



# Economic Impact

*“Science is the key to our prosperity, one of the driving forces of our economy, and it creates thousands of jobs that keep Britain at the leading edge.”*



John Innes Centre

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# Introduction

*“JIC contributes over £170 million annually to the UK economy”*

The John Innes Centre conducts basic research into plants and microbes.

Our research aims to answer key questions in biology and to provide solutions to important problems in food and energy production, promoting health and combating disease. We are able to take a long term view and have the skills and resources to make major advances in understanding that provide the foundations for achieving significant economic impact.

When President Obama addressed members of the National Academy of Sciences on April 27 2009 he spoke of the value of basic research:

*“No one can predict what new applications will be born of basic research: new treatments in our hospitals; new sources of efficient energy; new building materials; new kinds of crops more resistant to heat and drought.”*

This document describes some of the applications born of discoveries from basic research at the John Innes Centre and its antecedents. It attributes an estimated value to some of those applications, providing a snapshot of the economic impact of the institute’s research since it was first founded as the John Innes Horticultural Institution in 1910.

Recognising the contributions made so far gives us conviction that high-quality basic research at JIC will continue to contribute to knowledge generation and to economic advancement for UK plc and world-wide. In this document we also speculate on the future impact of our current research.

Working with our collaborators in academia and industry across the world, including our partner institutions on the Norwich Research Park, JIC science is directed at helping to find solutions to four of the six Grand Challenges defined by HM Treasury:

- Global Food Security
- Living with Environmental Change
- Healthy Ageing
- (Bio) Energy



## Background

The JIC is a company limited by guarantee and a charity. Our benefactor and major donor is the John Innes Foundation. Our principal research funder is the Biotechnology and Biological Sciences Research Council (BBSRC), together with the European Commission, and industry.

In 2008, JIC commissioned Edinburgh-based consultants DTZ to estimate the overall contribution our work has made to both the UK and the global economies.

"In part we asked the consultants to draw up this report in response to Treasury requests to provide evidence of economic benefits arising from our research" says Dr Steve Rawsthorne, science operations manager at JIC.



### ECONOMIC SNAPSHOT

JIC currently contributes over £170 million to the UK economy. The worldwide economic impact is more difficult to assess, but together with applications in the pipeline, this figure is likely to rise.

*"We knew full well that the work we have done has an impact, but the full scale of it was a pleasant surprise."*

## History

The John Innes Centre as it is known today was formed from:

The John Innes Horticultural Institution, 1910 – 1960

John Innes Institute, 1960 – 1990

The Plant Breeding Institute, 1912 – 1987

The Nitrogen Fixation Laboratory, 1963 – 1995

Following a bequest from Mr John Innes, a City of London merchant, William Bateson became the first director of the John Innes Horticultural Institution, later the John Innes Institute. It was the first UK centre for research in plant breeding and **genetics**. Bateson coined the word "genetics" and pioneered this new science.

Meanwhile, PBI pioneered the application of genetic principles to breeding improved varieties of wheat. Its first director, Sir Rowland Biffen, was the first plant breeder to recognise the potential of genetic improvement for developing economically important crop characteristics. In 1906 he said in a paper, "The breeder has now to recognise that new breeds can be built up with certainty by recombining characters."

In 1987 the PBI breeding programmes and farm site were privatised and the remaining scientists joined the John Innes Institute in Norwich as part of the Institute of Plant Science Research, which included the Nitrogen Fixation Laboratory at the University of Sussex. The latter moved to Norwich in 1995 after all of these organisations were merged in 1994 to form a new organisation, the John Innes Centre. Through this process, the scientific legacy of crop genetic improvement has continued at the John Innes Centre.



# A century of wheat improvement

Bread wheat, with an estimated world harvest of more than 550 million tonnes, is one of the most important food crops in the world. Today, the UK crop has an annual farm gate value of more than £2 billion, and is the UK's biggest crop export. British farmers grow approximately 16 million tonnes every year and export 2.5-3 million tonnes.

Biffen collected different wheat varieties from around the world to develop new lines from them. In 1916, PBI released the variety "Yeoman". British varieties, though better adapted to the UK and higher yielding, were unable to compete with foreign imports that made an aerated, fluffy loaf. Yeoman was a high yielding, strong wheat that made high quality loaves, and made a **major contribution to UK food supplies** in the early twentieth century.

In the 1960s and 70s, a 'Green Revolution' in agricultural production led to large increases in yield worldwide. The main contributors to this were elite wheat crops with the Rht (reduced height) character. This reduced the amount of straw in the plant while increasing grain yield.

Breeders at the PBI were among the first to use the Rht character to develop a stunningly successful set of wheat lines that dominated UK wheat production. This material is still used by breeders in the private sector, who have continued to increase wheat yields using knowledge generated at the PBI.

Scientists at the JIC identified the Rht gene itself in 1998 in a major breakthrough that increased our understanding of how plant height is controlled by hormones. Recent discoveries at JIC have also shown that the Rht gene can keep plants growing in sub-optimal conditions, suggesting new uses for this gene.



## ECONOMIC SNAPSHOT

Plant breeders, initially at the PBI, have used the Rht gene to increase UK wheat production by £75 million per annum. The contribution of semi-dwarfing genes to world wheat production is estimated at a staggering £3.4 billion annually.

Over its 75 year history breeders at the PBI produced over **130 new varieties of wheat and other crops**. The above figures are therefore just one example of its economic impact.

# Wheat research in the pipeline



## Wheat breeding

The success of wheat is partly due to its high fertility, a product of the stability of its genome. This stability is however also a barrier to introducing new traits.

JIC scientists have characterised a stretch of DNA responsible for the stability of the wheat genome, called the Ph1 locus. Ph1 is the major barrier to exchanging genetic material between the chromosomes of wheat and wild species. The scientists are now investigating the possibility of temporarily switching off the Ph1 locus to allow breeders to cross breed wheat with its wild relatives.

This has the potential to **revolutionise wheat breeding worldwide**. It would open up a large pool of desirable traits to commercial cultivars such as salt tolerance, drought resistance, pest and disease resistance and increased yield. These valuable traits are otherwise unavailable.

## Yield

Yield is a complex trait influenced by many environmental and genetic factors. 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 genome, known as quantitative trait loci (QTLs) have been identified that exert **large effects on yield**, in different environments. The molecular mechanisms underlying the genes are not well understood. JIC scientists are leading the effort to find the precise genetic basis for their effect on yield.

As part of this effort they are collaborating with the National Institute of Agricultural Botany (NIAB) on pre-competitive research to improve the genetic resources available to wheat breeders. JIC scientists are also leading work to determine the complete genetic make-up of bread wheat. This will be led by innovative applications of next generation DNA sequencing.

Wheat research has a profound social and economic impact because wheat feeds 40% of the world's population providing about 20% of the calories eaten globally.

## Nitrogen fixation

Plants require nitrogen, and crops require additional nitrogen to be added in the form of fertilisers. Fertilisers can increase yield by as much as 50%, but their production uses more fossil fuels than any other agricultural process. They also cause pollution when they leach into groundwater and the atmosphere. N<sub>2</sub>O created by producing and applying nitrogenous fertilisers is the most important greenhouse gas produced by agriculture.

Some plants, such as peas, source their own nitrogen by taking it from the air. These plants house bacteria in nodules on their roots. The bacteria take nitrogen from the air and convert it into a form of fixed nitrogen that plants can use. The interaction between the plant and the bacteria involves a complex system of signals.

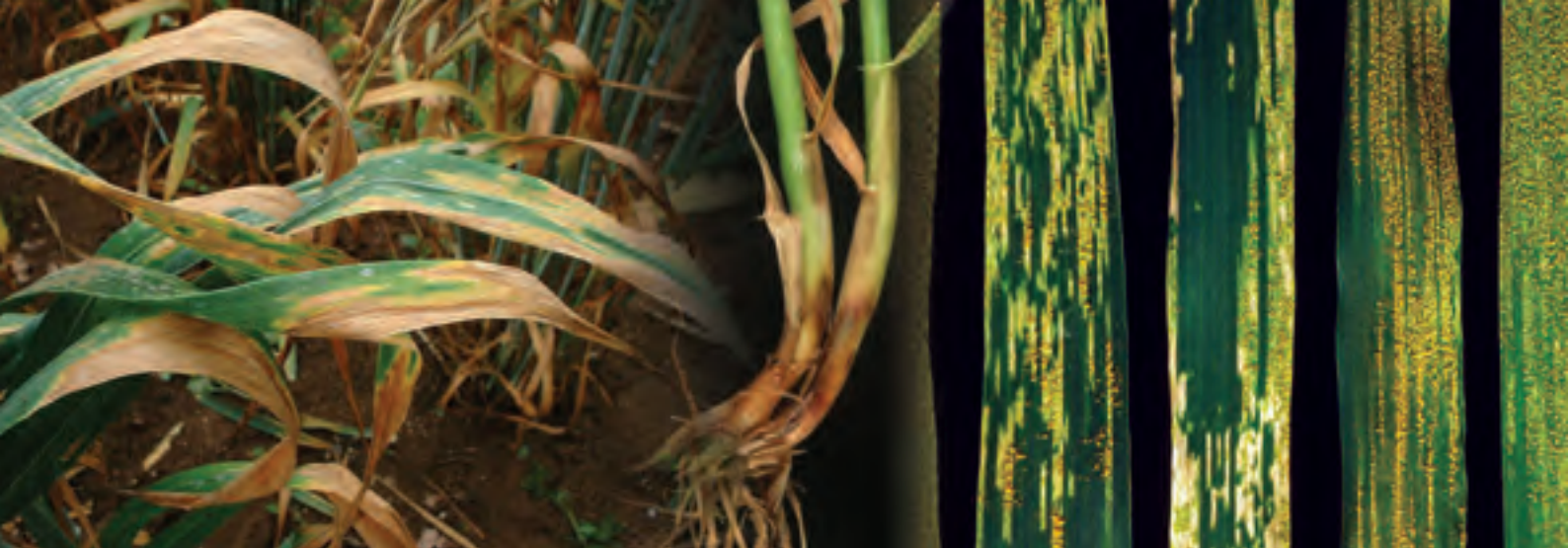
JIC scientists are working to understand these interactions and to develop new strategies to **transfer nitrogen fixation to other crops**. If successful these will lead to a substantial reduction in the carbon footprint of world agriculture and to the improved sustainability of crop production. Increased yields could be achieved with lower inputs.



### ECONOMIC SNAPSHOT

Nitrogen fertiliser production consumes 1.2% of the world's total energy on an annual basis. Extending the capacity for fixing nitrogen to maize, rice and wheat, would dramatically reduce the production costs of world agriculture.

Furthermore, by reducing the dependency of crops on an oil-guzzling and expensive process, it would also help reduce the impact of oil prices on the **price of food**.



# Combating crop diseases

Over the past 25 years, wheat production has been threatened by devastating diseases such as leaf blotch, yellow rust and eyespot. The major threats to barley have been scald and powdery mildew. These diseases cause total losses of at least £240 million per year in the UK.

Focusing on one disease as an example, leaf blotch caused by the fungus *Septoria tritici* is a major pest to high yielding varieties of wheat. In the major wheat-producing areas of the world, outbreaks are capable of reducing yields by 30-40%.

In 1998 in the UK alone, losses from this disease amounted to a cost of £35.5 million. Today ***Septoria tritici* is by far the most damaging foliar disease for wheat.**

During more than a decade of collaborations with breeding companies across Europe, JIC scientists have identified wheat genes that confer resistance to *Septoria tritici*. As one plant breeder put it, "JIC picked a hot topic before it was hot." This collaboration was behind the launch of the variety Alchemy in 2006, which is now the most widely grown winter wheat in the UK.

Full resistance is still yet to be achieved, so the collaboration with JIC continues to combat this pest.



## ECONOMIC SNAPSHOT

The worldwide impact on wheat production of achieving resistance to just one disease, ***Septoria tritici***, may be as much as £4.6 billion a year.

JIC is working on diseases experienced by UK farmers and farmers across the world, including the devastating 'take-all', a fungal disease most damaging to wheat and barley crops, and Ug99, a virulent strain of stem rust that first emerged in African wheat varieties.

Rusts are a global problem causing yield losses in millions of hectares annually. An estimated 37% of global wheat production is already affected by, or at potential risk from, Ug99 alone. Rusts evolve quickly to overcome resistance genes and fungicides. Scientists at JIC and The Sainsbury Laboratory on the same site are investigating ways to breed plants with broad, more long-lasting resistance.

Some crop diseases are caused by insect pests that are currently controlled by insecticides. Imminent legislation will restrict the use of many insecticides, so JIC scientists are investigating how plants, insects and the diseases they transfer interact. The new knowledge gained from this work will enable new management strategies to be designed without the use of banned pesticides.

The fundamental knowledge generated at JIC will also allow the agri-science community to **respond rapidly to newly emerging pests and diseases.**



Pea aphids



# More crop research

## Synteny – road maps to desirable traits

Synteny is a newly coined word that means “on the same ribbon”. The ribbons are chromosomes. Chromosomes vary widely between different organisms but similar blocks of genes can be found in the same relative positions. These blocks of similarity can be used to trace evolutionary history, or to look for the genetic basis of shared traits.

John Innes Centre scientists have studied the arrangement of genes in the chromosomes of cereal species. They discovered that all cereals share regions of similar gene order. This has allowed them to compare and line up genetic maps of barley, wheat, rice, maize, sorghum and millet.

These **‘road maps’ to desirable traits** are now part of the toolkit for research institutes across the world. They allow scientific goals to be achieved more quickly and efficiently, as required by their funders.

To provide a snapshot of how this translates into economic impact, organisations such as the International Rice Research Institute in the Philippines and CIMMYT (The International Maize and Wheat Improvement Center) in Mexico use such tools to help secure funding. Their combined annual budget is around £38 million, of which £2.6 million comes from the World Bank.



### ECONOMIC SNAPSHOT

JIC’s work on synteny can be seen to be supporting leverage of World Bank funding of £2.6 million per year into IRRI and CIMMYT.

## Peas

Research and breeding at John Innes Institute (JII) in the 1970s to improve the efficiency of pea harvesting led to the first registered “semi-leafless” pea varieties. Instead of leaves they have masses of intertwining tendrils that they use to hold each other up. They stand up better than more traditional varieties, are easier to harvest, have higher yields and use water more efficiently.



### ECONOMIC SNAPSHOT

Today the £38 million annual UK dried pea market consists entirely of semi-leafless varieties. They are also used extensively across the world.

Current research on peas could help breeders develop varieties able to withstand drought stress and climate change.

## Rapeseed

Rapeseed is cultivated in rotation with cereal crops, where it plays an important role in boosting their yield in subsequent seasons. It is the second largest crop worldwide after soybean for the production of oilseeds, and the third largest source of vegetable oil.

PBI scientists pioneered the development of doubled haploid lines that help plant breeders develop new varieties faster. Groups at JIC also pioneered the development of genetic maps that show the relative positions of genes controlling traits of interest. These maps provided the foundations on which all marker-assisted breeding work on oilseed rape has been built. A widely-used source of resistance to the important disease Light Leaf Spot came from work at JIC.



### ECONOMIC SNAPSHOT

The UK contributed 3.5% (2 million tonnes) of global rapeseed production in 2009 with the prices for rapeseed oil having reached \$900 per tonne. Improvement to a single trait, pod shattering, could double seed yields. Scientists at JIC have identified mechanisms involved in pod-shatter, providing clues as to how it can be controlled.

It is too early for most of the research conducted at JIC on brassicas to have reached the marketplace, but the potential is enormous as brassicas are such important food crops.



## More crop research in the pipeline

### Adapting crops to climate change

Crop productivity is critically dependent on optimal climate. Plants respond to adverse conditions by stopping growth, leading to reduced yields and major losses to farmers.

JIC scientists are uncovering the mechanisms by which plants respond, and hope to be able to alter these responses so they can continue to grow in sub-optimal conditions.

JIC scientists have also discovered how plants respond to over-wintering, a key agricultural trait that induces flowering the following spring. Flowering is the most important process in plant productivity. The detailed understanding of flowering built by JIC scientists in the past 20 years provides a strong foundation for adapting crops to an increasingly uncertain climate.

Recently, JIC scientists discovered that plants have a built-in **“thermometer” gene** that controls plant responses to small temperature changes. Further research in this area will provide crucial information for breeding crops able to cope with changes in growing seasons, temperature and water availability.

### Enriching crops

Scientists at the John Innes Centre and The Sainsbury Laboratory are developing improved potato lines with elevated levels of health-promoting flavonoids. Flavonoids are natural antioxidants that are better known for their abundance in berries and other fruits.

The improved lines will not only have added **consumer appeal** due to the health benefits, but they will improve the resistance of potatoes to late blight, giving them appeal to producers. A spin-out company called Norfolk Plant Sciences will exploit their global potential.

This research follows success in increasing anthocyanin levels in tomatoes. The tomatoes increased the life expectancy of cancer-prone mice and have received worldwide attention from the media and from industry. The anthocyanins gave them a rich purple colour.

### Making better bread and beer

As well as being a major energy store in plants, starch has many uses for humans. It is the main carbohydrate of nutritional importance in the human diet. In cereal grains, starch affects the baking quality of flour and the malting quality of barley for brewing. Pure starch from flour is also used in processed foods, paint, glue, paper, cosmetics, and biodegradable packing and plastic.

Each of these applications needs starches with different properties, but commercially grown wheat and barley contain starch with rather uniform properties.

Scientists at the JIC and the National Institute of Agricultural Botany (NIAB) have discovered wheat and barley lines from across the globe with starches of different physical properties. They are working with end users and breeders of wheat and barley to

**exploit commercially interesting lines.**

# Antibiotics

*Streptomyces* and other actinomycetes are the world's most important source of antibiotics, contributing over half of the current medically useful classes of antibiotics. Scientists at the JIC pioneered the discovery of genes responsible for antibiotic production in the soil bacteria *Streptomyces*. This work established ways to design new classes of anti-infectives that are able to combat major human diseases, including MRSA. It opens the possibility of creating designer antibiotics. JIC scientists continue to increase our understanding of how antibiotics are produced and are leaders in the commercialisation of their skills and resources. Their research **supports the discovery and commercial development of new antibiotics**. In 2008 the market for actinomycete-derived antibiotics was estimated at over \$11 billion.

Novacta, a JIC spin-out company, is working on discovering new anti-infectives that target *Clostridium difficile* and the superbug MRSA. It already has compounds in clinical trials. Deaths from *C. difficile* in England and Wales rose by 72% in just two years to reach 6,480 in 2007. A review by the National Institute of Clinical Excellence estimated the economic cost to the NHS of those deaths to be £194 million.



## ECONOMIC SNAPSHOT

If successful, the work on anti-infective technologies could save the UK economy £194 million by preventing avoidable deaths.

Another JIC spin-out, Procarta, is pioneering the development of a novel DNA based therapy to counter the growing problem of antibiotic resistance. The technology can also be used to extend the lifespan of existing drugs to which bacterial diseases have already developed resistance.

# Antibiotic research in the pipeline



JIC scientists continue to pioneer research into antibiotics, and provide indispensable skills, knowledge and technologies to aid our defence against killer pathogens.

They are pioneering fundamental research into an unusual class of clinically unexploited antibiotics that are **active against multi-drug resistant bacteria**. These studies have already led to the development of new antibiotics that are currently in clinical development.

They recently discovered that a "two-headed" antibiotic molecule neatly fits into two pockets of a bacterial enzyme. This enzyme is already targeted by antibiotics but the pockets have not been previously exploited. The discovery could help companies design new antibiotic molecules with a similar structure, or help them discover other molecules that fit into the pockets.





# Research frontiers

## Plant viruses to produce pharmaceuticals

Scientists are beginning to use plants to produce pharmaceuticals cheaply, safely, abundantly, and in a form that can be easily consumed. JIC scientists have already engineered cowpea plants to produce antibodies against a highly contagious gut virus that is particularly lethal to piglets.

The same technology helped produce candidate vaccines to the H1N1 swine flu virus in just 14 days. Chief Executive of the BBSRC Professor Douglas Kell commented:

*“This application shows the real value of investing in basic research in the early days so that we can have useful technologies further down the line.”*

The virus that causes the gut disease in piglets is similar to the virus that causes Severe Acute Respiratory Syndrome (SARS). Plants could be used to quickly generate large amounts of material to provide immediate protection to healthcare workers in the event of an outbreak.

Future research will look at producing cheap, reliable and convenient vaccines against **other livestock diseases**, including avian flu and blue tongue.

## Exploiting plant natural products

Plants produce a huge array of natural products that they use to colonize and adapt to their environment. These diverse products are not critical for survival under laboratory conditions, but in nature they give a plant certain advantages. For example, defence compounds to fight off herbivores and diseases, flower pigments to attract pollinators, or chemicals to suppress the growth of neighbouring plant species. They are also important because they promote health as part of our daily diet of fruit and vegetables.

Plant natural products are also exploited by humans as drugs, flavouring agents, fragrances, pesticides and food colourants. The diverse plants around the world produce about half a million different kinds of natural products and there is a rich reservoir of metabolic diversity that has not yet been tapped. JIC scientists are looking to understand how and why these compounds are made, with a view to discovering or engineering new products for agriculture, health and other bio-based industries.

For example, take-all is a fungal disease that affects around half the UK's wheat crops, costing the agricultural industry **up to £60 million a year**. Take-all cannot be easily controlled chemically or by choosing varieties with natural resistance.

However, JIC scientists have discovered that an antimicrobial natural product produced by oats provides protection against the take-all fungus. They also discovered that a cluster of genes is behind the production of this compound. Experiments are now underway to transfer components of this gene cluster from oats into wheat and other crops in order to breed resistance into them.

# Horticultural research

## Roses

From 1945 to the 1960s, the John Innes Horticultural Institution (JIHI) was home to the UK's national collection of roses with nearly 800 species. The keeper of the collection Gordon Rowley also assembled 31 of the most popular root stocks for experiments on rose propagation, compatibility problems, and field trials using different soil types.

Eight years of tests with rootstocks revealed that vigour and cold resistance are connected with the type of stock used. This means that the choice of stock influences plant size, the number of flowers produced and the growth of new shoots.

These insights provide the basis of the propagation technique used today to produce **many millions of roses** annually.

## Fruit

In 1951 the JIHI sent a series of woolly aphid-resistant apple rootstocks to research stations all over the Commonwealth and the US. Woolly aphid devastation was spreading round the world from Europe and North America. The rootstocks were the result of 30 years' experimental breeding by JIHI and East Malling Research Station. One is still a standard rootstock for garden and commercially grown apples today.

Fruit breeding was one of the main lines of research at the JIHI until around 1970. The first John Innes fruit variety to be released was a blackberry that went on general sale in 1934. This was the first of **53 new fruit varieties** released by JIHI over the next five decades. Other fruit studied included raspberries, strawberries, pears, plums and cherries.

As part of its contribution to the war effort JI published guidelines on tree-fruit varieties that should be grown together for effective pollination to increase the UK fruit crop.

A successful pear-apple hybrid was produced in 1952. Although it attracted a lot of media attention, the 'papple' never caught on.

## Compost

The John Innes name is synonymous with compost. However the John Innes Foundation and JIC have never exploited the name commercially, despite a close association with the initial development of compost.

After a series of disastrous crops of primroses grown for experiments in the 1930s, William Lawrence and John Newell of the JIHI began tests on alternative composts that would give consistently good results. They established optimum amounts of key nutrients and studied the effects of heat sterilisation in reducing pests and diseases.



### ECONOMIC SNAPSHOT

After hundreds of trials, the research led to recipes for two standard composts - one for seed sowing and one for potting. These are still the gold standard of growing media today, **a market worth £120 million in 2007.**

Lawrence and Newell recognised the contribution these recipes could make to raising productivity. They published the formulae in 1938, making them freely accessible to gardeners and the horticultural industry. Promoted by a leaflet campaign organised by JIHI, the recipes made a big contribution to the "Dig for Victory" campaign. JIHI received no financial benefit from the composts.

The horticultural retail trade has subsequently made **John Innes a household name.**



The John Innes Centenary Rose



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](http://www.jic.ac.uk)

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](http://www.bbsrc.ac.uk)

[www.foodsecurity.ac.uk](http://www.foodsecurity.ac.uk)

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