

UK bioscience

helping to safeguard the future supply of
our daily bread



British farmers produce some of the highest wheat yields in the world – 7.8 tonnes per hectare in 2013. The competitiveness of this highly valuable national industry is underpinned by a strong UK research base with a world-leading track record in wheat genetics and breeding.

The global challenge

Wheat is an important staple crop, providing 20% of all calories consumed by people worldwide¹. It is the leading source of vegetable protein in human food.

Demand for wheat is predicted to increase in the future as developing countries adopt more western diets². With the world's population set to reach nine billion by 2050, wheat production will have a crucial bearing on food security and the global economy in the coming decades. And, when combined with factors such as climate change and rising energy costs, farmers around the world will have to increase wheat production with more pressure on land while using fewer resources such as fertilisers, pesticides and water.

Historically, the UK has made good progress towards increasing yields. In 1940, wheat yields in Britain were around 2.5 tonnes per hectare³. New varieties and better farming practices introduced in the 1970s – during the 'Green Revolution' – mean that UK farmers regularly harvest more than eight tonnes per hectare today, compared to a worldwide average of about three tonnes per hectare. Yet, the rate of wheat yield increases in developed nations such as the UK has slowed since 1980 and, given the World Bank's estimate that global wheat production will have to rise by 60% between 2000 and 2050, this is a major concern.

Now, with access to new gene-based technologies and other advances in plant science and sustainable agricultural practice, bioscientists hope to direct a further step change in wheat yields. But, before we can herald the 'Second Green Revolution', we need to understand what yields may be possible in theory, and understand the key processes involved, to underpin the delivery of further yield gains in practice.

“One billion people currently go to bed hungry every night. By 2050 there will be another two billion mouths to feed. And experts predict the world will need to be able to grow 70% more food.”

“The UK's world class bioscience sector is dedicating vital knowledge and expertise to tackling this global problem.”

“Farmers need these innovations to protect their own livelihoods and the health of their communities.”

Deputy Prime Minister Nick Clegg, speaking about the Sustainable Crop Production Research for International Development programme (see page 9).



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Maintaining the UK's leading position in wheat research

With a strong international track record of leadership in wheat genetics and genomics research, UK researchers are in a good position to identify the next generation of important traits that will underpin the ability of UK agriculture to respond to the most pressing strategic challenges:

- to increase wheat yields without compromising quality
- to make wheat farming more sustainable
- to protect crops from the threats of pests and disease
- to develop varieties that can cope with climate change

BBSRC's investments in underpinning fundamental plant science are essential to support these strategic wheat research aims. A large share of BBSRC's wheat funding goes to the John Innes Centre and Rothamsted Research (£22M and £17M between 2004-10, respectively). This reflects a research agenda that requires long-term commitment to coordinated programmes, resources and infrastructure. A number of UK universities have also received considerable funding from BBSRC, which has enabled them to contribute significantly to wheat research.

In order to continue to deliver world-leading wheat research and innovation, the UK research base must be able to respond flexibly to strategic opportunities and challenges as well as changing research opportunities and demands. It must have appropriate access to the necessary tools, skills and resources, and interact effectively with sector stakeholders to ensure maximum knowledge exchange and impact.

Read about how BBSRC is helping to achieve this on the following pages.



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Major UK wheat research breakthroughs:



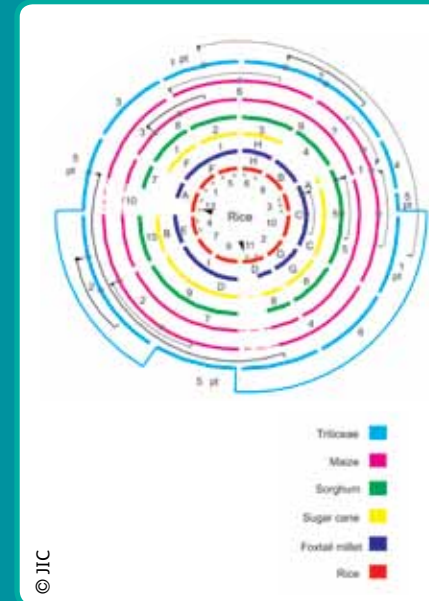
- The genetic basis of bread-making quality



- The Ppd1 gene, the primary gene controlling flowering time, discovered in the model plant *Arabidopsis*

- Ph1, the major chromosome pairing locus which stabilises wheat polyploidy

- Publication of the first draft sequence of the wheat genome



- Common patterns of gene order in the chromosomes of wheat and other cereals. This concept of cereal 'synteny' allowed rice and *Brachypodium* to be used for positional cloning of wheat and barley genes for major traits. Most genes that have been identified for major traits in wheat to date have been located through the synteny approach



- Discovery of the Rht1 gene – the so-called 'Green Revolution' gene which controls dwarfing

Setting a target

The **20:20 Wheat®** programme, launched in 2012 by BBSRC and its strategically-funded institute Rothamsted Research, has the goal of increasing UK wheat yields to 20 tonnes per hectare within 20 years.

Achieving this target would bring significant economic benefit to UK farmers, where every tonne per hectare increase in yield across the UK is estimated to be worth £318M per year at the farm gate. But the programme is not just about UK wheat yield: this ambitious target will help focus efforts to create multiple technologies that could benefit people around the world. Increasing wheat yield in Africa by two tonnes per hectare, for example, could have a significant impact on local and global food security.

The programme focuses on four main priorities:

1. **Maximising yield potential** – focusing on genetic improvement to increase total crop biomass and grain yield
2. **Protecting yield potential** – using advanced technologies to mitigate losses from important pests and diseases such as Septoria leaf blotch, Fusarium ear blight and 'Take-all'
3. **Determining soil resource interactions** – understanding how interactions between roots and the soil affect the way crops take up water and essential nutrients
4. **Using systems approaches to crop improvement** – exploring gene-environment interactions, complex traits and the performance of wheat types under climate change through mathematical models

The programme forms part of a larger body of work at Rothamsted Research to provide the scientific knowledge, innovation and new practices to increase crop productivity and quality, whilst developing environmentally sustainable solutions for agriculture through world-leading research in plant and soil science.



© Rothamsted Research

Learning from wheat's ancestors

The slowing of wheat yield increases is thought to be partly due to domestication eroding wheat genetic diversity.



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To overcome this bottleneck, experts in wheat genetics and breeding from the John Innes Centre, National Institute of Agricultural Botany, University of Nottingham, University of Bristol and Rothamsted Research are working together as part of the BBSRC-supported **Wheat Improvement Strategic Programme (WISP)** to identify new and useful genetic variation. They are doing this by performing experimental crosses of wheat 'parents' (wild wheat, landraces and other grasses, see page 7 National cereal collections for biodiversity conservation). They will also recreate the original cross that produced the first bread wheat to capture diversity from

modern wheat's ancestors. WISP researchers will use the resulting 'synthetic wheat' to produce new lines of bread wheat with improved resistance to diseases and insects, greater tolerance to drought, salt and heat, and enhanced yield.



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While these crosses may show poor agronomic performance compared to modern wheat varieties, they could help locate lost genes and traits valuable for improving performance in UK and global agriculture. The resulting resources, new genetic markers required for precision breeding and seed from experimental crosses, will be made freely available to breeders and researchers worldwide, although UK breeders and farmers will be among the first to benefit from this knowledge.

The resources created through WISP will also help young researchers initiate their own wheat research projects. The pooling of expertise will make it easier to train the next generation of scientists in skills needed for population development, genotyping and phenotyping – an emerging science that links genomics with plant ecophysiology and agronomy.

Co-ordinating public research funding

The Global Food Security Programme, as a partnership set up to coordinate key UK funders' strategic priorities, will play a major role in promoting a more joined up approach to research funding.



Led by BBSRC, the Programme is helping to facilitate appropriately co-ordinated, multidisciplinary research and related activities and the translation of research into practice and policy to generate positive impacts.

Tools and resources for wheat improvement

The size and complexity of the wheat genome – five times larger than a human’s – has been a significant barrier to crop improvement programmes. As a result, progress has been slower compared with other cereal crops such as rice – each wheat chromosome is bigger than the entire rice genome.

The UK has been a major contributor to the International Wheat Genome Sequencing Consortium (IWGSC). British bioscientists are using the latest sequencing technologies and championing new approaches towards this collective goal of completely sequencing the entire wheat genome sequence to reference standard. This will transform our ability to achieve strategic impacts in wheat improvement.

First draft genome sequence and analysis

In 2010, BBSRC-funded scientists took a major step towards sequencing the wheat genome by publicly releasing the first draft sequence of a reference bread wheat (Chinese spring). Although this draft was not detailed enough to determine the precise order of the genes, the sequences were sufficient to give access to 95% of all wheat genes and so were immediately useful.

A key feature of this research was the prompt release of the data into the public domain, in keeping with BBSRC’s data sharing principles, allowing other scientists and wheat breeding companies to use it rapidly in practical applications.

The work was conducted by scientists from the Universities of Liverpool and Bristol and the John Innes Centre (JIC) on Norwich Research Park, which receives strategic funding from BBSRC. The researchers collaborated with The Genome Analysis Centre (TGAC), also on Norwich Research Park, a national sequencing and bioinformatics facility established by BBSRC in 2009.

In November 2012 many of the same BBSRC-funded team, working with other UK, German and US scientists, published the first analysis of the bread wheat genome in *Nature*. The identification of around 96,000 wheat genes, and insights into some of the interactions between them, was a major

breakthrough towards breeding wheat varieties that are more productive and better able to cope with disease, drought and other stresses that cause crop losses. The data were again made freely available to other researchers, and the publication was greeted enthusiastically by many across the industry:

“An excellent example of how to achieve technology transfer from research lab through to practical deployment.”

The British Society of Plant Breeders

“[This] has proven to be an invaluable framework to identify sequence variation between wheat varieties. This in turn allowed the development of marker systems to interrogate the wheat genome in a much more efficient manner than hitherto possible; in particular to map the location of gene variants underlying important traits such as yield, quality and disease resistance.

“The important point is that wheat breeders can genetically dissect complex characters such as yield stability in a much more efficient manner than previously possible and thus can more rationally construct improved wheat varieties.”

Dr Peter Jack, from RAGT seeds



© JIC

National cereal collections for biodiversity conservation

The JIC **Germplasm Resources Unit**, a BBSRC-supported National Capability, holds the most authoritative cereal collections in the UK comprising 9,533 wheat, 10,841 barley and 2,640 oat accessions.

In addition to modern wheat cultivars, the collections include heritage varieties and locally-adapted primitive varieties or ‘landraces’ from across the world as well as large holdings of their wild relatives.

These collections form an important component of the UK’s contribution to the conservation of global plant genetic resources. Read an example of how researchers are using wheat’s ancestors to inform modern breeding programmes on page 5 Learning from wheat’s ancestors.



© Rothamsted Research

GM wheat on trial

BBSRC-funded scientists at Rothamsted Research are seeking novel ecological solutions for the control of cereal aphids, which reduce yields by sucking sap from plants and by transmitting harmful plant viruses.

Currently a large proportion of UK wheat is treated with broad spectrum insecticides whose repeated use can lead to resistant aphids. They also kill non-target insect species, which could damage biodiversity.

In 2012, the team planted a field trial of wheat that had been genetically modified to produce an alarm pheromone, (E)-β-farnesene, which is produced naturally by some other plants to repel aphids, but which attracts aphid predators such as ladybirds. The hope is that this will prevent these damaging pests from attacking wheat.

This work is the product of years of studying how insects naturally interact with one another, and with the plants that surround them in the ecosystem, through their natural chemistry. The decision to use genetic modification as a tool was taken after trying other approaches (such as synthetic dispensers and essential oils), which did not provide effective delivery of the repellent odour.



From lab to market

Wheat is a particularly critical crop for the populations most exposed to current and anticipated failures in food security. There are in the order of 1.2 billion wheat-dependent poor and 2.5bn⁴ wheat-consuming poor, living predominantly in Africa and Asia where wheat yields are particularly threatened by climate change-induced temperature increases. This was the driver behind a unique multi-national initiative to improve the sustainability of vital food crops, including wheat, in sub-Saharan Africa and Asia.

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Sustainable Crop Production Research for International Development (SCPRID)

The £16M SCPRID initiative brings funding from BBSRC and the UK Government's Department for International Development, with the Bill & Melinda Gates Foundation, the Department of Biotechnology of India's Ministry of Science and Technology and other partners.

Eleven research projects were announced as part of SCPRID in 2012, with the aim of building scientific capacity in developing countries, and tackling local scientific challenges.

Wheat research funded by SCPRID includes projects on:

- Sequencing DNA from historical collections to tackle wheat's worst enemy, 'yellow rust', to understand how it has evolved and to locate wheat genes best able to resist the pathogen in the future
- Exploiting wild wheat to produce better Indian varieties. The researchers aim to identify traits and genes in wild relatives which could be used in cultivated varieties to improve tolerance to heat and drought as well as resistance to pests and diseases

Underpinning support for UK industry

BBSRC has a strong track record of investment in collaborative research and training with industrial partners. For example, 13 stand alone wheat research projects have been funded through the LINK scheme since 2008.

CIRC also plays an important role in the supply of skilled individuals for academic research and industry through its support for targeted PhD studentships and employment of post-doctoral researchers.

14 companies have joined CIRC to date:

- BASF Plant Science Company GMBH
- Campden Technology Limited
- Elsoms Seeds
- HGCA
- KWS UK Ltd
- Limagrain UK Ltd
- Monsanto UK Limited
- National Association of British and Irish Millers (NABIM)
- RAGT Seeds Ltd
- The Scotch Whisky Research Institute (SWRI)
- Secobra Recherches
- Syngenta Seeds Ltd
- United Oilseeds Marketing Ltd
- Velcourt



The **Crop Improvement Research Club** is a £7M, five-year partnership between BBSRC, The Scottish Government and a consortium of leading companies, aimed at supporting innovative and excellent research to underpin the development of improved crop varieties that deliver increased productivity and consistent, high quality end products.

A key feature of the Club is the way that it facilitates the translation of knowledge between science and practice by providing the opportunity for seed companies, growers, processors and manufacturers to work together to support a portfolio of early, fundamental research and novel ideas.

The **AgriFood Advanced Training Partnership**, led by the University of Nottingham and also involving Cranfield University, Harper Adams University and Rothamsted Research, offers specialist courses in soil and water management, crop production and protection. It is one of four ATPs supported by BBSRC to deliver postgraduate-level professional development to agri-food industry specialists across the UK.

Making an international vision a reality

While wheat production varies considerably from country to country, all wheat-producing countries share the need to improve yield, tolerance to stress, pathogens and pests, as well as resource-use efficiency.

Cooperation, both between the public and private sectors and internationally, as well as the sharing of best practice will be vital to meet the targets for increasing global yields to at least 1.7% each year. For example, BBSRC funded researchers are making good use of BBSRC's International Schemes to develop international partnerships for wheat research. More than 20 awards have been made via BBSRC's International Partnering Awards, International Workshops and International Scientific Interchange Scheme.

In 2011, agriculture ministers from the G20 group of nations committed to developing an international initiative to coordinate worldwide research efforts in wheat genetics, genomics, physiology, breeding and agronomy.

The **Wheat Initiative** aims to encourage and support the development of a vibrant global public-private research community by sharing resources, capabilities, data and ideas to improve wheat productivity, quality and sustainable production around the world. It currently has members from public research and funding organisations from 12 countries, including BBSRC, as well as two international research centres and seven private global wheat breeding companies.

It will reinforce synergies between national and international research programmes for bread and durum wheat, improving agronomic practices and the development of innovative cropping systems, as well as facilitating and ensuring the rapid exchange of information and know-how among researchers, and supporting knowledge transfer to breeders and farmers.

One of the Wheat Initiative's key aims, increasing wheat yield and developing new wheat varieties adapted to different geographical regions, will be delivered by an international network of research funders and research organisations.

Instigated by BBSRC, CIMMYT (Mexico) and USAID (USA) in 2012, the network represents a long-term, global endeavour that utilises a collaborative approach to bring together funding from public and private research organisations from a large number of countries. It will support both core infrastructure and facilities alongside transnational open calls for research, all targeted at raising the yield potential of wheat.



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Over the first five years the partners are planning to invest US\$75-100M. All are committed to transparency, collaboration, open communication of results and data sharing and improved coordination to maximise global impact and eliminate duplication of effort. It is anticipated that the network will be formally launched in spring 2014.

At a glance

Wheat production was worth

£2Bn

to the UK economy in 2012, and processed wheat-derived products nearly ten times more⁵.

The UK's annual production is between

12-17M tonnes

of which up to **25%** is exported⁶.

Globally around **680** million tonnes of wheat is grown every year.

Wheat was grown on

two million

hectares of land (from a total of

17.2 million

hectares of farmland) in the UK in 2012⁷.

The wheat genome is

5 times larger

than the human genome and

37 times larger

than the rice genome.

Wheat is a particularly complex cereal to study. Some varieties have **two sets of chromosomes** (diploid), some have **four** (tetraploid) and **others six** (hexaploid).

Bread wheat (*Triticum aestivum*) provides over

20%

of the calories that we eat¹.

Over the next

50 years

more wheat needs to be grown than has been produced in the **10,000 years** since agriculture began.

In order to meet future demand the average annual increase in global wheat yield must jump from its current level of **below 1%** to at least

1.7%

Worldwide, more land is used to grow wheat than any other crop. It has overtaken rice to become the second most produced cereal after maize.

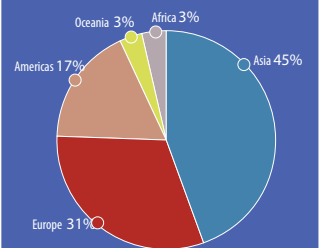
There are in the order of **1.2 billion**

wheat-dependent poor and **2.5bn** wheat-consuming poor, living predominantly in Africa and Asia⁴.

47%

of calories consumed in **North Africa and West and Central Asia** are from **wheat³**.

Wheat planted across continents⁸



BBSRC invests around £10M each year in world-class wheat research – from fundamental plant science through to pre-breeding, providing long-term support for national resources and helping to maintain the skills base.

By working in partnership with industry and the international research community, BBSRC ensures that efforts are focussed on creating the tools and technologies needed to increase UK and global wheat production, by sustainable means, and to meet future demands.

Further details can be found at www.bbsrc.ac.uk
Email: external.relations@bbsrc.ac.uk
Tel: 01793 414695

Further reading

Recommendations for a five-year strategy to help shape BBSRC funded wheat research
www.bbsrc.ac.uk/documents/2013-bbsrc-wheat-strategy-pdf/

Case study on UK wheat genetics research
www.bbsrc.ac.uk/documents/1310-wheat-genetics-uk-pdf/

www.wheatinitiative.org

¹ Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Sec.* DOI: 10.1007/s12571-013-0263-y

² Food security, farming, and climate change to 2050: Scenarios, results, policy options. IFPRI. DOI:10.2499/9780896291867

³ UK National Ecosystem Assessment Synthesis Report (2010)

⁴ Foresight. The Future of Food and Farming (2011) Final Project Report. The Government Office for Science, London.

⁵ Agriculture in the United Kingdom 2012 www.gov.uk/government/publications/agriculture-in-the-united-kingdom-2012

⁶ [Reference/webpagenolongeravailable–Feb2016]

⁷ Farming Statistics. Final Crop Areas, Yields, Livestock Populations and Agricultural Workforce at 1 June 2012, United Kingdom. Defra.

<http://webarchive.nationalarchives.gov.uk/20130123162956/http://www.defra.gov.uk/statistics/files/defra-stats-foodfarm-landuselivestock-farmingstats-june-statsrelease-june12finaluk-121220.pdf>

⁸ Wheat Initiative Vision

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