual separate promotions workshops for each level, to provide applicants with guidance and a clear framework within which to prepare their cases. Promotions are evaluated by unit level committees before being forwarded to Faculty and University level committees. In SVMS/SoB the Promotions Committee is the Leadership Team/sub-group of Leadership Team respectively. Promotions Committees help to strengthen applications, providing mentors and advocates to assist applicants prior to submissions to Faculty and University level committees.

Consistent with UoN's commitment to responsible use of research indicators (DORA signatory) and to support EDI policies, UoA6 does not consider journal metrics as part of the recruitment and promotion process. Candidates for promotion include their self-declared best five papers for consideration, which are read and assessed by promotions panels and external referees to establish international research quality.

Of 69 applications for promotion, 56 have been successful (81%) (3 to assistant professor, 29 to associate professor and 21 to full professor). 34 applications were made by women, of which 26 were successful (76%) while 35 applications were made by men, of which 30 were successful

(86%). This difference will be addressed in our EDI actions 2020-2026. Success rates for BAME and disabled staff were 100%, and include the first female BAME professor in UoA6 (Kaler).

2.10 Postgraduate Research Students

2.10.1 Profile and recruitment of PGRs

We have a large, dynamic PGR community of 375 students (July 2020) registered for M.Res/M.Phil/M.VM. or Ph.D. programmes. We awarded 515.96 FTE PhDs during the REF period. We had a near-equal gender balance (52% female) and 46% of awards were to BAME students, reflecting UoA6's international community of PGRs. UoA6 completion rate for the PG degrees during the review period was 93.7%. BBSRC provided funding for 19.8% of the students. Numbers of doctoral awards by year for UoA6 are:

Year	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	2019/20
FTE	54.98	69.90	76.14	82.34	84.64	68.67	79.27

Total=515.96.

2.10.2 Quality of PGR Supervision and Training

UoA6 has a Director of Postgraduate Research Students (SoB) and two sub-deans for Postgraduate Research (SVMS) with responsibility for PGR research culture and management by postgraduate committees that meet every two months and include student representation.

Students have at least two supervisors to ensure: (i) relevant expertise, especially when across disciplines; (ii) availability of supervision during periods of annual leave, work travel or sickness; (iii) additional feedback on written work, especially draft thesis chapters and research articles. All supervisors abide by the UoN's policy on Ph.D. supervision that includes: engagement with CPD; supporting students to plan their research and training; advising on regulations, services and facilities; ensuring students work safely; providing at least 10 formal supervision reports per year; supporting students with meetings, conferences, publications and preparation of their thesis; and ensuring that students submit all data prior to completion of their thesis.

PGR have access to all research facilities, with training in the use of state-of-the-art equipment. They are integrated into our research activities and work alongside postdoctoral researchers and interact freely with senior staff.

The UoN Researcher Academy supports PGRs through an SB office, providing training currently comprising ~80 individual researcher development courses. These courses are mapped against RCUK requirements, as defined in the Researcher Development Framework within the UoN Quality Manual, complement discipline-specific research training and seminar programmes where postdoctoral and outside speakers present their work, and where PGR contribution is mandatory.

To enhance the student experience, supervisors follow good practice as set out in the UoN Quality Manual. PG supervisor courses run annually covering all supervision aspects, including pastoral care, good practice standardisation, and support for supervisors and students, including well-being and mental health. Each PG student project is reviewed through robust Annual Reviews, conducted by a research expert not on the supervisory team, in year 1 checkpoint

(progress or terminate project) and years 2 and 3. Supervision quality (number of meetings, action points, actions taken, as recorded on meeting reports) is assessed with any deficiencies raised with PG committees and Executive teams for remedial action (e.g. replacement of supervisor).

We have introduced an annual UoA-wide postgraduate research symposium attended by PG students and staff. This, combined with well-established internal assessor appointments for each PGR student, has led to a greater celebration of students' contribution to our research culture. PGR students are encouraged to join learned societies to raise their profile in the wider research community. The quality and effectiveness of this supervision and support is evidenced in our strong successful completion rate and PGR achievements (section 2.10.4).

All PGR students have the opportunity to teach and are provided with training and peer mentoring support. 31 PGR students completed the Associate Teaching Certificate / and 36 the replacement (in 2019) Teaching and Learning Development programme, externally accredited by Advance HE. In 2019/20 80 PGRs were employed to demonstrate 1465.5 hours, including laboratory, computer-based, clinical and field practicals.

2.10.3 Scholarships, Studentships and Bursaries

The UoA played a key role in the UoN BBSRC DTP renewal (PI Z Wilson in UoA6). These have supported 93 standard studentships, 21 CASE studentships at UoN and 17 standard studentships and 3 CASE studentships with Rothamsted Research. The 2015-2019 DTP was in partnership with Diamond Light Source, East Malling Research and Rothamsted Research and associated with the Research Complex at Harwell, the Centre for Process Innovation's (CPI's) National Industrial Biotechnology Facility and Crops for the Future Research Centre (Kuala Lumpur, Malaysia). DTP programmes provide PGRs with world-class training programs focussed on BBSRC remit themes including (i) Molecules, Cells and Organisms, (ii) Global Food Security and (iii) Industrial Biotechnology and Bioenergy. The 2020-2024 Nottingham DTP award (full partners Nottingham Trent University and the National Biofilm Innovation Centre and 7 associate partners) will support 38 standard and 9 CASE four-year PhDs a year for five cohorts. Since the inception of the BBSRC DTPs UoA6 has increased commitments from 25% to 44% of non-staff budget to support match-funding of studentships and strategic investment in PGR students, e.g. in 2019 contributing £915k.

UoA6 leads on UoN's International Doctoral Training Programme with the University of Adelaide (Fisk) with 22 PhD students funded for 2015-2019 intake (£850k investment split 50:50 between UoN and Adelaide), with 18 hosted in UoA6. The Universities have renewed the programme for 2020-2024 intake (led from UoA6) with 46 PhD students (£2.68m investment from Adelaide and UoN Ningbo). FFB awarded 10 scholarships in collaboration with Rothamstead Research in International Agriculture. FFB has also recruited 12 PGR students within its innovation challenge projects.

2.10.4 PGR Student Achievements

The quality of our PGR community and supervision is evidenced by REF contributions, national and international prizes, awards and scholarships, PGR graduate careers outcomes and PGR service to learned societies:

- 82 different PGR students have contributed to 92 (27%) of our REF-submitted outputs.
- PGR prizes include 40 conference prizes for oral or poster presentations, 23 awards from national or international societies recognizing scientific contributions, 15 externally funded travel awards, and 4 outreach prizes.
- As of 2018 when evaluation data was available, 100% of PGR graduates were in employment or study 15 months after study completion, with over 90% in graduate level destinations. The economic value of our PGR degrees to students can be measured by a 20% uplift in salary (PGR graduate mean salary of £28,711 compared with £23,831 for BSc graduates).
- Three PGR students have served on committees of learned societies (Microbiological Society; Society for Applied Microbiology; British Society of Animal Science).

3. INCOME, INFRASTRUCTURE AND FACILITIES

3.1 Income

3.1.1 External grant income is £81.2m (Tables 3 & 4; REF4b). At £11.6m per annum, this is an increase of 22.6% over the £9.5m per annum income from REF2014 (£47.3m over a 5 year period), which previously represented an increase on the £6.3m annual RAE2008 income (£40.8m over 6.5 year period). This demonstrates enhanced research income in an increasingly competitive research funding landscape and is evidence that our research and impact strategies, coupled to enhanced staff and student support and development, is effective. While the income profile demonstrates a large support from RCUK (52.2%), substantial income from other sources demonstrates the success of our research and impact strategy implementation, including diversifying our funding portfolio and engagement with industry.

Table 3: External research income by category to nearest £1000

SPONSOR	TOTAL	%
BIS Research Councils, The Royal Society, British Academy & RSE	42,346.8	52.2%
UK-based charities (Open competitive process)	3,601.0	4.4%
UK-based charities (other)	327.4	0.4%
UK cent govtbodies/local auth, health & hosp authorities: **NIHR** (537155;543808;39178)	283.5	0.3%
UK cent govtbodies/local auth, health & hosp authorities: Ex NIHR	10,557.0	13.0%
UK cent govtbodies/local auth, health & hosp authorities: RDEC	1,494.6	1.8%
UK industry, commerce & public corporations	9,160.8	11.3%
Other sources	233.4	0.3%
EU govt bodies	6,330.5	7.8%
EU-based charities (open competitive process)	5.9	0.0%
EU industry, commerce & public corporations	1,387.0	1.7%
EU other	674.7	0.8%
Non-EU-based charities (open competitive process)	883.2	1.1%
Non-EU industry, commerce & public corporations	2,626.4	3.2%
Non-EU other	1,254.7	1.5%
TOTAL (£m)	**81.2**	**100**

Table 4: External research income by year

YEAR END	REF2021 Year	TOTAL / £m
31/07/14	2013	10.47
31/07/15	2014	12.32
31/07/16	2015	12.13
31/07/17	2016	12.52
31/07/18	2017	12.79
31/07/19	2018	11.78
31/07/20	2019	9.17
TOTAL (£m)		**81.18**

3.1.2 Profile of High Value Research Awards

Income was derived from 941 research awards. Two awards brought in >£4m into UoA6, with 7 awards of £1m-£4m and 22 awards between £500k and £1m. Our largest awards reflect the interdisciplinarity of UoA6, its research centres and strategic foci; the number of different PIs demonstrate both vitality and sustainability. Highlights are:

- **GeoNutrition** (section 1.3) received £11m, including our two largest awards (both £4.5m from Gates Foundation, Broadley) and two other large awards (RS-DFID £1.3m, Broadley; EPSRC £540k, Langley-Evans)
- **Wheat research** (section 3.3.4) received £7.5m of large awards, all from BBSRC, including the BBSRC strategic programme in Wheat Research (£1.5m, I King; £486k Mooney) and other large BBSRC awards (£1.43m and £437k to I King, £1m and £541k to Murchie, £679k J King, and £555k Z Wilson).
- **Antimicrobial resistance** (section 1.3) received £3.3m, including BBSRC UK-Argentina (£1m West), BBSRC (£600k Atterbury), the International Development Research Centre (£558k Egan), Cross-council AMR (£481k Stekel) and IUK (£411k Dottorini).
- **Ruminant health** received £3m, including EU H2020 funding (£765k Haig); AHDB (£686k Garnsworthy, £505k Green), BBSRC (£532k Leigh, £498k Tötemeyer).
- **DEFRA Farm Business Survey** research programme (2014-) received [text removed for publication] (consortium lead total) with [text removed for publication] for UoN (P Wilson).
- **Plant-soil interactions** received £2.8m that includes British Beet Research Organization (£745k Sparkes), BBSRC UK-Brazil (£677k Mooney), BBSRC GCRF (£595k Sjogersten) and BBSRC (£538k Ritz).
- The **Nottingham Arabidopsis Stock Centre** (section 3.3.5) received £1.7m from BBSRC (£1.1m and £638k May).

3.1.3 Research in-kind from National Facilities

£1m of in-kind research has been obtained from STFC facilities, including Diamond, the ISIS Neutron and Muon Source (2013: £194k; 2014: £176k; 2015: £168k; 2016: £230k; 2017: £247k; 2018: £10k; 2019: £22k) and £152k from NERC's NIGL, SIF and NEIF isotope facilities. These facilities have been used by 6 staff and 17 PGR students, leading to 18 research outputs, 5 of which are in the REF submission.

3.1.4 Income from Charities

£7.2m from 56 UK charities was obtained including: the Insulin-Dependent Diabetes Trust (1.89m); The Leverhulme Trust (£1.25m); the Dogs Trust (£477k); The Pet Plan Charitable Trust (£227k); The Society for Reproduction and Fertility (£388k); The Horse Trust (218k); The Wellcome Trust (£245k). £9.37m was from four overseas (excluding EU) charities, of which £9m was from the Bill and Melinda Gates Foundation (£4.5m and £4.5m).

3.1.5 Formal Grant Mentoring

Each school has a responsive mode grant submission mentoring scheme. Grants are reviewed and discussed by UoN experts with grant acquisition track records, with presentations to researchers to iterate improvements. Mentoring schemes have helped applicants plan, organize and discuss proposals. In SoB, of 55 grants mentored, 19 were awarded (35%). In SVMS, 13 grants were mentored with 5 successful (38% success rate), considerably above the BBSRC panel average (19-23%). Of the 22 PIs associated with large awards (section 3.1.2), 8 are women, an over-representation indicative of the research support for the development of our female academics.

3.2 Buildings and Space

The built infrastructure occupies >25,000m^2 of floor space across 44 buildings on the Sutton Bonington campus. Of this, there is: 5,200m^2 of office space for academic, research and support staff; >10,000m^2 of laboratory space; and 3,300m^2 of glasshouse space.

The University Farm supports livestock and crop research and comprises 459 hectares(ha), with 229ha of arable cropping and 119ha of grassland primarily supporting the dairy herd (through silage) and sheep flock (grazing). The Centre for Dairy Science Innovation occupies a 6.5ha site, while 8.3ha of the University Farm are used for crop trials. The farm benefits the wider environment (30ha of environmental stewardship (buffer strips of wild meadow; beetle banks); 40ha of woodland). Hospital and laboratory facilities of our Clinical Associates are used for clinical research.

3.3 Key Facilities in UoA6 and their contribution to income and output success

3.3.1 Future Food Beacon (**FFB:** Director, Salt) is an open research platform working across global food systems to deliver sustainable food and nutritional security. It combines the power of genome-enabled plant and animal sciences with cutting-edge nutritional science, food processing, manufacturing and digital technologies. The FFB research platforms include an EPSRC funded data platform for early child development, integrating numerous data sets on early educational outcomes, maternal and infant health, and mineral micronutrients in soil and crops aiming to transform early child development and learning outcomes in Malawi. FFB has invested in DeepSeq, UoN's high-throughput genomics facility that has sequenced and analysed over 2,500 SARS-CoV-2 genomes. These data have contributed to the understanding of the viral variants present in the population and the transmission patterns of the virus at a local, national and global level. FFB has provided strategic academic appointments and funding for UoA6's research (section 2.2), including: 9 Nottingham Research Fellows; 2 research

technologists; 5 postdoctoral research fellows; and 17 Ph.D. students. The FFB has also been a source of funding for ECRs and other staff (section 2.4).

3.3.2 The Centre for Dairy Science Innovation (**CDSI:** Director, Green) is one of four UK centres comprising the Centre for Innovation Excellence in Livestock (CIEL) funded by Innovate UK. CDSI provides a nutritional research unit with individual feeding for up to 100 high yielding dairy cows, flexible housing for two groups of 30 cows for research into environmental factors on performance, a containment (category 2) facility for studying pathogenesis and disease interventions in lactating cattle, and a youngstock facility for calves and heifers. The long-term investment in dairy science has been central to the generation of awards, outputs and impact. Three of our impact case studies are in dairy. CDSI supports our high-income dairy research in ruminant population health (section 3.1.2) and research on the transfer of antimicrobial resistance via farm slurry (sections 1.3; 3.1.2).

3.3.3 The Hounsfield Centre (Director, Mooney) is the world's first X-ray CT facility for plant and soil sciences. It has three CT systems that cover sample sizes from 1µm to 1m and a scanner integrated with a robotic arm and automated guided vehicle (hosted in a glasshouse) for 24/7 remote scanning. Typical objects include soil, rocks, bones, food, engineering materials, electronic components, with plant roots being ~50% of its work. The Hounsfield Centre's diverse research portfolio has been fundamental to BBSRC LINK programmes, doctoral training partnership schemes (e.g. iCASE) and services rendered work. The Hounsfield Centre has worked with over 20 companies including Syngenta, Bayer Cropscience, BASF, Verdisan, PepsiCo, Mondelez, Pipers Crisps, Rolls Royce, NSK Ltd, Micromass Ltd, Scaled Solutions Ltd., Upperton Pharma Solutions, ASI Solutions. Research outputs involving the Hounsfield include 90 research articles led by 49 different institutions (nationally and internationally), 20 from UoA6. The Centre underpins our research in GeoNutrition (sections 1.3; 3.1.2), plant-soil interactions (section 3.1.2) and plant roots (section 1.3).

3.3.4 The Nottingham BBSRC Wheat Research Centre (**WRC:** Director, I King) specialises in the generation of wheat-wild relative introgressions, transferring unique genetic variation from distantly related wild relatives into wheat. It includes three purpose-built glasshouses with temperature, light and irrigation control, seed storage, epifluorescence microscopy and SNP genotyping pipelines. Wheat research has attracted £7.5m of large awards (section 3.1.2) as well as numerous small awards; has appointed two new ECRs (both female, section 2.5). The centre underpins our success in wheat research, with 24 of our 337 REF-submitted outputs being in this area. The germplasm generated by the WRC has been distributed globally (e.g. USA, India, Mexico, Brazil, Africa, India, Australia, Europe, China, Canada), free of IP, to both public and private sectors for exploitation in breeding superior wheat varieties to meet food security challenges at a time of climate change.

3.3.5 National Arabidopsis Stock Centre (**NASC:** Director, May) provides seed (>100K seed stocks/year from 2013-2018, > 50 countries) and information resources to the International Arabidopsis Genome Programme and wider research community. It holds more than 800,000 stocks, representing 33.5% of all reported European plant germplasm accessions (European Search Catalogue for Plant Genetic Resources). It received external investment of £2.39m during the REF period (large awards in section 3.1.2). Details of NASC's contribution to Open Research and the wider community are in sections 1.9.2 and 4.6 respectively.

3.3.6 Advanced Data Analysis Centre (**ADAC:** Co-director, Emes) undertakes data analysis, machine learning and bioinformatics under the co-directorship of Emes (UoA6) and Garibaldi (Computer Science). The Bioinformatics element (50% of activity) was hosted in UoA6 until 2017 when ADAC expanded to provide wider expertise in research software engineering within the university Digital Research Service (DRS) on SB campus. Institutional investment of £492k helped create a self-sustaining research team consisting of 20+ staff with ADAC securing funding from government, charities and industrial consultancy > £40m. ADAC's work has underpinned much of our research in sequence analysis, genomics and interdisciplinary programmes.

3.3.7 The Wolfson Centre for Global Virus Research (Deputy-director, Daly) was initiated in 2019 with grants from Wolfson and UoN to establish a world-class research grouping, "One Virology". This includes state-of-the-art category 2 and 3, including SAPO 3 containment facilities, and office building at SB. This provides a focus for virology research across the University for new, emerging and re-emerging viruses. The category 3 / SAPO 3 (commissioned November 2020) hosts researchers in the PALE-blu bluetongue virus consortium (led by UoA6), SARS-CoV-2 and other funded projects.

3.3.8 The Sensory Science Centre (Director, Ford) supports research into how taste, aroma and texture integrate for flavour perception. It has state of the art facilities, including a suite of 10 booths designed to ISO Standards (ISO8589:1988), with controlled temperature, lighting and ventilation, as well as instrumentation including Dynataste delivery system and physiological recording equipment (Electromyography). The Sensory Science Centre underpins much of our applied research with the food and beverage industry and research-led CPD (section 4.7).

3.3.9 The Centre for Applied Bioethics (Director, Millar) includes outputs on Responsible Research and Innovation (RRI) and the development of ethical frameworks. The Centre is highly interdisciplinary with extensive international experience in four key areas: animals and humans in the laboratory; agri-food and energy production; animals and society; and ethical tools, including the Ethical Matrix. This research underpins research ethics and ethical training across all of our research areas. Millar is additionally the unit's main point of contact for applied bioethics at a local, national and international level.

3.4 Investment in Infrastructure and Facilities

Investment follows directly from our Research Strategy (section 1.4), specifically in capacity, development of partnerships and multidisciplinary research. We have unique national and international facilities that serve both to enhance our research and as centres for national and international collaboration. Specific strategic investments include:

- £6.85m for FFB, including £2.85m of capital and £3.99m of revenue. This has supported: staff employment; £3.7M of equipment for genomic data characterisation, high throughput phenotyping of plants and biomaterial characterization and nutritional analysis; £750k to support 50 projects across and beyond UoA6 (section 2.4).

- £6.85m into the CDSI, including: £6m investment from UoN and Innovate UK to establish the CDSI in 2016 extending existing facilities and expertise in Dairy Science, Dairy Herd Health and Welfare and Dairy Food Science. £600k in 2019 from the University, with

match-funding from CIEL (£250k), has developed new calf rearing facilities (section 3.3.2).

- £2.9m for the Hounsfield Centre, its three CT scanners, robotics and plant growth facilities and Laser Ablation Tomography providing novel technology for high-throughput dissection and imaging of biomaterials.

- £1.1m into plant and wheat research facilities, including £600k into a new growth room suite and £35K into glasshouses (including refurbishments and installation of irrigation systems). The Wheat Research Centre received: £200k for a Zeiss epifluorescence microscope; £120k for a SNP genotyping pipeline; and £155k for a new seed storage, threshing and sorting facility.

- £1.5m for the Wolfson Centre for Global Virus Research incorporating a new SAPO containment level 3 laboratory, £250k funded from the Wolfson Foundation, match-funded by UoN.

- £9m into the general amenities building used by staff and students as a hub for informal engagement (section 2.1). This includes the Graduate Centre for PGRs, including social activity, study space (section 3.2) and houses delivery of Researcher Academy training (section 2.10.2). It is used for UoA6-wide PGR symposium (section 2.10.2) and for Research Impact and Knowledge Exchange Events (2018) (section 1.5.2).

4. Collaboration and contribution to the research base, economy and society

4.1 Arrangements and support for development of research collaborations

Research and impact strategies encourage collaborative interactions with academic and non-academic partners, including industry, policy makers, charities and NGOs, locally, nationally and internationally. These have been facilitated by the appointment of dedicated impact staff (section 1.5.1), strategic academic appointments (e.g. ODA specialists; section 2.2.2) and investment in research infrastructure and facilities (section 3.4).

Academic and non-academic partnership development aims to create strong interdisciplinary teams to address global challenges and develop real-world solutions that deliver impact, supported by both internal (e.g. ICRF, HERMES, IAA) and external funding (e.g. 27 IUK project awards and 15 KTPs), dedicated professional services staff (R&I Corporate Partnerships team and IP/Commercialisation team) and local academic leads for KEF/Industry engagement (section 1.5.1).

4.2 Outputs associated with external collaborations

Collaboration is a key driver of our research and more than 2100 (80%) of our outputs have been co-authored with external partners (1489 international collaboration; 652 national collaboration; 223 academic-corporate collaboration; SciVal Analysis, July 2020). Of the many national research collaborations that have evolved during the reporting period, the most productive have been with the British Geological Survey (237 outputs); Nottingham University

Hospitals NHS Trust (101 Outputs); the University of Birmingham (87 outputs); the University of Cambridge (71 outputs); and Rothamsted Research (63 outputs).

UoA6 has extensive international collaborations, notably: the Chinese Academy of Agricultural Sciences (74 outputs); the Centre National de la Recherche Scientifique (66 outputs); the Institut National de la Recherche Agronomique (64 outputs); the University of Queensland (48) outputs; and the University of Adelaide (45 outputs).

UoA6 has successfully engaged with national and international companies and government agencies. Notable corporate research collaborators are with the RSK Group PLC (29 outputs); the Quality Milk Management Services (23 outputs); Unilever (15 outputs); Syngenta (9); and Pepsico (6).

4.3 Engagement with Industry

4.3.1 Directly Funded projects

We secured £13.17m of research funding from a total of 76 UK, EU and other international industry, commerce and public corporations between 2014 and 2020 (Table 3, section 3). The funding has supported research across the UoA and includes:

- Unilever (£1.3m), Dairy Crest (£361k), Pepsico International (£270k), Mondelez (£308k), McCain (£31k) and Nestle (£40k) to conduct food industry research on new ingredients, process improvements and minimising waste.
- ABInBev (formerly SABMiller) (£1.182m), Barth Innovation (£180k) and Molson Coors (£128k) to conduct research on brewing additives, process improvements and waste minimisation.
- Syngenta (£630k), Monsanto (£194k), KWS (£262k), Du Pont (£60k) and Bayer (£70k) for research on crop improvement and crop protection.
- Boviteq (£739k), Zoetis (formerly Pfizer) (£477k) and AB Agri Ltd (£392k) to conduct research on livestock breeding and production. CRV (£120K) for lameness in cattle.

In addition, industry directly fund some academic posts: ABInBev Chair in Brewing (Cook); ADAS- assistant professor (Bagheri); McCain Foods- assistant professor (Di Bari); and the British Horseracing Authority partially fund an associate professor (Paine).

4.3.2 UKRI Funded research with industry

Our UKRI funded research with industry demonstrates the breadth and depth of our applied Agriculture, Food and Veterinary research, with project collaborators from SMEs to multinationals and with international partners including from DAC-list countries.

Innovate UK Project Awards with industry (not including KTPs) total 27 projects worth £3.4m of awards to UoA6. These include 12 Agri-tech Catalyst awards (total £1.5m), 3 Health and Life Science awards (total £231k), 3 Nutrition for Life awards (total £143k), 2 UK-China AMR awards (total £426k), 2 Optimizing Food Composition awards (total £315k), 2 Crop and Livestock Disease challenge awards (total £538k), and 3 other awards (total £267k). The largest awards (>£200k to the unit) exemplify our research and impact breadth: FARMWATCH (UK-China £411k; Dottorini) on AMR in Chinese chicken production led by Nimrod Veterinary Products Ltd;

targeted supply chain ethylene removal to control the development of fresh produce (Agri-tech £360k; Seymour) led by Rsk Adas Ltd; Control of Botrytis by integrated UV and ethylene removal treatment (Agri-tech £300k; Dickinson) led by Flamingo Flowers Ltd; SporeID (Crop and Livestock £290k; Sparkes) to minimise the impact of disease on yield of the UK sugar beet crop led by the British Beet Research Organization; Pick, Store, Buy (Agri-tech £266k; Bagheri) to reduce waste for tomato production in Nigeria led by Pst Sensors Europe Ltd; PILAMM (Crop and Livestock £248k; Kaler) on sheep lameness monitoring led by Dunbia; and Novel Sodium Reduction Technologies (Food Composition £200k; Fisk) led by Mondelez.

Knowledge Transfer Partnerships (KTPs) applications achieved a 100% success rate, securing 15 since 2014, generating a total of £3m into UoA6 that helped businesses improve their competitiveness and productivity. Partners have included: The Processors and Growers Research Organisation (£271k and £232k), British Beet Research Organization (£242k and £230k), Unilever (£242k and £242k), Paragon Vets (£274k), Mr Lee's Pure Foods Co (£249k), Warner Edwards Distillery Ltd (£247k), Monkfield Nutrition (£202k), Buhler (£196k), ABF Grain Products Ltd (£159k), Pipers Crisps (£144k) – leading to an Impact Case Study (Fisk), Tangerine Holdings (£106k) and Torftech (£53k).

BBSRC LINK awards with industry total £1.5m awards (BBSRC-direct funding, excluding in-kind / in cash contributions) to UoA6 and include: QTL mapping of tomato fruit quality traits with Syngenta (£277k; Seymour) underpinning an ICS (Seymour - tomatoes); the role of phosphite in plant development with Verdesian Life Sciences, Headland Amenity, Trade Corporation International, Omex Environmental, Brian Lewis Agriculture and Biolchim (£502k; Swarup); controlling male fertility in wheat for hybrid breeding with AHDB, KWS, RAGT, Secobra and Limagrain (£367k; Z Wilson); and novel targets for increased muscle growth or feed efficiency with Zoetis (£335k; Brameld).

4.3.3 Industry Partnerships Supported by the European Regional Development Fund (ERDF)

The Food Innovation Centre has worked extensively with small and medium sized companies (SMEs) to develop new products and processes (EU ERDF funding, Ingenuity Plus, (£26k + £39k school match)), 2013-2015, followed by Enabling Innovation (£790k + £790k school match), 2016-2019. This has enabled approximately 150 East Midlands (Derbyshire & Nottinghamshire) SMEs to boost business growth through access to technical advice, equipment and academic consultation.

4.3.4 Industry Collaborations through Professional Representative Bodies

We partner with the major agricultural levy boards undertaking research and knowledge exchange to support UK agriculture. The AHDB Dairy-University of Nottingham Research Partnership on Animal Health, Welfare and Nutrition has two contracts (2011-2016 and 2016-2021; total value £4.2m of which ~£2.9m falls in this REF period). These contracts underpinned three of our ICSs (**Reducing dry period antibiotic use in UK dairy herds**; **Reducing clinical and subclinical mastitis in UK dairy herds**; **Changing industry practice towards using co-products as high performing dairy cattle feeds**). These contracts have included subcontracted collaborations with external partners (Harper Adams and RVC in both contracts;

plus Bristol, Aberystwyth and SAC in the first contract). Further AHDB contracts have also been in the areas of crop improvement (£427k) and sheep fertility, health and welfare (£100k).

4.3.5 Novel IP and Spin-Out Companies

Biomarker discovery work for acute kidney injury (Gardner with Devonald NUH HHS Trust) has an international patent (*Biomarkers related to kidney function and methods involving their use* (UK 1500200.9. filed on 7/1/15) for the UK/EU/USA/Canada) and NIHR-funded studies to commercialise and validate biomarkers in clinical studies. Discovery work in identifying novel antivirals for respiratory viruses (including Influenza virus and SARS-CoV-2) has led to patent PCT/GB2019/050977 and a further patent PCT/GB2020/052479 beyond the REF period (Chang) following extensive proof of concept studies. Rapid detection of bovine TB work, led to UK, EU and US patents (see ICS, Rees, Mycobacterium), with the spin-out company PBD Biotech Ltd to commercialise the test under exclusive licence. PBD Biotech Ltd has secured £845k to support this commercialization. Leigh has a patent (US 2012/0100174 A1) on the use of sortase anchored protein as vaccines for bovine mastitis caused by *Streptococcus uberis*. Seymour has an international patent (PCT/GB2015/051068) on the use of tomato extracts in cancer therapy, with clinical trials of agents expected to begin in 2022.

4.3.6 Industry Funding Leading to Impact Case Studies

Nine of the ICSs shortlisted for inclusion to this REF have benefitted from industrial investment. A total of £6.3m investment has delivered impact leading to additional sales, additional income or savings for industry partners. **This represents a return of £81.84 on every £1 invested by industry in UoN UoA6 research**. Examples of this impact include:

- The **British Dairy Herd National Mastitis Control Scheme** (ICS, Green) involved dairy industry engagement (through AHDB and NFU), dairy supply chain (e.g. Arla, Dairy Crest and Müller), retailers (e.g. Tesco, Asda, Sainsburys and Morrisons), relevant accreditation bodies (e.g. Red Tractor, RUMA, Soil Association) and the veterinary industry. Industry invested ~£750k and it is estimated that the mastitis control plan has led to savings across the industry of between £95m and £125m.
- **Changing industry practice towards using co-products as high performing dairy cattle feeds leading to increased co-product sales, milk yields and farm incomes** (ICS, Garnsworthy) benefitted dairy and involved AHDB, AB Agri Ltd, AB Vista Feed Ingredients, and retailers (e.g. Marks and Spencer), as well as DEFRA engagement and funding.
- **Transforming Pipers Crisps into a science led company acquired by PepsiCo** (ICS, Fisk) was a direct interaction with Pipers Crisps, a local food manufacturing company. It benefitted from two KTPs, leading to additional sales and savings due to new processes and products.

Industry impact not included within a submitted ICS includes **Optimising the delivery of superior genetics through advanced genomic selection of embryos** (Sinclair)**.** This was supported by industry, with a TSB/Innovate UK grant (TS/101069 £274k) with Paragon/XLVets, Cogent Breeding Ltd and Illumina Inc, leading to a BBSRC LINK grant (£2.7m) with Boviteq/Semex Canada/UK, Activf-ET (Paragon Vet Ltd/RAFT Solutions Ltd), JSR Genetics, Topigs-Norsvin (Norway/Netherlands) and Neogen Europe, a further Innovate UK grant (£518k

TSB 25261) with Paragon Vet Ltd, Boviteq/Semex and IMV Imaging (UK/France) and KTP 11542 (£274k) with Paragon.

4.4 Engagement with Government Agencies

UoA6 researchers have been successful in securing £11.3m of funding from 17 government bodies (Table 3, section 3).

UoA6 leads the DEFRA funded Farm Business Survey (FBS) for England (continuous funding since 2004, UoN award value in REF period is [text removed for publication]). FBS is the main source of data and intelligence on the economic performance of farm businesses in England and provides DEFRA with an evidence base to develop and analyse agricultural policies. This funding, combined with research on sustainable intensification in agriculture (DEFRA £337k), has led to one of UoA6's ICS: **Evidencing the development of the Agricultural Act 2020 and policy to support UK Agriculture outside of the EU.**

Funding on animal feed through the Sustainable Livestock Production LINK Programme (ENNBIO £429k) and also the Greenhouse Gas (GHG) Platform (DEFRA £388k) led to the ICS **Changing industry practice towards using co-products as high performing dairy cattle feeds leading to increased co-product sales, milk yields and farm incomes**, as well as industry engagement (see above). DEFRA funding on elephant welfare (£55k) directly led to UK Government policy changes and the development of a new UK Government mandated elephant behavioural welfare assessment tool for UK elephant-holding facilities and ICS **Improving the welfare of captive elephants through international policy and practice changes**. The Veterinary Medicines Directorate (VMD) funded research on Sheep Scab (£81k, Kaler) to develop best practice to control this condition.

Engagement with government has also led to Broadley being seconded (2018) as one of only four Senior Research Fellows in DFID's Research and Evidence Division - Agriculture Team.

4.5 Engagement with other external bodies

A major strength is the access UoA6 researchers have to clinical cases of farm and companion animal disease and injury, which informs the research community of new diseases emerging and facilitates rapid expertise deployment. Furthermore, it allows veterinary practices, farmers and animal owners to access evolving good practice for managing disease and injury led by the research groups. In addition to cited industry engagement (section 4.3), further examples include improvement in livestock and equine health, disease management and implementation of good practice through: The evidence-based medicine group; Precision Livestock, Big Data and Animal Health and Welfare Analytics; Equine Colic; and lameness and mastitis amongst others. Engagement and experience of veterinary research is facilitated by close association of SVMS with its seven associate primary and referral veterinary practices: Defence Animal Training Regiment; Dick White Referrals; Oakham Veterinary Hospital; Poultry Health Services; Peoples Dispensary for Sick Animals (PDSA); Scarsdale Veterinary Group (Farm and Equine); Scarsdale Veterinary Group (Pride Veterinary Centre); Twycross Zoo.

UoA6 provides direct support to a range of industry partners, drawing on our expertise and facilities including veterinary pathology (to veterinary surgeons), nutrition analysis, the

Hounsfield Centre (11 projects), field trials (11 projects including with Azotic, a UoN spinout), greenhouse trials (3 Azotic projects), plant pathology (4 Syngenta projects), microbiology (PDB Biotech), food processing (including Biopolymer Solutions and New Food Innovation, both companies holding offices on our campus) and food flavour.

4.6 International Development Research

UoA6's £17.6m international development funding (13 projects over £500k) includes or supports international development research with DAC-list countries. These include research projects contributing to UN Sustainable Development Goals 1 (zero poverty), 2 (zero hunger), 3 (good health and wellbeing), 10 (reduced inequalities), 12 (responsible consumption and production), and our engagement with international partners supports SDG 17 (partnerships for the goals). Specific highlight areas associated with large awards (section 3.1.2) are:

- The **Wheat Research Centre (WRC)** is a BBSRC strategic programme designing future wheat (£1.5M into UoA6) involving a collaboration including Rothamsted Research, the John Innes Centre and the Earlham Institute. The WRC has established links with the International Wheat Yield Partnership (IWYP), International Maize and Wheat Improvement Center (CIMMYT), the Indian Institute of Wheat and Barley Research (ICAR) and International Center for Agricultural Research in the Dry Areas (ICARDA). IWYP addresses the challenge of raising the genetic yield potential of wheat by up to 50% within two decades and funds 14 projects worldwide. UoA6 holds two projects to identify genetic variation in flowering morphology (£679K in collaboration with CIMMYT) and to use high throughput screening techniques to identify enhanced photosynthesis (£402K). The Global Crop Diversity Trust (£347K) funding for extending the genetic diversity of wheat is a collaboration with CIMMYT, ICAR and ICARDA. CIMMYT also partner on a project to understand traits to improve wheat yield and water use efficiency in Mexico (£541K).

- **Antimicrobial resistance research** includes international partners in Argentina, using data modelling and field trials to understand AMR transference between broiler farms and the environment (BBSRC ~£1m), and China to reduce antibiotic use in poultry through application of machine learning (IUK £479k). The International Development Research Centre (IDRC, via the AMR-InnoVet programme) funded (£712k) a collaborative programme with Vietnam seeking disease intervention targets for porcine *Streptococcus suis* infections.

- **Plant-soil interactions** include working with partners in Brazil (improve nitrogen-use) and in Malaysia and Indonesia to improve environmental sustainability of tropical peatlands (section 3.1.2). **NASC** (sections 1.9.2; 3.3.5) supports 50+ regular users from 18 DAC-list countries. **GeoNutrition** focuses upon improving micronutrient deficiency in foods working with partners in Ethiopia, Malawi and Zimbabwe (sections 1.3; 3.1.2). **FFB** has many international relationships including: the Brazilian Government, EMBRAPA and Universidade Federal de Lavras (Brazil); through a program for data sharing and institutional internationalization of the Higher Education Institutions and Research Institutions of Brazil Capes-PrInt. A partnership with the Bolivian Government, Parliamentary Federation against Hunger in Bolivia, is focused on equitable access to nutritious food in the urban environment. There are extensive international partners

associated with GeoNutrition (>£11m BMGF and GCRF funding, section 1.3) and UoA6 has partnerships in South Africa and Ghana on under-utilized crops and with Senegal on Pearl Millett; UoN-Sichuan Innovation Centre, based in Chengdu. An EU-China research and innovation partnership (ECRIP) funded mobility scheme "Network for Food Security" linked UoN, CIRAD France and Shanghai Jiao Tong University, China ($1m; 2015-19).

4.7 Research-Informed CPD

CPD courses informed by our research are important for knowledge exchange. SVMS has provided 256 separate CPD courses to the veterinary industry attended by a total of 2623 delegates, including those run by the Centre for Evidenced-Based Veterinary Medicine (CEVM) based upon mini-systematic reviews (27 published in the Veterinary Record) and made available to the veterinary industry via their website (www.bestbetsforvets.org). BASIS-accredited CPD courses, informed by UoA6 research on Advanced Sugar Beet Agronomy, have been run 4 times since 2015 to a total of 40 delegates, mainly from industry. UoA6's Sensory Science Centre has run 37 CPD courses in Sensory and Consumer Science, attracting over 400 delegates from over 100 different companies. Delegates benefit from training in advanced sensory science research methods developed by UoA6 researchers.

4.8 Esteem indicators and wider influence of contributions

The vitality and impact of our research is reflected in the large number of esteem indicators. These place our staff in positions to influence scientific strategies, lead new initiatives and act as ambassadors for UoA6 and the University. One highlight is MJ Bennett (Professor of Plant Sciences) 2020 election to Fellowship of the Royal Society for his outstanding research on roots and their environment. **Honours and Fellowships** have also been awarded to: two staff by the Royal Society of Chemistry; one by the Linnean Society; four by the Royal Colleges of Pathology or Veterinary Surgeons; and seven by international academies and Societies. **Prizes and medals** include: the Robert Fraser Gordon medal (Barrow) and the Royal Society Wolfson Research Merit award (MJ Bennett). BBSRC International Innovator of the Year (Broadley and Ander); Clarivate top 1% most highly cited Plant and Animal Researchers (MJ Bennett and Holdsworth); the Dalrymple-Champneys Cup and Medal (Green); and MBE Queens Birthday Honours List 2019 for Services for the Environment (Leng).

Ten of UoA6's staff are **Government and Senior Office bearers.** These include six on DEFRA advisory groups. Twenty of our staff sit on at least one **national or international advisory board panel**. Examples include: BBSRC Strategic Advisory Panels and The Wellcome Trust. Twenty-two of our staff are on at least one **professional association and learned society committee** or board and nine of these involve leadership roles, including in: the British Society of Soil Science; the Society for Applied Microbiology; The Veterinary Schools Council and the European Society of Veterinary Clinical Pathology.

Another measure of esteem includes leadership roles in, or membership of, **grant and fellowship awarding bodies**. Nineteen colleagues sit on one or more UKRI panels and five on research funding charity boards including the Wellcome Trust. These include fifteen on BBSRC panels, UKRI Future Leaders Fellowship Panel and the EPSC Manufacturing Research Hub. Four colleagues sit on UK professional body panels or facility panels. Fourteen colleagues sit on at least one International panel.

Within **journal and editorial boards**, we have six journal editors-in-chief and a further 20 academics are editorial board members, with several of these on multiple journal editorial boards.

Finally, the esteem with which our researchers are held is reflected in the membership, Chair or Trustee duties for **Charities and Trusts:** Animal Health Trust (Scientific Advisory Committee, Trustee and Councillor); Twycross Zoo (Trustee); Animal care and Ethics Committee; PDSA (Trustee).