Food Security

- What Next?

“There is a crucial role for plant science in developing new crops that are able to adapt to climate change, that have increased yields from reduced inputs such as water and fertilizers, that resist pests and diseases without the use of chemicals, and have improved nutritional qualities.”

John Innes Centre

THE SAINSBURY LABORATORY

Professor John Beddington, chief scientific advisor to the UK government:

"By 2030 we will need fifty per cent more food, something of the order of fifty percent more energy and about thirty per cent more fresh water and we have to do this while mitigating and adapting to climate change. This could create the potential for conflict."

Cover quote:

Professor Mike Bevan, Acting Director, John Innes Centre

What is the problem?

More people

The UN predicts that 9.2 billion people are likely to occupy our planet by 2050.

This is a population increase of 50%, but grain production will need to double as more people adopt a western diet.

People in China and other rapidly developing countries are eating more meat and dairy products so more grain is needed for animal feed.

Meanwhile, climate change has eroded production in Australia and demand for biofuels has reduced the cereals available for food in North America. And there is little prospect of major new cereal producing countries emerging to meet demand.

Less land

Prime agricultural land is being lost to erosion, desertification, salinisation and urbanisation. A survey by the Chinese government predicted in November 2008 that harvests could fall by 40 per cent in half a century if soil erosion continues at its current rate.

Less water

Agriculture is the largest consumer of water. Globally 70% of all available fresh water is used for irrigation. But agriculture will increasingly have to compete with other sectors due to population growth, industrialisation and urbanisation.

Climate change

The predicted changes in rainfall and temperature, and an increase in extreme weather events (floods and droughts) all pose significant risks to agriculture. For example, four million tonnes of rice are lost annually due to floods in India and Bangladesh alone.

The global distribution of certain crop pests and diseases is already expanding. For example, wheat stripe rust appeared in South Africa for the first time in 1996 and in Western Australia in 2002. The notorious tobacco whitefly has also steadily spread northwards over the past two decades from the tropics into temperate regions, infesting and spreading viruses to horticultural crops such as tomatoes, cucumbers, and beans. In addition, one of Europe's most destructive insect pests of brassica crops, the diamond-back moth, is now regularly appearing on UK crops.

Carbon footprint

Although crop plants absorb CO_2 from the atmosphere, their production releases large amounts of CO_2 and other greenhouse gases into the atmosphere.

For example, greenhouse gases are released in the production of fertilizers and during the consumption of fuel in agricultural machinery and distribution vehicles. The strain agriculture exerts on the planet needs to be reduced at the same time as increasing productivity.

North West Europe is one of the few politically stable world bread baskets, with some of the highest yielding and best quality crops in the world. Cereals and grass flourish with cool summers, mild winters and ample rainfall.

Our stability also allows scientific discovery to flourish. The UK could be the global beacon that catalyses a change in how the rest of the world addresses food security.

One goal for plant scientists is to help breeders significantly increase the yield of food and feed crops in a sustainable way.

In the 1970s, scientists at the Plant Breeding Institute (now the John Innes Centre) contributed to work on semi-dwarfing genes that brought the Green Revolution to Europe, enabling wheat yields to double. A similar breakthrough is now needed and JIC scientists are well placed to contribute again.

How can science help?

More food and feed

Yield is a complex trait influenced by many different environmental and genetic factors. Traditionally it was thought that the genetic component determining yield was made up of many different genes each exerting a small influence, but recent work led by the John Innes Centre has challenged this view. Several stretches of the wheat genome, known as quantitative trail loci (QTLs) have been identified that exert large effects on yield, in different environments.

WHAT NEXT
JIC scientists will lead the effort to find the precise genetic basis for the effect of QTLs on yield.

Today, wheat provides more nourishment for more people worldwide than any other crop. Bread wheat provides about 20 per cent of the calories eaten by humankind and is the UK's biggest crop export. British farmers grow roughly 16 million tons every year and export 5-6 million tons.

The high fertility of wheat is derived from the stability of its hybrid genome and JIC scientists recently discovered the stretch of DNA, the Ph1 locus, that affords this stability.

The stability of the wheat genome has a downside, as it is a barrier to introducing new traits from wild relatives. There are many traits that would be useful for enhancing yield and reducing the environmental footprint of growing wheat, for example reducing pesticide use by improving disease resistance.

WHAT NEXT
The ultimate goal in studying the Ph1 locus is to switch off its activity to allow traits to be introduced, then switch it back on.

Less water

To improve production using less water will require improved planting methods and the development of suitable cultivars.

The Green Revolution was fuelled in part by the introduction of wheat varieties carrying the Rht ("reduced height") gene.

WHAT NEXT
Scientists at JIC are researching whether these varieties can withstand mild drought stress. The aim is to determine whether the currently used dwarfing genes are suitable for an increasingly unpredictable climate.

Adapting to climate change

Plant breeding could help adapt crops to climate change and enable them to remain productive.

Many plants are dependent for their productivity on subtle cues from the environment. For example, in order to set seed successfully, many plants must experience a period of cold to trigger a process called vernalisation.

JIC scientists have discovered the molecular mechanism behind this process. If it doesn't get cold enough, flowering is delayed or may not happen at all. Some of the plants that need to be vernalised are important food species such as sugar beet, wheat and brassicas.

By understanding processes such as vernalisation and by using advanced breeding techniques to increase plants' resistance to heat and water stress, we can help them adapt to changes in growing seasons and changes in temperature and water availability.

WHAT NEXT
Work from JIC is revealing how temperature signals are sensed and how plants use this information to control their development. This research will be key for breeding temperature and drought-resistant crops.

Working with breeders, JIC scientists are channelling basic research into new varieties.

Fighting pests and diseases

Millions of hectares of crops are lost to pests and diseases every year. Improved resistance would significantly increase the amount of grain that can be harvested on existing land. Exploiting natural genetic resistance will also reduce costs and reduce the environmental load from manufacturing and applying pesticides.

A JIC scientist has discovered a gene able for the first time to confer broad resistance to a disease in wheat.

WHAT NEXT
Tests are now underway to determine whether the gene, that confers resistance to stripe rust, is effective in UK-adapted varieties. In a research collaboration with the National Institute of Agricultural Botany (NIAB), research results will be made available to breeders, so they can be quickly deployed into modern varieties for farmers.

The Sainsbury Laboratory (TSL) at JIC has embarked on an ambitious programme of research in collaboration with the Two Blades Foundation (2Blades). The aim is to ensure that ground-breaking discoveries are rapidly translated into practical solutions for farmers in all corners of the globe. Where disease resistant crops can benefit less developed countries, 2Blades will distribute technologies at no cost through national and international agencies or through local seed companies.

WHAT NEXT
A new highly virulent strain of wheat stem rust is currently a major threat to cereal production worldwide. Research will focus on identifying new effective genes from wild relatives to provide lasting sources of resistance for cultivated bread wheat.

Potato late blight is one of the most damaging crop diseases in recent history, responsible for around £4bn a year of crop losses worldwide. TSL scientists are at the heart of a research team that recently sequenced and analysed the pathogen's genome, discovering the reason for its adaptability and virulence. They have also identified a gene from a wild relative of potato that provides resistance even against an aggressive strain prevalent in the UK.

Minimising future impacts

JIC is working with climate scientists at the University of East Anglia to predict the likely impact of pests and diseases in the future.

WHAT NEXT
Information on pathology and resistance mechanisms can be applied to a 'weather generator' to model future disease scenarios. Measures to minimize their spread and impact can then be developed.

With the recent warmer winters, aphids and other disease vectors are more active earlier in the season.

WHAT NEXT
JIC research on the insect proteins involved in virus transmission will help reduce the impact of disease-carrying insects.

Acknowledgement: Researcher in field image courtesy Eastern Daily Press

How can science help?

Reducing agriculture's carbon footprint

Nitrogen

The Haber-Bosch process produces nitrogen fertilizers and is responsible for about half the fossil fuel usage of modern agriculture.

Nearly 80% of the air around us is nitrogen. Most plants cannot use this nitrogen directly, but legumes such as clover and beans can. Bacteria living in 'nodules' in their roots take nitrogen from the air and 'fix' it into a form the plants can use.

WHAT NEXT
JIC scientists are currently experimenting with helping rice host these helpful bacteria, which might be achievable using genetic modification. Extending the range of crops able to fix nitrogen would revolutionise the potential for global sustainability by massively reducing the carbon footprint of agriculture. This is a long term aspiration at JIC.

In the medium term, new crop varieties with improved nitrogen use efficiency are needed to reduce fertilizer use while maintaining high yields.

Extensive use of nitrogen fertilizers leads to the release of nitrous oxide, a greenhouse gas with up to 300 times the warming effect of carbon dioxide. It also allows nitrates to leak into ground water, reducing the quality of drinking water and causing nutrient pollution and algal blooms in coastal sea areas.

Sulphur

Brassica crops have a particularly high demand for sulphur and need for sulphur fertilizer.

WHAT NEXT
A team including JIC scientists has already discovered a gene that could reduce the use of sulphur fertilizers. The scientists have discovered the key gene for controlling the accumulation of sulphate in the related model plant *Arabidopsis thaliana*.

Phosphate

Phosphate is an essential nutrient for plant growth and large amounts of phosphate fertilizer are spread on agricultural land. It is a non-renewable resource that is expensive to mine and transport. It also runs into rivers causing pollution.

Plants mine for phosphate in the soil using root hairs that grow out from the surface of the root. Plants with longer hairs can extract more phosphate form the soil than shorter hairs.

WHAT NEXT
Scientists at JIC have discovered the mechanism that controls the length of root hairs. Using this knowledge they are developing crops that are better at extracting phosphate from the soil. Less phosphate will be needed to maintain crop yields.

Reducing petrochemical use

Plants produce raw materials such as starches, oils and natural pharmaceuticals that can be used in the manufacture of products including drugs, lubricants and plastics.

WHAT NEXT
To help reduce our reliance on petrochemicals, JIC scientists are researching ways that plants could be used as "green factories".

Nutrition

An important aspect of food security is ensuring that our diet provides all the nutrition we need. In the West where food is abundant, many of us are still not eating the recommended five portions of fruit and vegetables a day to help prevent chronic diseases. The annual cost to the NHS of diet-related disease is estimated to be £20 billion and rising.

Plant pigments called anthocyanins, found at high levels in berries such as blackberry, cranberry and chokeberry, offer protection against certain cancers, cardiovascular disease and age-related degenerative diseases. However, berries are a seasonal fruit and can be expensive to buy.

Scientists at JIC conducted experiments to see whether a more common fruit, the tomato, could be engineered to be high in anythocyanins and have the same health benefits.

To test their potential benefits the tomatoes were fed to cancer-susceptible mice. The lifespan of the mice was significantly extended compared to mice fed a diet supplemented with normal red tomatoes.

WHAT NEXT

The scientists are also conducting research on potatoes to determine whether they can produce lines that combine enhanced flavonoid content with late blight resistance. Flavonoids are health-promoting compounds that are found at high levels in citrus fruits, berries, onions and tea but only low levels in potatoes.

Changes in agronomic practices and in climate are increasing *Fusarium* head blight. The disease contaminates wheat and barley grain with toxic metabolites and can harm human and animal health.

WHAT NEXT

JIC scientists are unravelling how the fungus infects the grain and are identifying sources of resistance that will protect yields and ensure safe cereals and cereal products for the future.

Capturing the breakthroughs

Our culture is oriented towards early capture and exploration of breakthroughs. The discovery pipeline is enhanced by inter-disciplinary goal-oriented clusters, focusing on model-crop translations, innovation and delivery of technologies and know-how to end users

Sharing knowledge worldwide

Certain vital scientific skills are in short supply. To share our excitement and knowledge of what is possible with leading-edge science, we are training the next generation of scientists both in the UK and abroad, and collaborating with breeders and other research organisations globally. JIC trains scientists at PhD, Masters and Post-Doctoral level.

For example, through the Kirkhouse Trust, two JIC scientists designed courses in marker assisted selection for plant breeders in Bangalore. Working with farmers who bring their knowledge of crop production and useful traits, the newly trained plant breeders can help make improvements to the local legume crop. In China JIC is training scientists in reverse genetics to help them identify the functions of rice genes.

JIC is also a participant in the Generation Challenge Programme to help developing countries access improved plants.

Our scientists have strong links with CIMMYT, an organisation to improve the productivity and profitability of maize and wheat in developing countries.

WHAT NEXT

With collaborators including CIMMYT, we are mining over 3000 lines of bread wheat collected from around the world in the early twentieth century. The aim is to identify new genes that will accelerate progress in wheat breeding programmes across the world.

John Innes Centre

John Innes has been at the forefront of scientific breakthroughs to benefit society since its foundation in 1910 with pioneering research in genetics. Today, research at the John Innes Centre is enabling us to tackle the unprecedented challenges facing the world being driven by human activity

- food security
- sustainable land use
- increased cost of energy and commodities
- living with the impact of rapid environmental change
- rapid loss of biodiversity
- reduced reliance on petrochemicals
- increased population pressures
- healthy ageing and control of infectious diseases
- the production of sufficient safe and nutritious food

www.jic.ac.uk

BBSRC bioscience for the future

BBSRC is one of 7 Research Councils that work together as Research Councils UK (RCUK). It is funded from the Government's Department for Business, Innovation and Skills.

BBSRC's mission is to promote and support high-quality basic, strategic and applied research and related postgraduate training relating to the understanding and exploitation of biological systems.

The BBSRC supports world-class research in some of the most exciting areas of contemporary science, with a total of around 1600 scientists and 2000 research students in universities and institutes in the UK.

Its research helps to tackle several major challenges such as the impact of climate change, a healthier old age, and sustainable food production, land use and energy production.

The John Innes Centre is an Institute of the BBSRC.

www.bbsrc.ac.uk
www.foodsecurity.ac.uk

THE SAINSBURY LABORATORY

The Sainsbury Laboratory receives generous core funding from the Gatsby Charitable Foundation, works in close partnership with University of East Anglia and the John Innes Centre, and is located at JIC.

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