SOCIETY OF Biology

UK Plant Science

Current status & future challenges

UK Plant Sciences Federation

About the UK Plant Sciences Federation

The UK Plant Sciences Federation (UKPSF) is a special interest group of the Society of Biology. It brings together the UK plant science community to develop a coordinated approach to policy and practice in research, industry, funding, education and outreach, in this vital sector of the biosciences.

The specific aims of the UKPSF are to:

- Increase understanding of the significance of plant science among Government, funders, industry and society.
- Formulate a coordinated strategy and vision for UK plant science that will be used to inform policy.
- Help improve the general funding environment for UK plant science research and education.
- Create a forum for debate that is independent and inclusive across the breadth of plant science.
- Provide a focus and contact point for UK plant science.
- Support efforts to inspire, educate and train the next generation of plant scientists.

UKPSF Member Organisations

Agriculture and Horticulture Development Board
Association of Applied Biologists
BASIS Registration Ltd
Bayer
Biochemical Society
Biosciences KTN
British Crop Production Council
British Ecological Society
British Society for Plant Pathology
British Society of Plant Breeders
Food and Environment Research Agency
Forest Products Research Institute
GARNet – Arabidopsis Research Community
Gatsby Plant Science Summer School Project
Genetics Society
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Monogram – Cereal and Grasses Research Community
Oxford University Press
Plant Bioscience Limited
The Rosaceae Network
Royal Botanical Gardens, Kew
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Science and Plants for Schools
SCI Horticulture Group
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UK plant scientists are well-positioned to respond to critical challenges of the 21st century: ensuring food security, adapting to and mitigating climate change, protecting biodiversity and improving global health.

The UK is internationally recognised for its excellence in plant science. It has world-leading fundamental plant science research that contributes to a diverse range of key industries including agriculture, pharmaceuticals, forestry and industrial biotechnology. The application of plant science knowledge offers unique benefits to the UK economy, international development and trade. However, there is currently unmet potential for translating research into innovative solutions.

Given sufficient support, UK plant scientists are well-positioned to respond to critical challenges of the 21st century: ensuring food security, adapting to and mitigating climate change, protecting biodiversity and improving global health. Nevertheless, the magnitude of these challenges must not be underestimated.

The extent to which UK plant science can realise its full potential depends critically upon the decisions and actions taken now by policymakers, funders, scientists and educators. Communicating, coordinating and integrating these efforts will enhance our success.

Executive summary

The UK Plant Sciences Federation has consulted with more than 300 representatives of the UK plant science community to identify strategic priorities and develop recommendations to build on existing strengths, fill critical gaps and guarantee the UK's success in meeting the challenges ahead. Based on our findings, our recommendations are to:

- **Increase investment in plant science urgently.** Government and industry must work together to build capacity by doubling current funding across the spectrum of plant science. They must develop integrated fundamental and applied programmes of research to increase crop productivity and resilience while conserving natural ecosystems. Centres for Agricultural Innovation that focus on crop improvement and crop protection would deliver much-needed progress towards food security and sustainability.

- **Create a stable funding strategy in the long term.** Extreme swings in policy and research funding priorities on a 5–10 year cycle are destructive to skills, infrastructure and innovation. We must create a long-term, balanced portfolio of basic and applied plant science research to generate a more durable system that produces a constant flow of knowledge and research outputs. This will be crucial to reinforce the UK's position as a world leader in plant science, which in turn will attract greater international collaboration and commercial investment.

- **Enable effective translation of plant science research into applications.** We need to increase the number of plant scientists engaging in public-private partnerships. Plant science must be well-represented in knowledge exchange schemes generated through, for example, the UK Strategy for Agricultural Technologies. Mechanisms to support translation of research into practice must be simple, stable and readily accessible, to encourage the scale of uptake necessary to maximise opportunities for beneficial innovation.

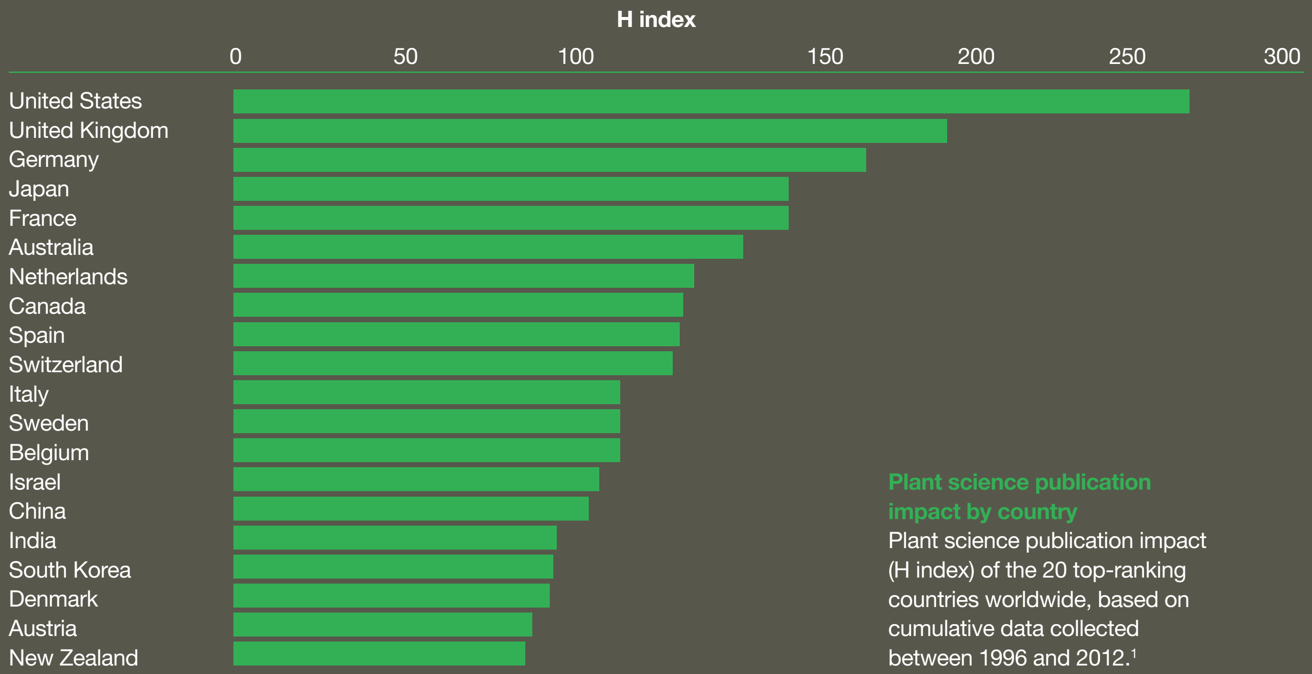
- **Inspire a new generation of plant scientists.** Organisations responsible for developing biology qualifications must actively involve plant scientists to ensure the content of their qualifications and associated materials support high quality plant science learning in schools and colleges. Trainee and qualified biology teachers must have greater access to opportunities to enhance their knowledge in plant science and develop strategies to teach it at secondary level. Universities must respond by encouraging and supporting teachers of bioscience undergraduates – potentially through teaching fellowships – to incorporate plant science more effectively into their courses.

- **Ensure that education and training meets the needs of employers.** Employers and educators should provide more and better-targeted apprenticeships, employee training, industrial studentships, degree content, further education and postgraduate courses. Training should be a core requisite of the Centres for Agricultural Innovation created through the UK Strategy for Agricultural Technologies. Education and training opportunities must be directed to fill skills gaps in plant taxonomy and identification, crop science, horticultural science, plant pathology, field studies and plant physiology.

- **Facilitate the creation of regulatory frameworks that are evidence- and risk-based, transparent, and which enable innovation.** Given the challenges associated with sustainable intensification, it is crucial that plant scientists, commercial plant breeders, industry and UK farmers are able to deploy all of the advancing knowledge, tools and technologies available. The UKPSF will support efforts made by UK policymakers and regulatory bodies to remove unnecessarily burdensome regulation and ensure that science-based evidence is paramount in determining the balance between benefits and risks of adopting new technologies, products and practices.

The world faces rapid global population growth, climate change and the depletion of natural resources. Improving sustainability and supporting economic growth are global and domestic priorities. Plant scientists have a vital role in developing better food and non-food production systems, biodiversity management and conservation of the natural environment. The need for solutions from them has never been greater.

For plant scientists in the UK, the next few decades will be crucial. We need to increase our fundamental understanding of plant biology and the interactions between plants and the environment to conserve botanical diversity, make step changes in the genetic improvement of crops, and develop more sustainable land management practices. These advances will help to support and improve economic growth, ecosystem function, health and quality of life.



Plant science publication impact by country
Plant science publication impact (H index) of the 20 top-ranking countries worldwide, based on cumulative data collected between 1996 and 2012.[1]

Introduction

The UK ranks second in the world for plant science publication impact

The UK has a world-leading fundamental plant science research base within universities and research institutes. It is placed second in global rankings of plant science publication impact.[1] Of the five countries with the highest plant science publication impact, the UK is the most efficient. This is true whether expressed as publication impact per capita, or as a function of gross domestic product (GDP).[a]

Plant science research has led to a broad array of intellectual properties including plant varieties and novel chemically active compounds. The UK is strong in wheat, barley, forage grass and soft-fruit breeding, with a number of competitive and successful plant breeding companies carrying out commercial research and development (R&D) activities. The annual contribution to the UK economy of wheat, barley and forage maize breeding alone is in the range of £1–1.3bn, producing a 40-fold return on investment.[2] Since 1982, at least 88% of yield increases for the major cereal crops and oilseed rape in the UK are estimated to have arisen through plant genetic improvement.[3]

Further examples of UK plant science with wide-reaching benefits include the development of new biotechnology solutions,[4] tools and technologies to advance research,[5–6] small molecules for crop protection and other purposes,[7–8] and foods with improved health benefits.[9–13]

- One of the UK's top plant science research institutes, the John Innes Centre, produces £30.4m of Gross Value Added for the UK economy each year.[10]

- The revenue from commercialisation of UK plant science technologies by Plant Bioscience Limited (PBL), a small independent technology management company, totalled nearly £3m in 2012.

Although UK plant science research offers opportunities to the business sector, and pioneering innovations have already emerged, there remains unmet potential for the translation of basic scientific knowledge into applications.

The launch of the £160m UK Strategy for Agricultural Technologies[14] in July 2013 reflects the Government's recognition of the importance of the agricultural technology sector to the UK economy. It shows commitment to encourage investment that will place the UK at the forefront of agricultural innovation. The Government has rightly acknowledged that investment in the conduct and exploitation of plant science research will not only benefit the UK's economic performance and sustainability but will also have a positive impact worldwide. We are keen to see this potential realised.

Science is necessary but not enough

Beneficial outcomes cannot be guaranteed through scientific advances alone. Strategic planning coupled with political and societal engagement is needed to mobilise the UK plant science community's full potential to deliver appropriate solutions.

To gain maximum value from investment in UK plant science, we must:

- Maintain and expand fundamental plant science research.
- Translate basic knowledge effectively into outcomes that improve agriculture, horticulture, forestry, protection of biodiversity, human nutrition, health and wellbeing.
- Develop a long-term investment strategy with continuity of funding.
- Create education and training opportunities to inspire and equip current and future plant biologists with the necessary expertise and skills.
- Ensure communication and coordination across all stakeholders, including Government, industry, research organisations, education institutions and non-governmental organisations.
- Provide an evidence-based regulatory environment that is proportionate to risk and enables innovation.

The UK Plant Sciences Federation is a unified voice for plant scientists in the UK. In December 2012, we launched a series of surveys and interviews with over 300 plant scientists working across a range of disciplines and types of organisation,[b] to assess the current status of UK plant science. This report, based on a year of consultation and discussion, aims to:

- Identify the key challenges facing UK plant scientists in the next decade.
- Analyse the current capacity of the UK plant science community to meet these challenges.
- Identify strategic priorities and make recommendations on how to build and sustain capacity in UK plant science to ensure the challenges are met successfully.

[a] Data from 2012–2013:
US (GDP US$16.2tn, population 317 million);
UK (GDP US$2.5tn, population 64 million);
Germany (GDP US$3.4tn, population 81 million);
Japan (GDP US$6.0tn, population 127 million);
France (GDP US$2.6tn, population 66 million).
GDP figures obtained from the World Bank.

[b] Respondents comprised plant scientists based at UK universities/higher education institutions, research institutes, companies, charities, government departments, non-departmental public bodies, learned societies, museums, botanic gardens and trade unions. Details of the survey response demographics are presented in the Annex.

We asked representatives of the UK plant science community to outline their main challenges for the next decade. The most frequent responses are summarised here.

Challenge 1: Food security

- Improving yield and reducing food waste
- Adapting to climate change and extreme weather
- Tackling plant pests and disease

Challenge 2: Producing healthier foods

Challenge 3: Environmental sustainability

- Using resources more efficiently
- Protecting biodiversity

Challenge 4: A green bioeconomy

- Producing bioenergy
- Making bioproducts

Research challenges

Food security

Survey respondents identified food security as the greatest challenge for UK plant scientists.

- The global population is expected to reach 9.6 billion by 2050 meaning there will be 2.4 billion extra people to feed.[15]
- Global food production must increase by 60–110% to meet this demand.[16–18]
- UK consumers are at risk from supply restrictions and increasing food prices.

The UK's vulnerability

- The UK has a proud history of agricultural innovation but over the last 25 years its productivity has slowed markedly compared with competitors. There has been no overall increase in UK agricultural output since 1986.[19]
- Only 62% of the UK's food is produced domestically. We are increasingly dependent on imports, sourcing an annual £37.6bn of food, feed and drink from overseas.[19]

UK consumers are in a vulnerable position as volatility in global food supply will inevitably impact on food prices and availability. There have already been three major spikes in global food prices since 2007 and such fluctuations are expected to continue.[20–21] Increased food prices will also affect international trade balances. As a net importer of food, the UK is predicted to suffer economically[22] unless we can improve our situation.

2.4bn

extra people to feed by 2050

Improving yield and reducing food waste

Expanding urban populations and the need to avoid cultivating more land will require increased productivity per unit of land, energy and water.[23] To meet global production targets, plant scientists must develop higher yielding, more resilient and resource-efficient crop varieties alongside more efficient agricultural practices.

UK plant breeders continue to develop new varieties giving annual yield increases of 0.5% in field trials.[2] However, this genetic potential is not consistently realised on farms, where yields have plateaued in recent years. Closing this 'yield gap' – the difference between maximum yield potential and actual yields – poses a particular problem.

Reducing postharvest losses from poor storage conditions, pests and diseases is a priority to reduce food waste in developing countries. In developed countries, the emphasis should be on devising innovative storage solutions and extending product freshness and shelf-life without compromising quality.

As our fundamental understanding of plant genetics, biochemistry, physiology and evolution increases, we discover how these underpin the processes by which plants respond to the environment. Plant scientists must work to translate knowledge from model species into crops, identify and exploit genetic diversity in crops and their wild relatives, and integrate large data sets to understand how plant genes relate to physical characteristics under field conditions and postharvest.

Adapting to climate change and extreme weather

Erratic and extreme weather conditions such as drought, flooding and extended periods of high or low temperature have affected crop yields badly in the UK and worldwide.

- In 2012, there were drought warnings early in the year followed by the UK's second wettest summer on record. These resulted in reduced wheat quality and yield, and the smallest potato harvest in 30 years. Income from UK farming also fell by 14% in real terms.[19]
- Many areas of the world experienced droughts in 2012, causing global crop losses totalling US$40bn.[24]
- Difficult winter planting conditions in 2008 and a wet harvest caused lower than expected UK crop yields in 2009.[25]
- A dry, cloudy spring followed by a wet summer in 2007 reduced yields of most UK crops.[25]
- UK crop yields in 2001 were reduced by flooding in late 2000.[25]

Breeding crop varieties that are resilient to climate change will not be a trivial task. The combination of factors including geography, day length, light intensity, carbon dioxide concentration, temperature and rainfall will create a multitude of possible environmental conditions to which crops must adapt over the next 30–50 years. Gene identification, modelling, selective breeding and field testing under artificial and controlled conditions are needed to generate and assess the performance of new crop varieties.

Adapting crops to climate change using wild relatives

Over the past 10,000 years of agriculture many important traits have been bred out of crops, leaving them vulnerable to pests, diseases and climate change. Wild relatives of crop plants contain a rich source of genetic diversity, which provides valuable traits that can be introduced into crops to make them higher yielding and more resilient to environmental stresses.

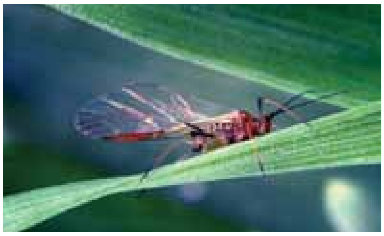
The commercial value of crop varieties benefiting from wild relative genes is currently estimated at £44bn, and this could increase to £128bn in the future. However, many crop wild relatives are in danger of extinction and are not currently preserved in gene banks.

A project led by the Global Crop Diversity Trust in collaboration with Kew's Millennium Seed Bank aims to collect and catalogue the wild relatives of 29 of the most important food crops worldwide. These collections will be conserved in gene banks, prepared for use in plant breeding programmes and assessed for useful agricultural traits. The resulting information and seed stocks will be made available to researchers and plant breeders around the world.

www.cwrdiversity.org

Crop wild relatives: A valuable resource for crop development. PricewaterhouseCoopers LLP (July 2013).

Maxted, N. *et al. Crop Science* **52**(2), 774–785 (2012).



Increasing our understanding of how plants respond to and tolerate climatic stress will also enable the development of novel solutions, including small molecules that can mitigate stress in crops.

Tackling plant pests and disease
Up to 40% of global crop yields are lost to plant pests and diseases each year.[26] It is predicted that this will worsen as different pathogens and pests are able to thrive under new climatic conditions.[27] Crop protection currently saves UK consumers an estimated £70bn in annual food costs.[28] Nevertheless, increased pesticide resistance,[29] concerns over the environmental effects of pesticide use,[30] stringent European Union (EU) pesticide regulations[31] and a lack of identified genetic resistance[32] are significant obstacles to future crop protection.

Developing new, effective crop protection solutions is possible provided the UK maintains a broad and well-supported plant science research base. We will benefit by building on existing strengths, such as the UK's world-leading research on the molecular and genetic basis of plant–pathogen interactions. By supporting both fundamental science and related translational activities we can breed more resistant plant varieties, develop new innovative crop protection chemicals and design better integrated pest management systems.

40%

Up to 40% of global crop yields are lost to plant pests and diseases each year

Breeding resistance to leaf blotch disease in wheat

Wheat is the UK's largest and most commercially important crop, with an annual farm gate value of over £2.2bn. Leaf blotch, caused by the fungal pathogen *Septoria tritici*, is the most damaging foliar disease of wheat. It has the capacity to reduce wheat yields by 30–40% and can cause UK crop losses of up to £35.5m a year.

Following over a decade of collaborations with European breeding companies, researchers at the UK's John Innes Centre have identified wheat genes that confer resistance to *Septoria tritici*. They have helped breeders to combine several sources of resistance in high yielding cultivars and the resulting products have been commercially available since 2006.

Impact of the John Innes Centre. Brookdale Consulting (2013).

John Innes Centre Economic Impact Brochure (2010).

Environmentally sustainable pest management in wheat

Wheat yields can be significantly reduced by aphids, which draw sap from plants and transmit diseases to them. Repeated pesticide application can result in resistant aphids, and kills other insect species including natural predators of aphids.

Scientists at Rothamsted Research in the UK have genetically modified wheat plants to contain an 'alarm pheromone' which aphids produce to alert one another of danger. (E)-β-farnesene is made naturally by some plants as a defence mechanism, and not only repels aphids, but also attracts their natural enemies.

The genetically modified (GM) wheat could help promote sustainable and environmentally friendly agriculture by reducing insecticide use and any associated negative effects on biodiversity.

www.rothamsted.ac.uk/success-stories

Al Abassi, S. *et al. J. Chem. Ecol.* **26**(7), 1765–1771 (2000).

Beale, M. H. *et al. PNAS* **103**(27), 10509–10513 (2006).

In addition to producing more food globally, there is increasing pressure to improve the nutritional value of food.

- Two billion people worldwide suffer from micronutrient deficiencies.[33]
- Cardiovascular disease causes 50,000 premature deaths in the UK each year.[10]
- The UK National Health Service would save at least £30m per year if cardiovascular events were reduced by just 1%.[10]

Through traditional breeding and biotechnology approaches, plant science offers opportunities to develop food crops with higher nutritional values, novel health benefits and reduced levels of undesirable compounds.

Health-promoting 'super-broccoli'

Scientists at Norwich Research Park have developed a variety of 'super-broccoli' which may help protect the body against age-related illnesses such as cancer, diabetes and heart disease.

Beneforté broccoli is the result of a 10-year breeding programme in which a commercial broccoli was crossed with a wild variety containing high levels of glucoraphanin. This health-promoting compound encourages cardiovascular health, cell regeneration and antioxidant activity. Studies show that Beneforté contains two to three times more glucoraphanin than other leading commercial broccoli varieties and that people who eat it have improved metabolic function. Beneforté broccoli has been marketed in the UK since 2011.

www.superbroccoli.info

Impact of the Institute of Food Research. Brookdale Consulting (2013).

Impact of the John Innes Centre. Brookdale Consulting (2013).

Designing healthy seed alternatives

Consuming moderate amounts of omega-3 long chain polyunsaturated fatty acids found in oily fish is associated with improved cardiovascular health and cognitive development. However, marine fish stocks are in decline and current fish farming practices are unsustainable because fish are fed on fish-meal, which uses about 97% of all fish oil produced.

UK scientists have identified genes for synthesising long chain polyunsaturated fatty acids in microorganisms, and used them to create transgenic oilseed plants that produce high levels of these healthy oils. This could provide a sustainable source of healthy oils for use in nutritional supplements, fish and other animal feeds, novel foods, pharmaceuticals and cosmetics.

www.rothamsted.ac.uk/success-stories

Qi, B. *et al. Nat. Biotechnol.* **22**(6), 739–745 (2004).

Ruiz-Lopez N. *et al. Metab. Eng.* **17**(100), 30–41 (2013).

Ruiz-Lopez, N. *et al. Plant J.* (2013). Accepted Article. doi: 10.1111/tpj.12378.

Producing healthier foods

Using resources more efficiently

The "Green Revolution" of the mid-20th century saw the development of semi-dwarf cereals able to respond to increased nitrogen fertiliser application.[34] This boosted global yields of wheat and rice. Nitrogen fertilisers drive high yields but their manufacture accounts for about 50% of the fossil fuel energy consumed by agricultural production systems.[35] Their production, and the soil processes of nitrification and denitrification resulting from their use, are also significant sources of nitrous oxide, a potent greenhouse gas.[36]

Phosphate mined for use in fertilisers is a finite and rapidly depleting resource, making its continued use unsustainable.[37] Leaching of nitrogen and phosphate fertilisers from the soil also causes water pollution and eutrophication.[38]

Agriculture currently accounts for 70% of the world's fresh water usage.[24] With expanding populations, urbanisation and industrialisation – particularly in developing countries – demand for water will only increase.

Scientists need an improved understanding of the genetic factors involved with how plants take up and respond to water and nutrients. This could help us produce crops that deliver high yields with reduced inputs and less wastage of resources.

Improving fertiliser efficiency

In wet weather, about 15–20% of nitrogen fertiliser is washed from agricultural soils by rain water. However, UK researchers have patented a process by which biodiesel co-products can be applied to soils, nitrogen fertilisers or soil amendments, preventing up to 99% of nitrogen loss to aquatic systems. This could significantly improve nitrogen fertiliser delivery to crops and reduce nitrate pollution from farming.

www.rothamsted.ac.uk/success-stories

Redmile-Gordon, M. & Brookes, P. World patent WO 2011015833 A1 (2010).

70%

Agriculture accounts for 70% of the world's fresh water use

Engineering cereals to associate with nitrogen-fixing bacteria

British researchers have uncovered genes that enable certain plants to associate with nitrogen-fixing bacteria. This opens up the possibility of genetically engineering cereal crops that can form symbioses with nitrogen-fixing bacteria to utilise nitrogen from the air. Such a technology could reduce or even eliminate the need for fertilisers, and improve crop yields for farmers in the developing world by as much as 50%.

Impact of the John Innes Centre. Brookdale Consulting (2013).

Environmental sustainability

Protecting biodiversity

Biodiversity contributes to the economy, human health and social wellbeing. It provides sources of food, bioproducts, flood control, climate change mitigation, clean water and recreation.[39] There has been a significant decline however, in both UK and global biodiversity in the last 50–60 years.[40–41] Much of this has been attributed to human activities including land use change, agricultural practices and pollution.

Agriculture currently accounts for 70% of UK land use and agricultural systems also provide valuable habitats for many wild species.[19] Some biodiversity contributes to agricultural productivity through pollination, pest and disease control and providing genetic resources for breeding. However, 67% of wildlife species found on UK farmland (including broadleaved plants, butterflies, bumblebees, birds and mammals) were estimated to be under threat from agricultural practices in 2000,[40] and 14% of farmland flowering plants are on the national Red List of threatened species.[42]

Around 60% of all UK plant species are in population decline and a quarter of heathland and semi-natural grassland flowering plants are now threatened.[42]

Invasive pest and disease species are among the primary causes of biodiversity loss[43] and are an increasing risk to the health of British trees and other wild plants. The outbreak of Dutch elm disease in the UK during the 1970s resulted in the loss of over 30 million English elms.[44] This had a devastating impact on ecosystems; for example, the national white-letter hairstreak butterfly population shrank by 70%.[42]

Pests and diseases are believed to be responsible for approximately £130m of annual losses to the UK forestry industry each year, although it is likely that this is a significant underestimate.[44] Furthermore, at least a dozen introduced tree pests and diseases have been newly identified or become more damaging to native species during the past decade. Without urgent action, this number is likely to rise.

Conservation of biodiversity is a key priority for science and policymaking. The Department for Environment, Food and Rural Affairs (Defra) has set an objective to halt overall biodiversity loss in the UK by 2020.[45] The 2011 UK National Ecosystem Assessment provided an initial understanding of how biodiversity underpins UK ecosystem services and the causes of biodiversity loss.[40] Nevertheless, monitoring data for some biodiversity groups are currently inadequate.

Improved methodologies and capacity for monitoring biodiversity change are needed. We must also develop a greater understanding of emergent pests and diseases, their identification, evolution, movement, and cellular and molecular interactions with plants. This knowledge will help to develop novel approaches to disease control, including ways to identify new invasive outbreaks early, monitor their spread, and identify and select for resistance.

Collaborative action to combat ash dieback

Ash dieback disease is a serious threat to the UK's 120 million ash trees – one of the most common types of broadleaf tree in Britain. The disease, caused by the fungus *Chalara fraxinea,* has already devastated ash populations across continental Europe.

Following the discovery of ash dieback in the UK in 2012, British scientists and funders responded rapidly by launching collaborative research initiatives and citizen science projects to help fight the disease.

Scientists at Forest Research and the Food and Environment Research Agency immediately began to track the disease outbreak and helped to develop a fast, portable test for diagnosing infected trees in the field.

Research teams at Queen Mary University of London, The Sainsbury Laboratory, the John Innes Centre, The Genome Analysis Centre and the University of Edinburgh were instrumental in establishing genome sequencing projects. They have already determined preliminary genome sequences of a native UK ash tree, a Danish ash tree with tolerance to the disease, and the disease-causing fungus. The projects aim to uncover genetic clues as to how the fungus attacks the trees, and to reveal genetic differences between resistant and susceptible trees that could underpin disease resistance.

An online crowdsourcing hub, OpenAshDieback, was developed to allow immediate sharing of genome data between researchers around the world. Scientists can also contribute towards one another's analyses, allowing faster progress to be made through collaborative efforts.

Citizen science initiatives pioneered in the UK are inviting the public to help by playing a Facebook puzzle game that analyses real genomic sequence data, or by monitoring the spread of ash dieback via smartphone apps.

www.forestry.gov.uk/chalara
http://livingashproject.org.uk
www.ashgenome.org
http://oadb.tsl.ac.uk
www.facebook.com/fraxinusgame
www.ashtag.org
www.forestry.gov.uk/treealert

Commercial bioenergy crop development

The Institute of Biological, Environmental and Rural Sciences (IBERS) at Aberystwyth University is leading a public–private partnership that aims to bring new seed-based Miscanthus hybrids to market. Miscanthus is a promising bioenergy crop as certain varieties produce high biomass yields with low input; however it has not previously been grown from seed as an agricultural crop.

Expert agronomists at IBERS form part of an international team working across Europe and the USA. They are applying their knowledge of seed production systems to Miscanthus and hope to make pre-commercial seed available for farmers in 2014.

www.miscanthusbreeding.org

Producing bioenergy

Climate change, depletion of fossil fuels, rising energy prices and increasing global energy demand, mean that renewable energy sources are becoming ever more important. The UK has committed to seek alternatives to fossil fuels and aims to obtain 15% of its energy from renewable sources by 2020.[46]

Plant-based biofuels have a valuable role to play in meeting this target. There are concerns however, about the potential environmental and humanitarian impacts of indirect land use change,[47] and that redirecting food crops for biofuel production will compromise food security.[48]

Plant scientists have a big opportunity to develop more efficient biofuel feedstocks with increased biomass or different quality attributes that will help meet energy demands sustainably. Biodiesel production from algal biomass does not present the same land use problems as fuel from food crops, but this process is only in the early stages of development and requires further investment before it can be used on a commercial scale.[49]

40%

By 2030, global energy demand is predicted to rise by 40%

A green bioeconomy

Making bioproducts

Diminishing fossil fuel supplies mean we need sustainable methods of producing high value chemicals, plastics and other products previously derived exclusively from oil or coal. Crops, crop residues and food waste provide useful alternative sources of oils and carbohydrates, which plant scientists can exploit to help meet this demand.[50]

Plants also contain a large number of natural products with a wide range of possible uses in the pharmaceutical, agrochemical, and food and drink industries.[10] However, in many cases these cannot be purified in sufficiently high quantities to be useful on an industrial scale. Research to identify useful plant products will open up more opportunities for commercial application. We also need to understand and potentially manipulate the biochemical pathways involved in product synthesis, and to develop ways of scaling up production and improving extraction.

The development of protein-based drugs is the fastest growing sector in the pharmaceutical industry.[10] In 2011, the global market value for therapeutic antibodies was an estimated US$23bn. Scientists can engineer plants as 'biological factories' to produce novel vaccines, antibodies and other therapeutic proteins. By designing new and improved production methods, we can capitalise on this market to generate greater inward investment and growth in the UK pharmaceutical sector.

Producing vaccines and pharmaceuticals in plants

A UK team from the John Innes Centre has developed a novel system for safe, efficient, and high-yielding protein production in plants, which can be used for vaccine and drug development.

The system enables vaccine production to begin within two weeks of identifying a new pathogen, compared with 6–12 months using conventional methods. This offers great potential for emergency vaccination programmes in response to disease pandemics. It is estimated that reducing the incidence of flu by just 1% would save the UK economy £13.5m per year.

The technology is licensed to the Canadian company, Medicago Inc, which is using the system to produce a number of vaccines and therapeutic protein products currently in development.

Innovator of the year 2012: Meet the innovators. BBSRC (2012).

Impact of the John Innes Centre. Brookdale Consulting (2013).

More than 90% of UK plant scientists surveyed thought that a better, more coherent strategy for UK research is needed. Here we outline four key areas which, given greater support, would better enable plant scientists to meet the research challenges identified.

1: Education, training and skills

2: Funding

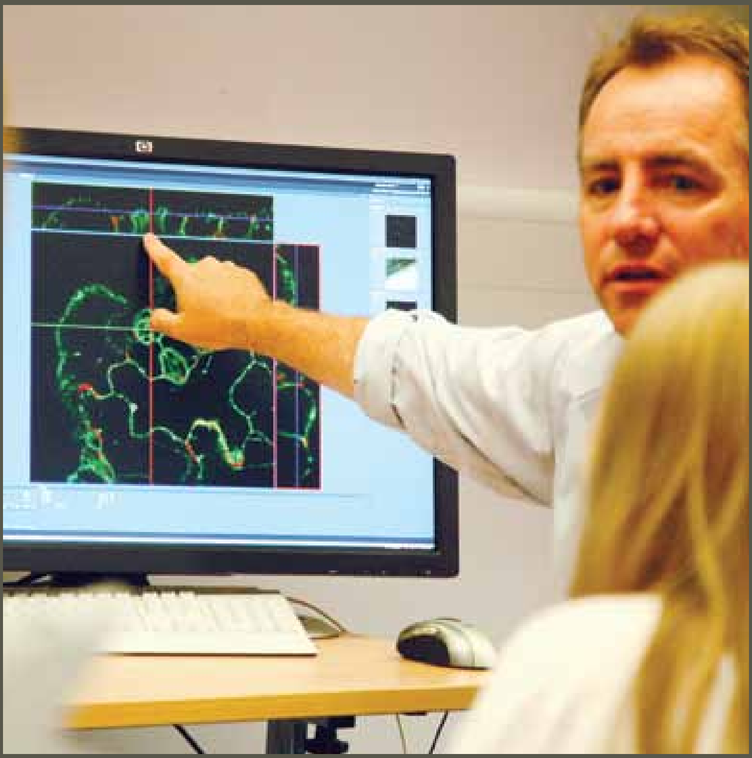
- The need for increased investment
- Investment in knowledge exchange
- Stability of funding

3: Collaboration

4: Regulation to encourage innovation

- Genetic modification
- Access to and benefit-sharing of plant genetic resources

Meeting the challenges



Educating and inspiring the next generation of plant scientists was identified as the top strategic priority to be addressed at the UK level.

To address the research challenges identified in our survey, it is critical that we produce successive generations of adaptable, diversely skilled plant scientists. A talented workforce will also attract overseas investment in R&D, acting as a major driver for UK innovation and economic growth.

According to our survey results, the UK is judged to be strong in fundamental plant science research, particularly in the following areas:

- plant–pathogen and plant–pest interactions
- plant genetics and genomics
- cereal breeding
- plant genetic modification (GM) technologies
- ecology
- abiotic stress response
- resource use efficiency
- plant phenotyping
- plant molecular biology.

Despite the UK's strengths in many areas of plant science, 96% of senior personnel from a range of UK public, private and third sector research institutions expressed concerns about gaps in plant science skills within their own organisations. Furthermore, aside from funding issues, insufficient numbers and an inadequate skills base were seen as the greatest barriers to meeting future challenges in UK plant science.

96%

96% of organisations surveyed expressed concerns over gaps in the skills of UK plant scientists

Education, training & skills

In 2009, the Biotechnology and Biological Sciences Research Council (BBSRC) and the then Biosciences Federation[c] held a public consultation to identify strategically important and vulnerable areas of UK bioscience expertise. Plant and agricultural sciences were highlighted by more respondents (76%) than any other discipline as strategically important capabilities that were already vulnerable or liable to become so.[51]

According to the 47 organisations we surveyed, the UK still has major skills shortages. We need improved training in-house, as well as through degree, postgraduate and specialised courses, in the areas of:

- general plant science
- taxonomy and identification
- crop science
- horticultural science
- plant pathology
- plant physiology
- field studies.

Additional shortages were noted in ecology, plant entomology and nematology, genetics and weed science.

Applied and field skills are particularly in demand. For example, employers reported difficulties hiring scientists with specialist practical expertise in plant taxonomy, horticultural science, plant pathology and soil science.[51–53] Without sufficient education and training opportunities in these areas, research bottlenecks will form and outputs will fail to translate into practice.

Being prepared for and responding to plant disease outbreaks is a case in point. Although the UK has centres of excellence in the molecular biology of plant disease resistance pathways, there is a major shortage of UK field pathologists.

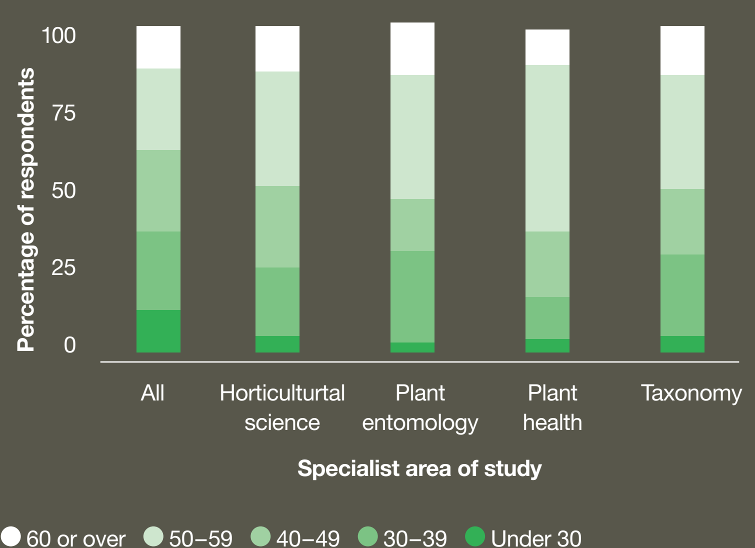
A large proportion of professionals with specialist plant science skills are nearing retirement and there is a shortage of UK expertise available to replace them.

- 62% of plant health specialists surveyed were aged 50 or over – only 4% were under 30 years old.[d]
- 50% of taxonomists surveyed were aged 50 or over – only 5% were under 30 years old.
- 49% of horticultural scientists surveyed were aged 50 or over – only 5% were under 30 years old.

Recent reports have also highlighted concerns about the age profile of the scientific workforce in these areas, as well as in plant entomology, physiology, breeding and soil science.[51–56] The nation's capacity to teach these subjects has already been compromised and vital skills have been lost from the UK scientific community. If no action is taken, this loss may be irreversible within 10–15 years.

It is crucial that education and training strategies are designed to respond to the needs of industry and technology sectors so that scientists are equipped with the necessary expertise for success in employment and to benefit society at large. Useful opportunities could be created through apprenticeships, employer-led training, industrial studentships, degree content, further education, postgraduate courses and teaching fellowships.

Age profile of survey respondents in vulnerable skills areas



[c] In 2009 the Biosciences Federation merged with the Institute of Biology to form the Society of Biology.

[d] Overall age distribution of 216 survey respondents who provided information on their age and research area: 13% under 30 years, 24% aged 30–39 years, 25% aged 40–49 years, 25% aged 50–59 years, 13% aged 60 years or over.

Reasons for skills gaps

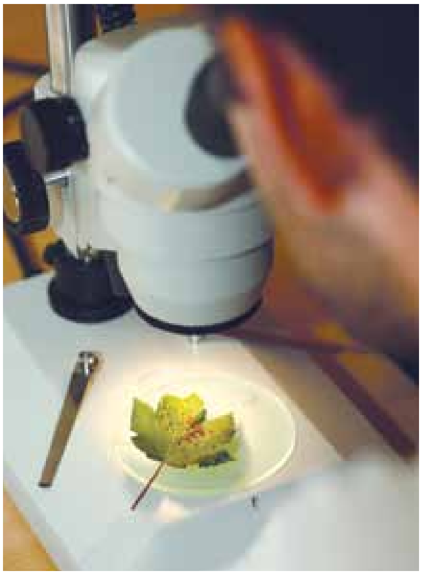
Low student interest in plant science reduces course availability

Many respondents expressed concerns about the low level of plant science uptake by students at degree level. Previous research carried out on behalf of the Gatsby Charitable Foundation also showed that the majority of UK students beginning biological science courses at university show little interest in, or knowledge of, plants.[57]

One reason cited for the low uptake of plant sciences was a perceived lack of clear career options for plant science graduates. Because of the increasing need for plant scientists to tackle major sustainability issues, more effort is needed to communicate the relevant opportunities to students considering bioscience degrees and careers. A leaflet produced by the Society for Experimental Biology and the UKPSF in 2013, titled 'Your Future with Plant Science', aims to address this need.

The relatively low level of student interest in plant science compared with other biosciences has contributed to a decline in the number of UK higher education institutions (HEIs) offering specialist plant science degree courses.[53,54,57] Although many UK universities include some plant science within biology degrees, others offer little exposure to it.

Evidence suggests however, that exposing first year undergraduates to high quality plant science teaching can be successful in stimulating greater interest and uptake of plant science courses in their second and final years, and can increase the number of graduates selecting plant-based PhDs.[58]



The Gatsby Plant Science Summer School

In 2004, the Gatsby Charitable Foundation began an annual summer school that selects 80 high-achieving first year undergraduate students from 26 UK universities. It immerses them in a week-long series of lectures, tutorials, practical classes and careers sessions, covering a broad range of cutting-edge plant science topics.

A five-year study on the impact of the summer school demonstrates that participants show a significantly greater and sustained interest in plant science afterwards. Many changed their degree course selection to contain more plant science modules and those who went on to study for PhDs were nearly four times more likely to choose plant science topics than biology graduates who had not attended the school.

Levesley, A. *et al. Plant Cell* **24**(4), 1306–1315 (2012).

Changes to biology curricula in schools and colleges

Biology is a core part of science curricula across the UK, and the most popular science at A-Level. It has proved difficult to keep the biology curriculum in step with contemporary research as well as reflecting the broad base of core concepts across the many biological disciplines.

The current position has left plant science poorly represented in biology curricula compared with biomedical science. This provides little incentive for busy teachers to invest time and energy in plant science education – particularly those who have neither a significant background in plant science from their degree, nor many opportunities to gain professional development in the subject. Furthermore, with plant science less visible at university, teachers may find it difficult to encourage school students to appreciate its importance as a thriving area of bioscience which they should aspire to study.

Unstable funding influences education and training

Funding fashions and patterns strongly influence which areas flourish or remain as richly skilled. Changes in political priorities and persistent erosion of funding for undervalued areas inevitably lead to skills shortages in certain areas.

- The withdrawal of Government funding from near-market research in the 1980s, followed by annual cuts to Defra's R&D budget since 2005,[59] have led to a decline in applied science skills.

- BBSRC continues to run competitive research funding calls, allocating grants to a percentage of applications submitted to a committee. This method may not be the most appropriate for small fields of research as it can have disproportionate effects on the future of the discipline.

- The combination of costly infrastructure requirements (e.g. controlled plant growth facilities) and restricted funding opportunities for plant sciences, can encourage narrower faculty recruitment concentrated in specific areas. This in turn exacerbates the risk to vulnerable plant science topics and leads to degree courses with gaps in these areas.

Uneven distribution of skills

The distribution of expertise across UK research institutions is less even in some plant science specialisms than others, with the majority of skilled scientists concentrated in non-teaching organisations.

- Most field plant pathologists in the UK are based within a small number of research institutes.

- UK crop research tends to be focussed within research institutes and companies because universities often lack the finances and facilities to carry out this type of work.

In areas where the majority of expertise resides outside of the academic community, the capacity of UK HEIs to teach particular specialist topics is potentially compromised and many such topics are not represented well in undergraduate courses.

Lack of employer-based training

For non-educational organisations it does not make economic sense to provide in-house training to graduates lacking particular expertise if there is a supply of suitably trained staff from overseas. Companies therefore recruit from elsewhere in the world so as to obtain the skills they need at minimum cost. Nevertheless, even for highly skilled scientists, the stringency of immigration restrictions makes this increasingly difficult.

Technological innovation and economic impact require continuity throughout a research delivery system with a balance of basic and applied research that sees ideas through from concept to application. Achieving a healthy flow throughout this system requires a joined-up funding strategy that maintains critical outputs of fundamental knowledge, addresses strategic research priorities and preserves and builds on scientific skill sets.

UK plant science receives a total investment of approximately £125m per year from Government, levy boards and charities. This includes research and capital investment of £75m from BBSRC and £23.3m from the Gatsby Charitable Foundation,[e] the two major funders of plant science research in the UK. Smaller contributions are also made by the Technology Strategy Board, Defra, Agriculture and Horticulture Development Board, Natural Environment Research Council (NERC) and Engineering and Physical Sciences Research Council (EPSRC). However, plant science receives less than 4% of UK public research funding.

Annual UK plant science research spend

Funding body	Total funding, £m per annum	Plant science funding, £m per annum
Biotechnology and Biological Sciences Research Council[f]	387.1	75.0
Natural Environment Research Council[f]	124.3	6.4
Engineering and Physical Sciences Research Council[f]	568.5	2.1
Medical Research Council[f]	288.8	0.0
Economic and Social Research Council[f]	141.6	0.0
Science and Technology Facilities Council[f]	122.8	0.0
Arts and Humanities Research Council[f]	60.6	0.0
Technology Strategy Board[g]	301.8	5.8
Department for Environment, Food and Rural Affairs[f]	105.0	1.3
Department for International Development[g]	250.0	0.0
Royal Society[h]	42.0	No data obtained
Gatsby Charitable Foundation[e]	58.2	23.3
Wellcome Trust[f]	467.3	0.0
Cancer Research UK[g]	332.0	0.0
Gates Foundation[i]	36.8	0.0
Horticultural Development Company[g]	4.1	4.1
Home Grown Cereals Authority[g]	4.2	4.2
Potato Council[g]	3.1	3.1

Funding

[e] Average grant funding for financial years 2007/08–2011/12 (which included building the Sainsbury Laboratory, Cambridge). The expected future plant science spend is £13m per annum.
[f] Research funding awarded during the financial year 2010/2011.
[g] Research funding awarded during the financial year 2011/2012.
[h] Research funding awarded during the financial year 2009/10.
[i] Research funding awarded during 2011.

4%

Plant science receives less than 4% of UK public research funding

Our survey indicates that the UK plant science community agrees with Government and Research Councils over the high level research priorities for UK bioscience: food security, adapting to and mitigating climate change, conserving biodiversity, health and industrial biotechnology. However, 69% of survey respondents felt that the UK lacks an appropriate national strategy for investment in plant science to address these priorities.

The need for increased investment
Given the scale of the research challenges that plant scientists must address, greater public investment will be needed to achieve critical outputs.

UK plant scientists maintain their world-leading reputation despite receiving relatively low investment. However, the future of this reputation is far from assured; although they achieve relatively high impact, the annual number of UK plant science publications has decreased since 1996.[60] In contrast, publication outputs from 18 of the 19 other leading countries increased during this period,[60] as did the annual number of UK papers published across all scientific disciplines.[61]

Having one major public funding agency for plant science has potential merits in creating a coherent, overriding investment strategy. However, it has placed plant science at a disadvantage relative to other areas of biology that can obtain funding from multiple public sources. Non-strategic grant applications must compete for a very limited pot of BBSRC money (12–15% of BBSRC's responsive mode budget) and plant science research that does not fit easily within BBSRC's remit has few other opportunities to receive funding.

69%

69% of respondents said the UK lacks an appropriate national strategy for investment in plant science

Investment in knowledge exchange
Knowledge exchange was identified in our survey as the biggest weakness in the UK research and funding strategy. Communication between plant scientists and industry representatives from different stages of the research delivery system is crucial. Routes and networks to facilitate this will help to strengthen the whole community and provide opportunities to leverage more funding for research.

Translational research is currently funded through grants of up to two years of BBSRC follow-on funding, and support for business collaborations through BBSRC LINK grants and Technology Strategy Board awards. Academics must have a concept or product with a clear commercial application, and a business plan or commercial buy-in, to apply for these funding opportunities. This may be feasible for industrial biotechnological applications where the product is a chemical or enzyme, but for researchers working towards easing the food security crisis it can be a difficult funding structure. The timeframes involved in producing plants or plant products for commercial use are too long for many investors. For example, breeding programmes can take 10–15 years to develop a commercial crop variety after the pre-breeding stage. New varieties must then pass stringent field trials before they can be marketed in the UK. This represents a large financial investment with a high risk of failure.

A Government focus on funding the early stages of applied research for which there is no predictable pay-out for companies could bring great benefits. For example, the basic understanding of crop genomics can identify important traits which can be targeted by plant breeders. The greater the public investment in this stage, the greater the likelihood that an economic pull will be generated to attract industry funding later. The resulting knowledge would also be widely available for researchers around the world to use for public good.

There has been a significant push from Government to stimulate public–private partnerships, including new incentives developed as part of the UK Strategy for Agricultural Technologies. While UK researchers have the potential to do well as a result of these initiatives, it requires a change in culture for many scientists. Academics and industry representatives reported that they have been deterred by the heavy administrative load associated with Technology Strategy Board funding schemes, as compared to the previous Defra LINK programme. Furthermore, they expressed concerns that Technology Strategy Board funding opportunities are limited to strategic calls, rather than open calls which allow applicants to submit proposals based on work the industrial partner considers to have good business potential. Government and funders must address these issues to encourage greater uptake and increase the number of innovative concepts brought to market.

Stability of funding

Continuity and stability of funding were concerns among respondents. Strategic priorities rightfully change but past radical policy shifts, and the resultant restructuring of funding sources and allocations, have left holes in the research system. For example, the loss of funding for applied plant science from the Ministry of Agriculture, Fisheries and Food in 1986, followed by a 33% cut (in real terms) to the Defra R&D budget between 2005/06 and 2010/11, placed pressure on BBSRC to fill this gap. Resources are now spread even more thinly as a result.

An appropriate, stable balance of funding is needed, without the policy swings between more fundamental and more applied research which we have experienced in recent decades. Without sustained funding for fundamental plant science alongside financial support and encouragement for more applied and translational research, the research system risks fracture. It is crucial that the UK Strategy for Agricultural Technologies takes a long-term view and recognises the underpinning value of basic plant science as well as research of more immediate application.

A key attribute of fundamental research is that it is impossible to predict its future impact. Many pioneering breakthroughs with global influence originated from basic discoveries made in plant science.[62] For instance, the identification by UK researchers of small interfering RNAs (siRNAs) as mediators of gene silencing in plants[63] has given rise to numerous applications in drug development, gene therapy, diagnostics and crop biotechnology. RNA therapeutic technologies licensed to pharmaceutical companies are currently undergoing clinical trials, with the potential to generate multi-million pound revenues.

Timescales for funding must also be realistic. In practice, it is difficult for researchers to obtain sequential grants for long-term projects, so group leaders have three to five years to turn basic research into an applied concept that attracts industrial investment. This is a very short timeframe for plant scientists who often need to create several sequential generations of plants to obtain results, particularly those working on tree and crop species.

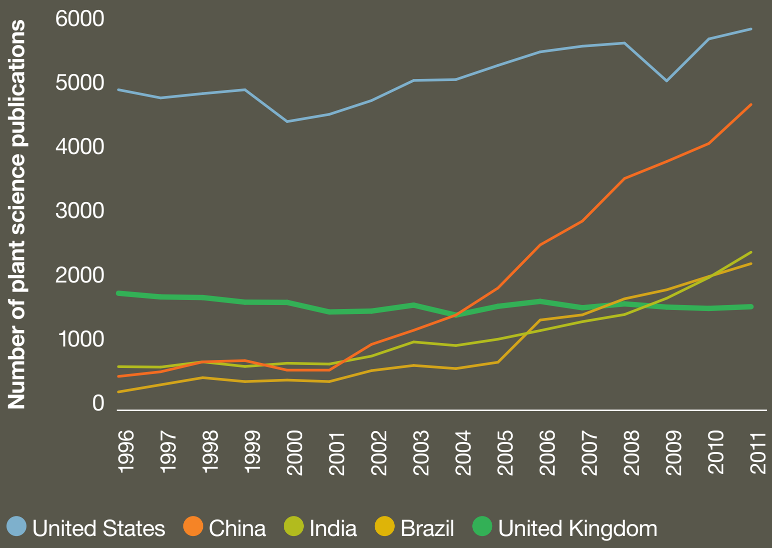
Survey respondents identified international collaboration and coordination as the most important strategic priority for UK plant science at the international level.

Many scientific problems of the 21st century span a multitude of disciplines and some of the key research questions are now too large to be handled by just one research group. Scientific papers from international collaborations also have greater citation impact than those that are purely domestic.[61]

UK Research Councils have recognised the ever-increasing need for collaborative work and have begun to encourage research partnerships by establishing special initiatives, cross-council funding schemes, industrial partnership and international partnering awards. Popular funding schemes among the plant scientists we surveyed included:

- Doctoral Training Partnerships (DTP)[j]
- CASE studentships[k]
- Crop Improvement Research Club (CIRC)[l]
- BBSRC Longer and Larger (LoLa) grants[m]
- Rural Economy and Land Use (Relu) Programme[n]

Plant science publication outputs by country[60]



Collaborative research has increased as a result of such schemes, and UK scientists are demonstrating their ability to generate impact by working with others. In plant science, the proportion of UK publications involving collaborations with other countries increased from 39% in 1996 to 69% in 2012 (compared with 47% of publications across all subjects).[1]

Even though UK plant scientists are already collaborating widely, it is vital to maintain the international competitiveness and leadership of their research to attract international partners and foreign investment. Emerging economies such as China, India and Brazil are investing heavily in science and technology and have now surpassed the UK in the number of plant science publications produced annually (although UK publication impact remains high).[60] While these countries continue to look towards global centres of excellence such as the UK for collaborative opportunities, it is important that these relationships are nurtured in the immediate term to pave the way for future alliances.

[j] www.bbsrc.ac.uk/dtp

[k] www.bbsrc.ac.uk/funding/studentships/case.aspx

[l] www.bbsrc.ac.uk/business/collaborative-research/industry-clubs/crop/crop-index.aspx

[m] www.monogram.ac.uk/wg6.php

[n] www.relu.ac.uk

Collaboration

Given the challenges associated with increasing sustainable agricultural production, scientists, breeders, industry and farmers must be able to deploy all of the advancing knowledge, tools and technologies available to them. This requires an evidence-based regulatory environment that encourages innovation.

Respondents expressed concerns that the current and future EU regulatory framework creates significant barriers to innovation in a number of areas. Specifically, these are:

- High costs, long timescales and commercial uncertainty with bringing GM crops to market under current regulations.
- Forthcoming legislation on access and benefit-sharing arrangements relating to the use of plant genetic resources may be onerous for industry and academics. This could discourage rather than encourage the use and exchange of plant genetic resources.
- The change from a risk- to hazard-based approach to decisions on approval or withdrawal of agrochemicals,[64] threatens to reduce crop yields and increase the cost of production.

Regulation to encourage innovation

Genetic modification

Genetic modification is a useful tool that can be exploited for crop improvement to deliver social, economic and environmental benefits. It offers the potential to overcome some of the limitations of conventional breeding methods; for example by conferring resistance to certain crop pests where there is no known resistance gene in the available breeding pool. However, within the European context there are difficulties.

The current EU regulatory approvals process for GM crop cultivation is slow and costly, and a politicised environment for decision-making causes a high degree of commercial uncertainty over bringing GM varieties to market.[65] This deters biotechnology companies from basing their R&D activities in Europe and investing in products for the European market.

During the past year, two major agricultural biotechnology companies, BASF and Monsanto announced their withdrawal of approval requests to cultivate GM crops in Europe. Both companies cited the lack of commercial prospects for GM varieties in the EU as reasons. BASF has also moved its plant science R&D headquarters from Germany to the United States where it said it would focus on developing varieties for "attractive markets" in the Americas and Asia.

As a consequence, the UK and the rest of Europe are falling behind other areas of the world in an important area of crop innovation, missing out on the associated creation of jobs and growth, as well as potential environmental and consumer benefits.

The UK has pioneered a number of crop transformation technologies over the past 30 years, the impact of which can be seen on a global scale.[66] However the limited opportunities for exploiting these technologies commercially have prevented the UK from reaping the benefits of its own innovations.

It is encouraging that the UK Government has begun to show support for the potential offered by GM research and has pledged to: *"work with the European Commission and other member states for consistency in the use of the precautionary principle, particularly as it applies to new and emerging technologies, GM and pesticides."* [14]

The UK at the forefront of plant transformation technologies

1983
Researchers at the Plant Breeding Institute (PBI) in Cambridge showed that bacterial genes could be inserted into the genome of a tobacco plant. The introduced genes were expressed and inherited by subsequent generations of plants.

1984
Mike Bevan at PBI created the first 'binary vector' – used to deliver DNA into plant cells to create genetically modified plants. The vector was distributed to thousands of researchers worldwide and became the foundation for many plant transformation technologies.

1987
Bevan and colleagues developed the β-glucuronidase (GUS) reporter gene system. This can be used to visualise a gene's expression at the cellular level in transgenic plants. The publication describing this system is the most highly cited paper in the field of plant transformation.

1988
Scientists at the University of Nottingham and agri-tech company, Zeneca, used anti-sense technology to silence a gene involved with fruit ripening in tomato. This led to the development of a GM tomato puree, the first GM food product on sale in the UK.

2012
The global value of transgenic crops was estimated to be US$14.84bn.

Bevan, M. W. *et al. Nature* **304**(5922), 184–187 (1983).

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Jefferson, R. A. *et al. EMBO J.* **6**(13), 3901–3907 (1987).

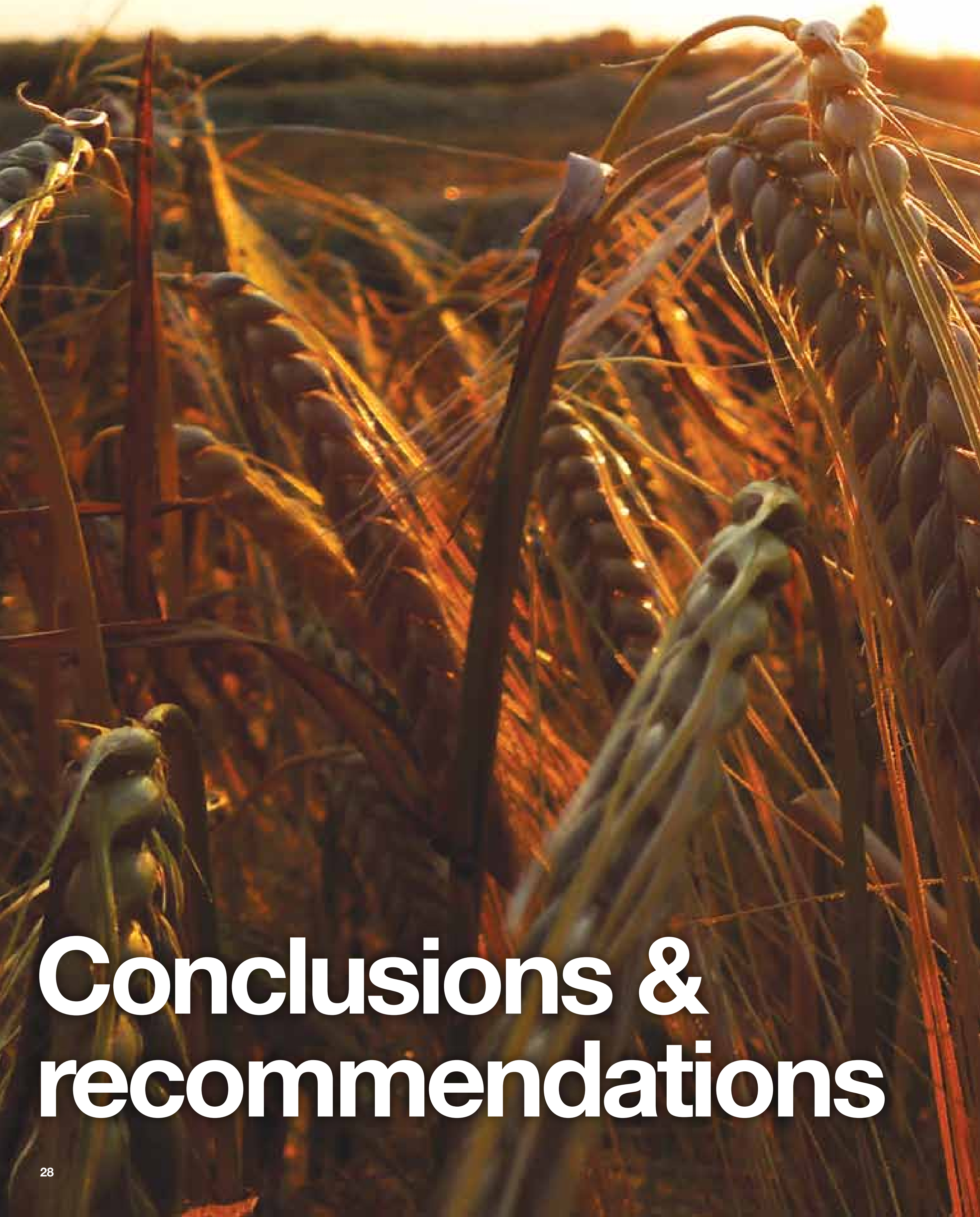
Smith, C. J. S. *et al. Nature* **334**(6184),724–726 (1988).

Access to and benefit-sharing of plant genetic resources

Genetic diversity is a valuable resource to scientific research and plant breeding.[67] However, the use and exchange of genetic resources can give rise to potential conflicts between the country of origin and scientists, over access to genetic resources and the sharing of associated benefits.

The 2009 International Treaty on Plant Genetic Resources for Food and Agriculture[68] established an effective standard Material Transfer Agreement for access and benefit-sharing of genetic resources from 64 major food crops. However, some species important to the UK economy and research base are not covered, including soft fruit (excluding strawberry), ornamental flowers and vegetables.

The Nagoya Protocol of the Convention on Biological Diversity[69] is intended to define access and benefit-sharing arrangements for species not covered by the International Treaty. It is similar in scope to the Treaty, and is being implemented in several countries worldwide. At the time of writing, the EU is negotiating a regulation to implement the Nagoya Protocol. The final wording is not yet agreed but the European Parliament has proposed a number of measures that go beyond the requirements of the Protocol and, if implemented, may represent a deterrent rather than incentive to use plant genetic resources in research and breeding. It is important that all plant science stakeholders are informed and actively involved in relevant discussions, as high-level regulations could have major implications on day-to-day research.



Conclusions & recommendations

Increased investment in plant science is urgently needed

Government and industry must work together to build capacity by doubling current funding across the spectrum of plant science. They must develop integrated fundamental and applied programmes of research to increase crop productivity and resilience while conserving natural ecosystems. Centres for Agricultural Innovation that focus on crop improvement and crop protection would deliver much-needed progress towards food security and sustainability.

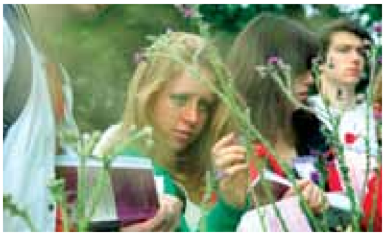
Stability of funding is essential in the long term

Extreme swings in policy and research funding priorities on a 5–10 year cycle are destructive to skills, infrastructure and innovation. We must create a long-term, balanced portfolio of basic and applied plant science research to generate a more durable system that produces a constant flow of knowledge and research outputs. This will be crucial to reinforce the UK's position as a world leader in plant science, which in turn will attract greater international collaboration and commercial investment.

Effective translation of plant science research into applications is vital

We need to increase the number of plant scientists engaging in public–private partnerships. Plant science must be well-represented in knowledge exchange schemes generated through, for example, the UK Strategy for Agricultural Technologies. Mechanisms to support translation of research into practice must be simple, stable and readily accessible, to encourage the scale of uptake necessary to maximise opportunities for beneficial innovation.

Conclusions & recommendations



We must inspire a new generation of plant scientists

Organisations responsible for developing biology qualifications must actively involve plant scientists to ensure the content of their qualifications and associated materials support high quality plant science learning in schools and colleges. Trainee and qualified biology teachers must have greater access to opportunities to enhance their knowledge in plant science and develop strategies to teach it at secondary level. Universities must respond by encouraging and supporting teachers of bioscience undergraduates – potentially through teaching fellowships – to incorporate plant science more effectively into their courses.

Education and training must meet the needs of employers

Employers and educators should provide more and better-targeted apprenticeships, employee training, industrial studentships, degree content, further education and postgraduate courses. Training should be a core requisite of the Centres for Agricultural Innovation created through the UK Strategy for Agricultural Technologies. Education and training opportunities must be directed to fill skills gaps in plant taxonomy and identification, crop science, horticultural science, plant pathology, field studies and plant physiology.

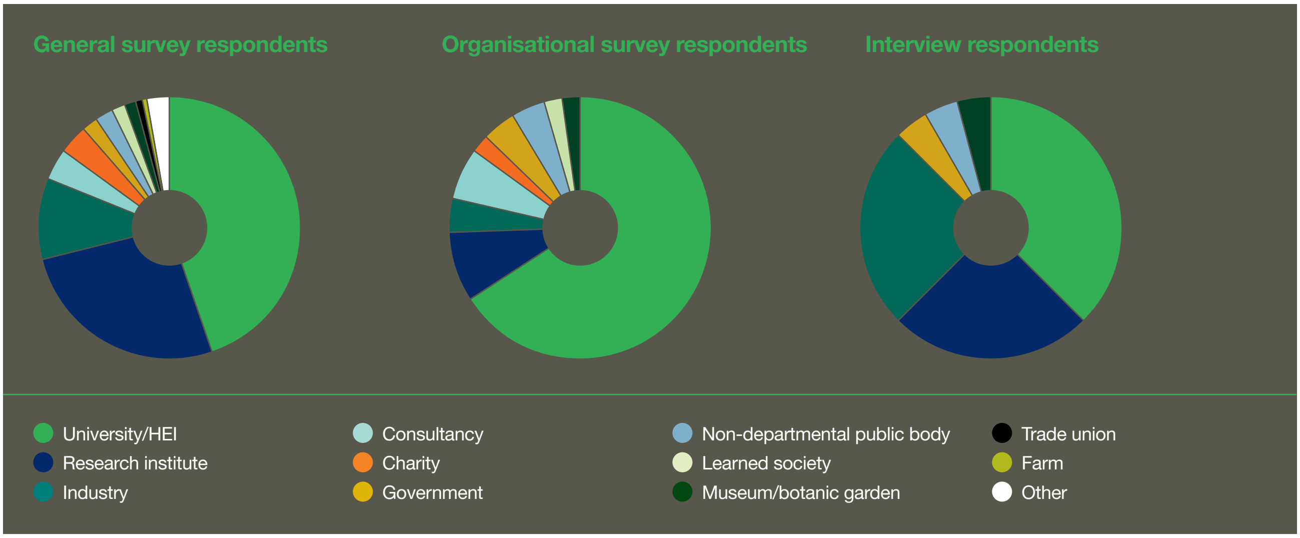
Regulatory frameworks must be more evidence- and risk-based, transparent, and enabling of innovation

Given the challenges associated with sustainable intensification, it is crucial that plant scientists, commercial plant breeders, industry and UK farmers are able to deploy all of the advancing knowledge, tools and technologies available. The UKPSF will support efforts made by UK policymakers and regulatory bodies to remove unnecessarily burdensome regulation and ensure that science-based evidence is paramount in determining the balance between benefits and risks of adopting new technologies, products and practices.

Annex – Data collection and response demographics

Data presented in this report were collected through surveys and interviews with plant scientists working across a range of disciplines and types of organisation in the UK.

Our primary survey asked 257 individuals to specify what they consider to be the major challenges for UK plant science to address during the next decade, and what they think about the current strategy for funding and management of UK plant science. Views were also obtained on the current status and requirements of plant science training and skills in the UK, through a survey of 47 heads of departments and organisations associated with the plant sciences. Following the surveys, in-depth interviews were carried out with 24 individuals representing a cross-section of expertise within the UK plant science community.



Abbreviations

BBSRC	Biotechnology and Biological Sciences Research Council
bn	billion
Defra	Department for Environment, Food and Rural Affairs
EPSRC	Engineering and Physical Sciences Research Council
EU	European Union
GDP	gross domestic product
GM	genetically modified / genetic modification
GUS	β-glucuronidase
HEI	higher education institution
IBERS	Institute of Biological, Environmental and Rural Sciences
m	million
NERC	Natural Environment Research Council
PBI	Plant Breeding Institute
R&D	research and development
RNA	ribonucleic acid
siRNA	small interfering RNA
tn	trillion
UKPSF	UK Plant Sciences Federation

Report design by vincentdesign.co.uk

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