The John Innes Centre magazine
Summer 2018

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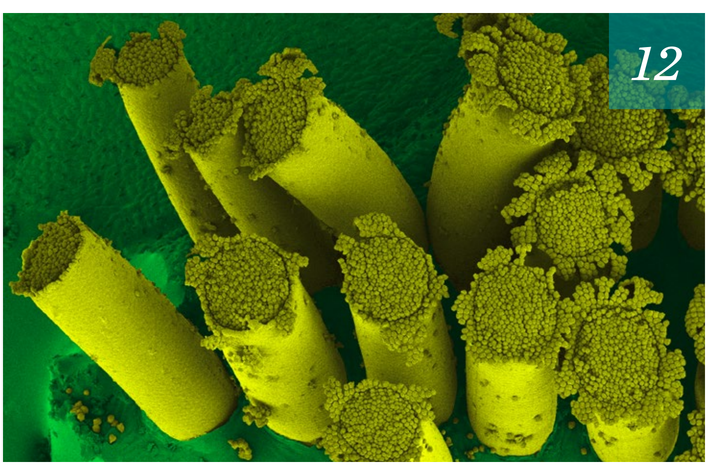
John Innes Centre
Unlocking Nature's Diversity

Advances



Welcome

Professor Dale Sanders introduces Advances

Occasionally, a scientific breakthrough will radically change the way the scientists work, or affect how they approach and think about a problem or concept. The invention of the microscope in the 17th century is a classic example of a technology that revolutionised the scientific endeavour at the time.

The publication of the wheat genome in 2014 has proven to be a turning point in the way scientists work with this notoriously complex crop plant. In this issue, we explore some of the breakthroughs that have followed this publication and consider the future of wheat as a food source.

We delve into the ongoing revolution in glasshouse and growth room technologies. The speed breeding platform, co-developed by Dr Brande Wulff and colleagues in Australia, deserves attention. The platform provides an opportunity to grow plants more quickly, enabling a wide range of crops to be cycled in record time, which in turn accelerates the impact of our research.

Technologies like this, combined with the complete sequenced genomes of crops, and other exciting new technologies designed to visualise and monitor plants as they grow, help us to understand the fundamental links between the codes of life, DNA and what a plant looks like out in the field.

We have an opinion piece from Professor Cathie Martin FRS, where she reflects on recent conversations about the importance of plants in our diets. We also congratulate Professor Martin on her recent election to Fellow of the Royal Society.

John Innes Centre

Unlocking Nature's Diversity

About the John Innes Centre

The John Innes Centre is a world-leading research centre based on the Norwich Research Park. Our mission is to generate knowledge of plants and microbes through innovative research, to train scientists for the future and apply our knowledge to benefit agriculture, health and well-being and the environment.

John Innes Centre* Advances *Editorial & Content Team
Adrian Galvin, Felicity Perry, Andrew Lawn and Oliver Heaton
Photography Andrew Davis

Cover images clockwise from top left: Purple, bronze and red tomatoes, Dr Brande Wulff at speed breeding glasshouse John Innes Centre, modern wheat, pod shatter in oilseed rape, stem-rust on barberry

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Fast forward to a space-inspired future of crops

Speed breeding and wheat; meeting the challenge of feeding the nine billion by 2050

On 1 January 2018, Dr Brande Wulff was away from it all, walking with family in the mountains of Spain. The new year dawned three days later when he returned to a cascade of emails from around the world.

While he was away, a research paper, on which he was a lead author, was published in the journal *Nature Plants*. It was about speed breeding, which Dr Wulff, a wheat scientist at the John Innes Centre, is pioneering alongside colleagues in Australia. People, and lots of them from all walks of life – academics, journalists, crop breeders, general folk – wanted to hear more about the method for growing plants faster.

"I was overwhelmed," recalls Dr Wulff. "I have never in my life experienced such a response to a published piece of work – so many people wanted to ask questions about speed breeding." Some wanted to check the details – about the type of optimised LED lighting used in place of sodium vapour lamps, or the intensive day length regimes of up to 22 hours, or the temperatures or CO_2 levels used. These conditions, when taken together, coax wheat plants and other crops on the Norwich Research Park to reach adulthood in eight weeks – two-and-a-half times faster than before. Others were intrigued that a technology inspired by space travel and NASA experiments to grow crops extraterrestrially was back on Earth as a potential answer to feeding the world.

"I guess one reason for its popularity is that the technology is very simple but the result is very graphic," says Dr Wulff. "You see a wheat plant, which is small and puny at five-and-a-half weeks, and then you look at the plant next to it grown under speed breeding conditions. It's big and luscious and green and has lots of seed. The difference is remarkable and it captures the imagination," he adds.

While speed breeding is a research platform that promises to revolutionise the development of a whole range of crops, its arrival has been most closely associated with wheat. Dr Wulff believes that the status of the iconic crop – which has delivered the daily bread of civilisations – has much to do with making the story so popular.

> The technology is very simple but the result is very graphic... The difference [in plants] is remarkable and it captures the imagination

"The public understand the connection with wheat and bread," he argues. Bread is ubiquitous in our diet. Dr Cristobal Uauy (also a wheat researcher at the John Innes Centre) has calculated that the average person eats 15 wheat plants a day. Wheat is said to have built the pyramids in Egypt, because it provided the daily bread for the workers for over 30 years.

Wheat is a crop of antiquity, domesticated 10-12 thousand years ago. It is set to play a major part in meeting the challenges of a more populated future. "Wheat provides 20 per cent of the calories we consume and about 20 per cent of the protein we need. It is the most widely grown of any crop. People can instinctively understand that if we can improve wheat production and do it quickly, we have a chance of feeding a growing population," says Dr Wulff.

The International Wheat Initiative has identified many key traits that must be improved to achieve the 1.6 per cent yield increase that is predicted to be needed to help feed a global population of 9.6 billion people by 2050. To do this, many crops need to be more nutritious, higher yielding, more disease resistant and climate change resilient.

These improvements can only be achieved through fundamental research, and ensuring this understanding is translated into the staple crops we rely on. Crop improvements take many years using traditional breeding methods, and it can be decades in complex crops like wheat. Speed breeding means it is possible to grow six generations of wheat per year instead of two, and there are plans go even faster. In addition to global outcomes, there is a strong domestic call for the UK to quickly develop varieties of crops that can be grown in a range of environments, including in vertical farms and indoors.

"A generation ago we were producing 80 per cent of the food we consume in the UK," says Dr Wulff. "Today it is only 60 per cent and within half a generation that will fall to 50 per cent. It means that we are vulnerable, because we depend on other countries for our food."

Despite these successes, speed breeding is still undergoing intensive revisions. There is a low-cost desktop version of the technology in development, and Dr Wulff and his team are currently planning speed breeding 3.0, which involves using enhanced LED lighting, atmospheric controls and hydroponics. There is even a record bid in the offing with the team modelling hydroponic systems trying to beat the current best of eight weeks for a generation of wheat. While a record push may seem like a frivolous use of time, it promises to create more awareness of the technology; a serious stunt with a purpose. By pushing the limits of the technology, the team will learn valuable lessons that can then be ploughed back into improvements for the next speed breeding platform.

"It's a technology that is very easy to replicate around the world," says Dr Wulff. "I think it will be adopted very quickly, and that will contribute to the impact. I would like to think that in ten years from now you could walk into a field and point to plants whose attributes and traits were developed using this technology."

DIGGING INTO WHEAT'S WILD PAST

Essentially three plants in one, common wheat, or bread wheat, is a crop so genetically complex that for many years understanding it at a molecular level has only been possible via fundamental works on less complicated model plants. Discoveries using these model species have then been translated to improvements in wheat.

Advances in DNA sequence analysis of the wheat genome have been accompanied by a suite of genomic research and breeding tools, which has enabled an exciting new dawn in the study of wheat.

Alongside speed breeding, the John Innes Centre has led an international consortium to develop a genomic directory called Open Wild Wheat, which will allow researchers and breeders to scan the genomes of wild relatives of modern wheat to recover disease resistance genes lost in the process of domestication.

Meanwhile, speed cloning allows researchers to identify useful genes such as one that controls disease resistance by their genetic 'address' and then cloning them for introduction into elite varieties.

"Wheat is an exciting place, we are at a watershed moment," says Dr Brande Wulff. "There is going to be an exponential growth in the identification of genes associated with discrete traits," he adds.

A study that isolated a gene controlling the shape and size of wheat spikelets is just one of the advances causing excitement

"It's been very hard to get to the genetics that control this trait because of the complexity of the wheat genome"

FROM BLACK SHEEP TO FAMILY FOLD

A study that isolated a gene controlling the shape and size of spikelets in wheat highlighted the advances in genomics and the associated technology, which are causing excitement in the wheat research community.

The paper in *The Plant Cell* outlined a discovery that could result in higher yields in wheat. For Dr Scott Boden, author of the paper and a project leader at the John Innes Centre, this breakthrough also highlighted a broader point. "It's been very hard to get to the genetics that control this trait because of the complexity of the wheat genome, but now the resources are becoming available that allow us to understand what contributes to them, it's not just a wild goose chase any more.

"Wheat has been the black sheep, lagging behind the rest of the cereal research community. Following the publication of this paper, many people in the corn and rice communities have contacted me. People have said 'we did not know you could do this in wheat!' I think this is really encouraging."

Science Spotlight

A round-up of recent research from the John Innes Centre

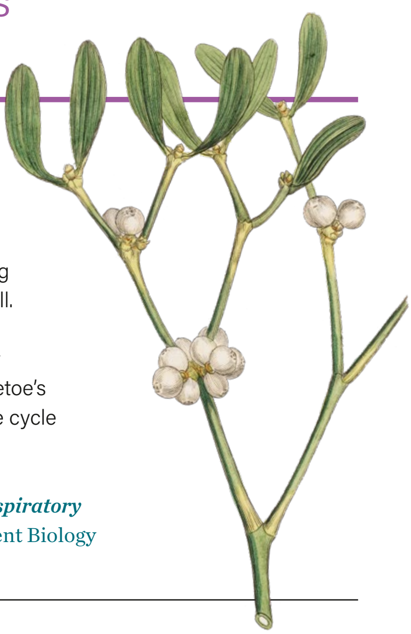
Solution to harmful algal blooms raises hope of environmental benefits

A cheap, safe and effective method of dealing with harmful algal blooms is on the verge of being introduced following successful field and lab tests. Moves to adopt use of hydrogen peroxide (H_2O_2) as an effective treatment against toxic algae are already underway following the results of new research by a team from the John Innes Centre and the University of East Anglia (UEA).

Dr Ben Wagstaff, one of the authors of the study from the John Innes Centre said, "We've demonstrated that the use of hydrogen peroxide is a practical, relatively easy way of managing algal blooms." The work in the Broads National Park could have widespread implications for the way harmful algal blooms are managed in waterways worldwide.

+ ***Insights into toxic* Prymnesium parvum *blooms: the role of sugars and algal viruses*** *was published in* Biochemical Society Transactions
DOI: 10.1042/BST20170393

Mistletoe mystery – something's missing from the kissing plant



Mistletoe has evolved in a manner that makes it unique among multicellular organisms. It is lacking a key piece of machinery essential for aerobic respiration in animals and plants. An enzyme called Complex I is missing in European mistletoe (*Viscum album*).

Instead, mistletoe uses alternative energy pathways including glycolysis, which generates energy in a different part of the cell. This, combined with the nutrients generously provided by its host trees, provides European mistletoe with all the necessary requirements to keep hale and healthy. The discovery of mistletoe's remarkable metabolism provides a unique window into the life cycle of a high-profile parasite in evolutionary time.

+ ***Absence of Complex I Is Associated with Diminished Respiratory Chain Function in European Mistletoe*** *was published in* Current Biology
DOI: 10.1016/j.cub.2018.03.036

Chance discovery links inflammatory bowel disease with common bacterial gut toxin

New research has uncovered a surprise link between a common bacterial toxin found in the gut and inflammatory bowel disease (IBD).

The intercontinental team have established a connection between microcin B17, a well-known toxin produced by E. coli bacteria, and IBD. The John Innes Centre scientists, led by Professor Tony Maxwell, have been working with microcin B17 for several years in their search for new antibiotics. It is produced by E. coli (*Escherichia coli*) as a weapon against other bacteria in the gut.

The two teams worked together to show that breakdown products from the toxin seem to trigger gut inflammation that is characteristic of IBD. The research also identifies the oxazole class of aromatic organic compounds as a new source of environmental and microbial triggers of gastrointestinal inflammation.

+ ***Dietary and Microbial Oxazoles Induce Intestinal Inflammation by Modulating Epithelial Derived Aryl Hydrocarbon Receptor Responses*** *was published in* Cell
DOI: 10.1016/j.cell.2018.04.037

Sound new technique tunes into the shifting shapes of biology

It's one of the major challenges of biology – how to accurately quantify the mass of swarming, shifting shapes that make up the matter of life.

Being able to adequately quantify and compare the shapes of cells or organisms is of ultimate importance for biology. This is because the shape of cells, organs and even entire organisms represent the outcome of internal processes – how genes and proteins interact and trigger biophysical manifestations.

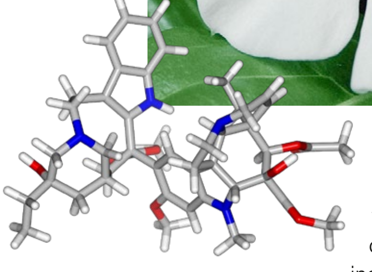
The labs of Dr Veronica Grieneisen and Dr Stan Marée have devised an ingenious method of measuring those elusive life forms thanks to some serious mathematical modelling and a little musical inspiration.

The novel technique, called LOCO-EFA, is already being enthusiastically taken up by international teams of researchers who intend to use it to quantify cell and leaf shape and even palaeontologists investigating the evolution of organism shape.

+ ***Morphometrics of complex cell shapes: Lobe Contribution Elliptic Fourier Analysis (LOCO-EFA)*** *was published in* Development

DOI: 10.1242/dev.156778

Periwinkle research uncovers pathway to cancer-fighting drugs



The crucial last steps in a 60-year quest to unravel the complex chemistry of Madagascar periwinkle have been taken, in a breakthrough that opens up the potential for rapid synthesis of cancer-fighting compounds.

After 15 years of research the team have located the final missing genes in the genome of the periwinkle that are devoted to building the chemical vinblastine. This valuable natural product has been used as an anti-cancer drug since it was discovered in the 1950s.

Until now, it has taken approximately 500kg of dried leaves to produce 1g of vinblastine. But the new study uses modern genome sequencing techniques to identify the final missing genes in the pathway. This research also identifies enzymes that build vinblastine precursor chemicals, which include catharanthine and tabersonine. These can be readily chemically coupled using synthetic biology techniques to give vinblastine.

+ ***Biosynthesis of the Vinblastine and Vincristine Precursors, Caranthine and Tabersonine*** *was published in* Science.

DOI: 10.1126/science.aat4100

Temperature resilient crops now an "achievable dream"

The vision of crop improvement in the face of climate change is outlined in research that establishes a genetic link between increased temperature and the problem of 'pod shatter' (premature seed dispersal) in oilseed rape.

Research led by Dr Vinod Kumar and Professor Lars Østergaard reveals that pod shatter is enhanced at higher temperatures across diverse species in the *Brassicaceae* family, including cauliflower, broccoli and kale.

This new understanding brings the prospect of creating crops that are better adapted to warmer temperatures a step closer. Dr Vinod Kumar, a co-author of the paper, explained the findings, saying, "It's almost as if there is a thermostat that controls seed dispersal, or pod shatter. As we learn how it works, we could in the future 'rewire' it so seed dispersal does not happen at the same pace at higher temperatures."

Controlling seed dispersal, or pod shatter, is a major issue for farmers of oilseed rape worldwide, who lose between 15-20% of yield on average per year due to prematurely dispersed seeds lost in the field.

+ ***Temperature Modulates Tissue-Specification Program to Control Fruit Dehiscence in Brassicaceae*** *was published in* Molecular Plant.

DOI: 10.1016/j.molp.2018.01.003

Glasshouses at night

Light is a major component in many of our projects, whether for the growth of plants in our glasshouses, for the controlled environment rooms and cabinets, or for our bioimaging department.

Initial trials in the glasshouses (pictured here) have shown that the new LED lighting could save 15% in electricity consumption and provide a better, more controlled spectrum of light. This new controllable light casts a distinctly pink glow, as upping the red part of the spectrum produces better conditions in which to grow plants.

LED upgrades to our growth facilities will see the replacement of more than 1,200 fluorescent tubes and it is hoped will save energy across the glasshouses and controlled environment rooms.

Accelerated Development

Improvements in nutrition and yield of staple crops must be accelerated as the global population increases towards ten billion people, with most consumption expected to occur in developing countries

Today, wheat is the grown on more land than any other crop. It provides 20 per cent of global calories and protein. But improvements are difficult because wheat is so genetically complex – many species are polyploids with up to three sets of chromosomes as is the case with (hexaploid) bread wheat. The Green Revolution of the 1940s-1960s introduced improvements such as dwarfing genes and shuttle breeding. However, to meet future demand, crop improvements must be achieved more rapidly. The world must produce 60 per cent more wheat by 2050, according to the Wheat Initiative, an international body coordinating wheat research. And with genetic improvements taking up to 20 years using current approaches the race is on.

Wheat – the past

Wheat is a grass, which was first cultivated 10-12,000 years ago in the Fertile Crescent from the Nile in Egypt to the Euphrates in modern Iraq.

20th century

The Green Revolution of the 1940s-1960s introduced improvements such as dwarfing genes which allowed resources to be diverted towards seed production and made plants more resistant to wind and rain.

Norman Borlaug, architect of the Green Revolution in wheat, introduced shuttle breeding techniques allowing breeders to grow two generations of wheat each year.

~10,000 YEARS AGO
POPULATION = 5 MILLION

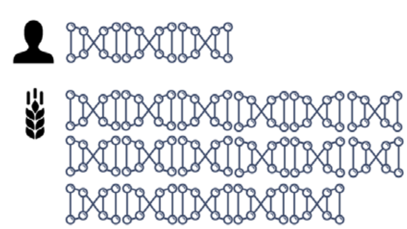
1804: POP = 1 BILLION (BN)

1922: POP = 2 BN

Just how complicated is the wheat genome?

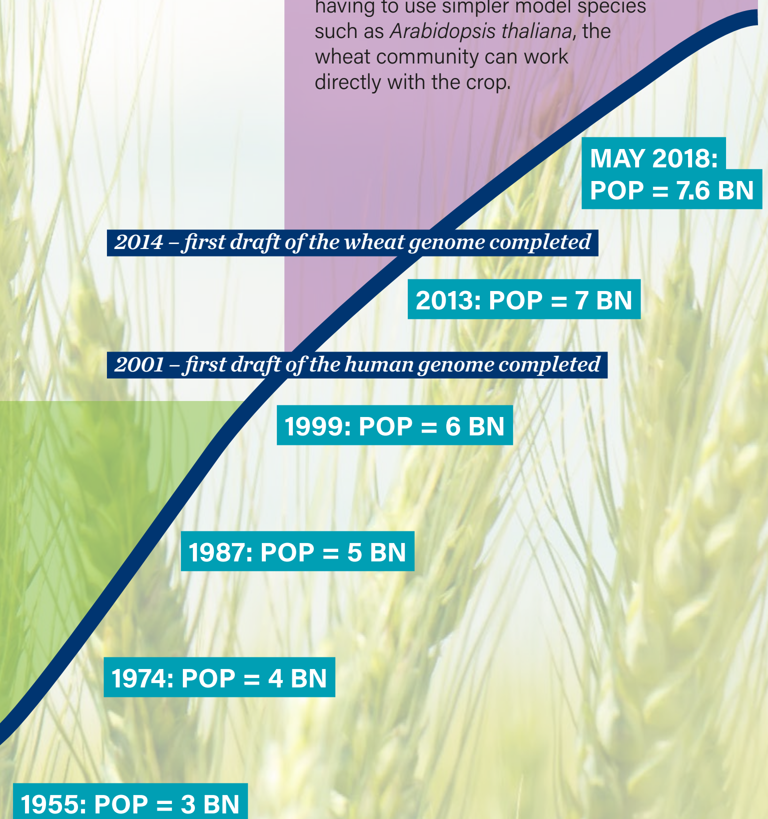
Some varieties of wheat contain 17 billion pairs of genetic information. In comparison, the human genome contains just three billion, split over two copies of each chromosome (diploid). Wheat has a hexaploid genome, with six copies of each chromosome. This means that the genome is both large, and complicated to work with.

Wheat's giant genome



21st century solutions

Genomic and technological breakthroughs have delivered fresh impetus to wheat research. It means that instead of having to use simpler model species such as *Arabidopsis thaliana*, the wheat community can work directly with the crop.



Selected milestones in the development of 21st century wheat

2013: CRISPR/Cas9, or gene editing is first reported in the scientific literature.

2014: Chromosome-based draft genome sequence of wheat published in the journal *Science*.

2015: Open access genomics resources are published. These include PolyMarker, a web-based portal which designs specific genetic markers in wheat and is used by many UK and European molecular breeders.

2015: Two free, open source resources draw together information. These are wheat-expression.com and wheat-training.com.

2016: Approaches using mutant and natural populations allow speed cloning of genes from wheat and their wild relatives.

2017: The most accurate and complete DNA sequence analysis of the wheat genome is published.

2017: A free database of ten million mutations in bread and pasta wheat varieties is launched. The break-through mutant resource called Wheat TILLING speeds up the development of sought after traits.

2017: Designing Future Wheat – A national UK wheat research program involving more than 25 groups of scientists is funded through the BBSRC's Institute Strategic Programs for five years.

2017: First version of chromosome-based reference sequence for wheat is made available.

January 2018: Speed-breeding protocols are published. Up to six generations of wheat can be grown each year, compared to the usual two or three.

March 2018: OpenWildWheat.org International consortium launches new genomic tool, a genetic directory including the sequences of 150 wild wheats belonging to a goat grass species called *Aegilops tauschii* ssp. *strangulata*.

This will enable breeders to scan the genomes of wild relatives of modern wheat to find the disease-fighting properties lost during the process of domestication.

2018: CRISPR/Cas9 has become the tool of choice for gene-editing in plants, not only to knock out genes but also to edit within genes.

2018: Professor Graham Moore uses CRISPR/Cas9 derived mutants to introduce useful traits in to wheat.

On the trail of a forgotten pathogen

First report of stem rust in decades calls for critical close monitoring

Close collaboration between scientists, conservationists and crop breeders is vital to prepare for the potential re-emergence of stem rust in the UK.

Among efforts to safeguard cereals is a partnership between John Innes Centre researchers and Butterfly Conservation naturalists who have started monitoring the location of common barberry (*Berberis vulgaris*). The hedgerow shrub has increased in popularity over recent decades and has been widely planted in conservation efforts to preserve the barberry carpet moth, an endangered species that relies on barberry as a habitat and food source.

However, common barberry has another altogether more threatening role as an alternate sexual host for stem rust, a pathogen that has been associated with crop failure and famine throughout history.

Following a report by Dr Diane Saunders and Dr Brande Wulff from the John Innes Centre of a single wheat plant infected with stem rust in Suffolk – the first case in the UK in more than 60 years – and an outbreak of wheat stem rust in Sweden that has been linked to barberry, it may be timely to recall the uncompromising historical approach to the hedgerow shrub.

It is thought that barberry was introduced to England around 500 years ago. It was then ripped from the landscape, a process which began around 300 years ago when farmers noticed links between its presence near fields and crop disease. In the United States in the early 20th century, barberry was the focus of a major state and federal-supported policy of mass removal in a campaign billed 'The Barberry or Bread.' Fast forward a century and a proactive and precautionary approach is being adopted in the light of recent developments in the UK. This approach balances the needs of crop protection and wildlife conservation and is supported by scientific research.

Dr Diane Saunders said, "Right now we do not have wheat stem rust, as far as we know, established in this country, so to make dramatic decisions like ripping out all the barberry bushes is not something we would support. But what we can do is to be proactive and prepare for the

A close-up of an aecium. Photo by Joe Win, The Sainsbury Laboratory future by documenting the location of barberry bushes. Then, if wheat stem rust does re-emerge, we can remove them if necessary but only from areas where they could cause an issue in escalating cereal rust diversity."

The proactive approach aligns with that of Butterfly Conservation as part of Natural England's *Back from the Brink* programme.

The infected wheat plant discovered in Suffolk was shown to be infected by the Digalu race the fungus, which was responsible for a devastating outbreak of stem rust in Ethiopia in 2013 and smaller outbreaks in Sweden, Denmark and Germany in the same year. Follow-up investigations found that over 80 per cent of UK wheat varieties tested are susceptible to the strain of the pathogen found in Suffolk.

Further analysis by Dr Daniel Bebber at Exeter University showed that changes in climatic conditions over the past 25 years suggest increasingly conducive conditions for fungal pathogen growth and infection.

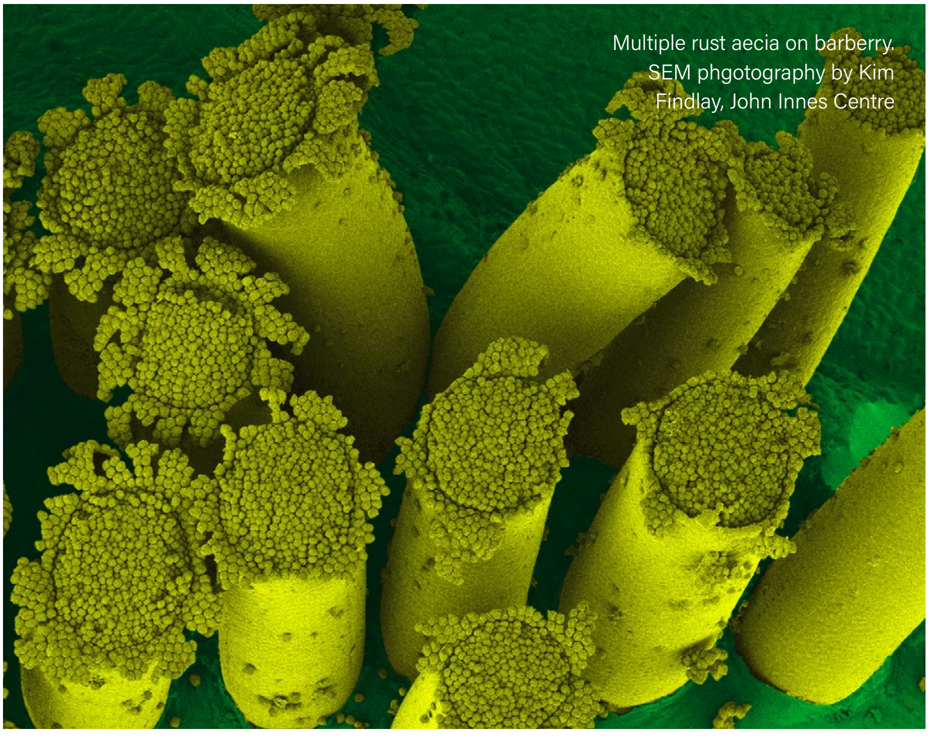
On cereal crops, stem rust undergoes asexual reproduction using the plant's own resources to produce millions of genetically identical spores. The type of spores it generates on cereals can travel thousands of kilometres on the wind. However, when barberry is next to a cereal, the pathogen uses it as an alternate host to complete its sexual cycle, potentially leading to a swathe of new genetic strains.

Fortunately, the spores that form on barberry likely only travel relatively short distances. For a barberry bush to spread rust to a cereal field they must be in close proximity. However, the exact safe distance is unclear in the current literature. Research underway in Dr Saunders' team, and funded by the core institute strategic programmes at the John Innes Centre, is starting to address key questions such as determining the safe distance between barberry bushes and cereal crops.

Proactive steps must also involve working with breeders to identify sources of resistance within current UK wheat lines which could be introduced into crops, says Dr Saunders.

A number of funding initiatives are being explored to make this proactive approach more effective and broader to include citizens scientists and partners from leisure and tourism. "Funding permitted, we'd like to get the public involved," said Dr Saunders. "A lot of these bushes are in areas where people go for walks and they could easily report locations using a mobile app and upload pictures of rust infecting barberry. Then we'd see if it was something that would be useful to go out and sample and thereby better target our resources.

"With the recent outbreaks of wheat stem rust across Europe it is important we take these early warning signs seriously, take stock and put an informed response plan in place should the worst happen and wheat stem rust re-establishes here," she added. "We are hopeful that with future funding we can make the scientific advances necessary to develop a plan that takes into account both the interests of conservation and crop protection."



Multiple rust aecia on barberry. SEM phgotography by Kim Findlay, John Innes Centre

> Changes in climatic conditions over the past 25 years suggest increasingly conducive conditions for fungal pathogen growth

Stem rust disease lesions on wheat. Photo by Paul Fenwick, Limagrain, UK. Ltd

Eat your greens... and your purples

Just back from Brussels, Professor Cathie Martin FRS reflects on the conversations with colleagues at the European Parliament about importance of plants in our diet

The price of fruit and vegetables and ways to support the horticultural sector was one of the subjects being discussed at a recent meeting between Professor Cathie Martin, a project leader at the John Innes Centre, and colleagues at the European Parliament. "Because if they produce more affordable, locally sourced, good quality fruit and veg that would help to address many health problems. Medicine is not healthcare, food is healthcare… medicine is sick care."

Other beneficial food interventions advocated by Professor Martin include free fruit for schoolchildren and free side salads in work canteens. In her own lab there is a weekly delivery of locally sourced fruit. She recalls her time as a student volunteer helping single-parent families in the Merseyside town of Halewood, "The only food outlets were a fish and chip shop and a convenience store. There was no fruit and veg. Many of the kids had never seen decent food."

The link between diet and health has been a growing passion in the career of Professor Martin who in May was elected as a Fellow of the Royal Society, the 29th scientist in the 108-year history of the John Innes Centre to receive the honour. Having studied for a doctorate on germination in castor seeds – "I never wanted to work on that again, I was allergic to the seeds" – she gratefully seized on a "fantastic opportunity" to join the John Innes Centre in 1983, to research transposable elements (also known as jumping genes) in *Antirrhinum majus* (garden snapdragon). Later she was part of a team that successfully cloned the R locus in pea: this is the gene that determines whether the seed is round or wrinkled and was made famous by Gregor Mendel the founding figure of genetics.

Professor Martin identifies two factors – one personal and the other professional – as influencing her scientific direction. The first was being diagnosed with Type I diabetes shortly after she had finished her PhD at Cambridge in 1981. "Understanding my condition has contributed to the desire not to be taking extra medicines in addition to insulin but to achieve health and well-being through diet," she says.

But how do you translate the message of food as medicine on a societal scale?

In 2002 at a conference Professor Martin met another delegate, an Italian epidemiologist studying the benefits of the Mediterranean diet. "She was brilliant and incredibly enthusiastic in explaining her studies; how they involved people from their local area somewhere between Rome and Naples and how they could easily recruit 25,000 people to study the effects of healthy food because people there are very proud of their diet," she recalls. "It made me realise that anthocyanins are quite common in the Mediterranean diet and we should investigate if they had health benefits," she adds.

The next step was to find foods that either contained compounds such as anthocyanins or resveratrol; or which could be biofortified in food crops using metabolic engineering. "We wanted to see if some of the compounds present in blueberries, blackberries and red wine, for example, could be made in tomatoes because tomatoes are an affordable basic food and the most consumed fruit or vegetable in the world."

Today, Professor Martin is probably best known for her purple tomatoes – genetically modified using in some cases genes from snapdragon that impart anthocyanin-rich purple pigment. Cancer-prone mice live 30 per cent longer when their diet is supplemented with purple tomatoes rather than red ones. Another purple tomato growing in the John Innes Centre glasshouse contains in one fruit the same amount of resveratrol as in 50 bottles of red wine. Other lines developed using GM technology include yellow tomatoes containing flavonols, which are good antioxidants, and bronze tomatoes that have shown in tests to have strong effects on suppressing inflammation in bowel conditions such as colitis. A good deal of this work has been funded by European collaboration projects. "The European projects have been fantastic because they have taken me out of my comfort zone focussing on academic research and allowed me to learn much more about applications," says Professor Martin.

More recently I wanted to do research that my mother could understand – coloured, healthy tomatoes had potential!

In 2014 she won a BBSRC Most Promising Innovator award along with Dr Eugenio Butelli for their development of the purple tomatoes. A spin out company jointly set up by Professor Martin, Norfolk Plant Sciences, is awaiting regulatory approval in North America to produce seedless purple tomato juice made from GM varieties. Professor Martin believes the product will probably be driven by internet sales, "People can choose for themselves that way," she says.

It will be a consumable brought about by a colourful, accessible and health-enhancing product supported by scientific evidence for their protective effects. "I was always more interested in what you could do with scientific understanding rather than just publishing a paper saying this is how it works," she says. "More recently, I wanted to do research that my mother could understand; transposable elements in flowers was never going to work, but coloured, healthy tomatoes had potential!"

A centre of excellence

CEPAMS is a unique collaboration between three centres of excellence thousands of miles apart working together to transform global nutrition and health

The Centre of Excellence for Plant and Microbial Science (CEPAMS) brings together three world-leading laboratories in the UK and China to achieve the global aspirations of food security and sustainable health care.

The partnership between the John Innes Centre (JIC) and the Chinese Academy of Sciences (CAS) is built on a strong history of scientific links which stretch back to the earliest days of UK-China research collaboration.

The Centre, which was established in 2014, nurtures excellent science and focuses on the improvement of food crops and the production of high value, beneficial products from plants and microbes. The mission of CEPAMS is to maximise the synergy of CAS and JIC research, working together for excellent science and global public good.

The John Innes Centre now counts over 100 scientifically active alumni in China, many of whom have reached senior positions in the Chinese science system. A group of these alumni initiated a discussion about the concept of having a "JIC in China", this directly led to CEPAMS being developed by JIC and CAS.

Working together

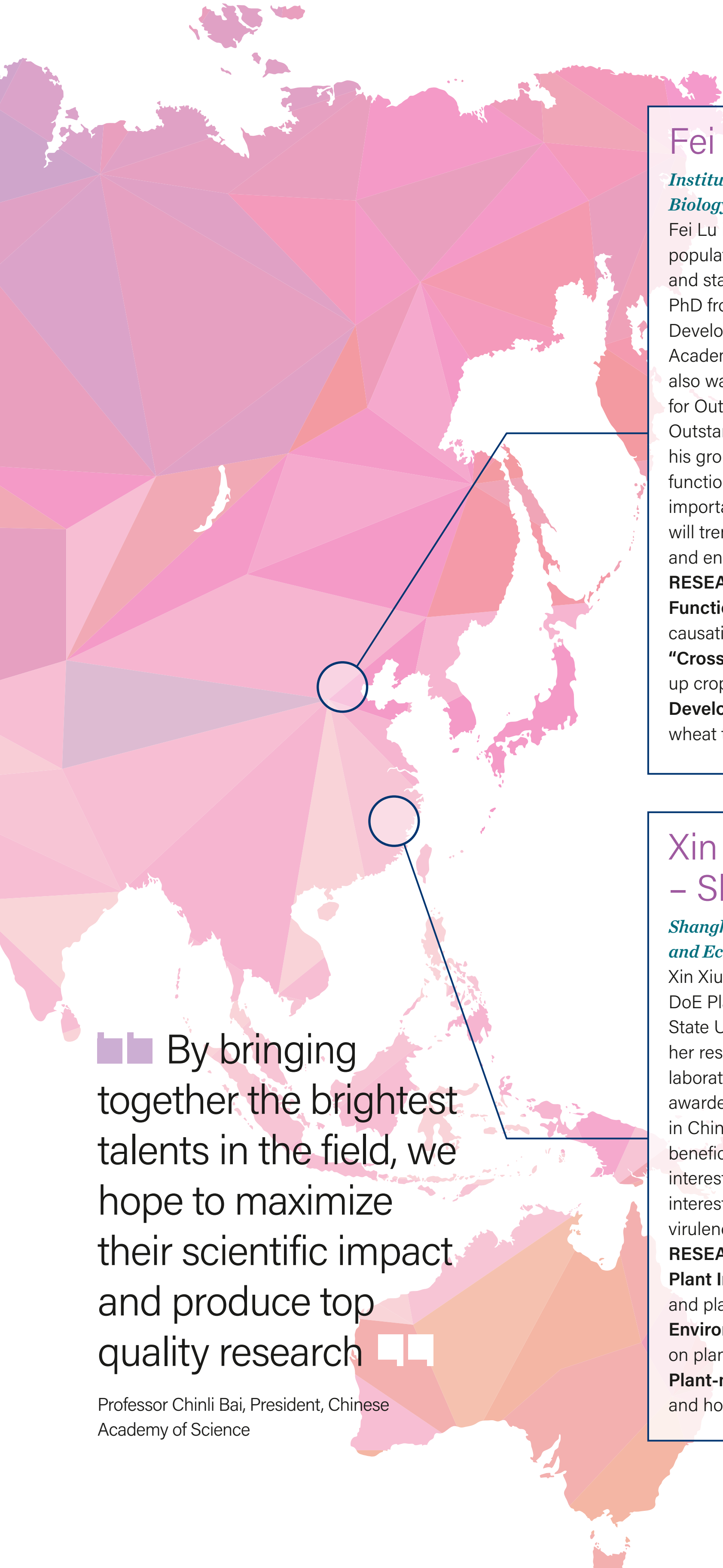
Co-directors of CEPAMS Professors Cao Xiaofeng and Ray Dixon work side-by-side to lead this collaboration, bringing together scientists from across the globe and facilitating excellence in plant and microbial science.

Professor Ray Dixon of JIC "CEPAMS strives for both excellence and impact. I believe that it is only through combining scientific excellence with strategic relevance that we can address the major societal and environmental challenges that lie ahead."

Professor Cao Xiaofeng of CAS "CEPAMS is truly a synergy of the very best science and the very best scientists in China and the UK. I believe that this synergy has tremendous potential for excellent scientific output and global public good."

CEPAMS FACT FILE

- Set up in 2014, CEPAMS brings together three world-leading institutes in the UK and China to tackle the global challenges of food security and sustainable health care.
- It's a collaboration between the John Innes Centre and the Chinese Academy of Sciences.
- CEPAMS is funded by the Chinese Academy of Science (CAS), the UK Biotechnology and Biological Sciences Research Council (BBSRC) and the Newton Fund.
- The Centre nurtures excellent science and focuses on the improvement of food crops and the production of high-value, beneficial products from plants and microbes.
- So far, seven China-based project leaders have been recruited who will work in laboratories based in Beijing or Shanghai and by the end of 2019 we hope to have recruited ten.



Fei Lu – Beijing

Institute of Genetics and Developmental Biology in Beijing (IGDB)

Fei Lu is a plant geneticist, with expertise on population genetics, quantitative genetics, and statistical genomics. He received his PhD from the Institute of Genetics and Developmental Biology (IGDB), Chinese Academy of Sciences (CAS) where he also was awarded the President Award for Outstanding Student and Award for Outstanding Graduate of CAS. Enthusiastic about crop improvement, his group is working on maize and wheat, trying to develop an effective functional genome prediction approach to pinpoint causal variants of important agronomic traits. The successful development of this approach will tremendously expand the application of genomic editing technologies and enable a brand new "cross-free" breeding.

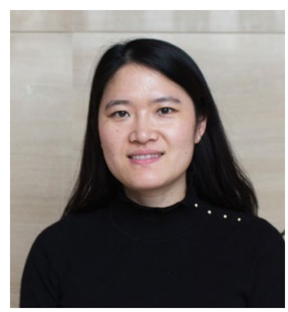
RESEARCH AREAS

Functional Genome Prediction – approaches to pinpoint large-effect and causative variants controlling phenotypes.

"Cross-free" Breeding – developing genomic editing technologies, to speed up crop improvement.

Developing Models for Wider Use – utilising research from maize and wheat to benefit genetic improvement of many other crops.

Xin Xiufang – Shanghai



Shanghai Institute of Plant Physiology and Ecology (SIPPE)

Xin Xiufang joined CEPAMS in 2017 from the DoE Plant Research Laboratory at Michigan State University. She has already established her research group in CEPAMS' brand new laboratories in Shanghai and has been awarded the prestigious "1000 Talents" status in China. Xin studies the interactions between plants and microbes – both beneficial interactions and detrimental interactions. On the former, her interest lies in how plants control a "healthy" microbiome. On the latter, her interest is in the interplay between the plant's immunity and the pathogen's virulence mechanisms. Both are crucial to sustainable agriculture globally.

RESEARCH AREAS

Plant Immunity Dynamics – the interplay between bacterial pathogenesis and plant immunity.

Environment and Disease – the mechanisms of environmental influence on plant diseases.

Plant-microbiome interactions – how plants maintain the leaf microbiome and how leaf microbiome influences plant health.

> By bringing together the brightest talents in the field, we hope to maximize their scientific impact and produce top quality research

Professor Chinli Bai, President, Chinese Academy of Science

Awards & achievements

Scientists at the John Innes Centre are recognised for their contributions to the research community, both nationally and internationally

Dr Cristobal Uauy

Royal Agricultural Society of England Research Medal

World-leading wheat scientist, Dr Uauy, has been awarded the prestigious Research Medal by The Royal Agricultural Society of England (RASE).

The award recognises a string of benefits delivered by the work of Dr Uauy and his team in developing genomic techniques – and sharing them with national and international community of wheat researchers and breeders.

Dr Uauy, a project leader in crop genetics, uses modern molecular genetic approaches to identify genes that deliver yield and quality improvements to wheat. Valuable traits developed using these ground-breaking techniques include increased grain size, resistance to pests and pathogens, biofortification and reduced pre-harvest sprouting.

Professor Dale Sanders

Prestigious 10-year China Talent Visa

In a ceremony at the Chinese Embassy in London, His Excellency Ambassador Liu Xiaoming presented John Innes Centre Director, Professor Dale Sanders FRS, with a 10-year China Talent Visa (R).

The visa, which allows the holder to travel freely to China for 10 years, recognises the sustained collaboration with the People's Republic of China that Professor Sanders has led over many years, and the expertise he brings to the cross-cultural scientific endeavour.

Professor Sanders said, "It is a great honour to receive this 10-year visa from the Chinese government. For many years I have collaborated with scientists in China, and the initiation of the CEPAMS labs in Beijing and Shanghai has been very successful."

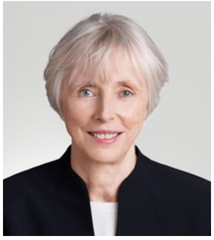
Professor Cathie Martin

Elected as Fellow of the Royal Society

Professor Martin, a project leader in metabolic biology, has been elected as a Fellow of the Royal Society.

During her career, Professor Martin FRS has been a powerful advocate and practitioner in the application of plant science for human health, and has researched plant genetics and metabolism to provide new insights into plant developmental and metabolic processes. "This is an honour. I would like to thank the many inspiring colleagues and collaborators, particularly from the John Innes Centre, and from around the world who have worked with me along the way," she said.

Professor Martin's work has made important contributions to the understanding of cell shaping, and to the biosynthesis and diversity of plant polyphenolic molecules that are beneficial to human health.



Professor Dame Caroline Dean

Royal Society Professorship

Professor Dean is one of six world-leading scientists named as recipients of a Royal Society Research Professorship.

The professorships provide long-term support for internationally recognised scientists from diverse areas including biochemistry, genetics, mathematics, chemistry, developmental biology and physics. The posts are the Royal Society's premier research awards and help release the best researchers from teaching and administration to allow them to focus on research.

Juan Carlos De La Conception

Crop disease researcher heads to Parliament

PhD Student, Juan Carlos De La Conception visited the Houses of Parliament to explain the science behind his research into rice-blast, a devastating global crop pathogen. His research was shortlisted from hundreds of participants to be part of the Parliamentary poster competition, STEM for Britain. At the event, early career scientists presented their research to politicians and leading academics.

Dr Rachel Prior

We caught up with Dr Rachel Prior who recently completed her PhD. Having been introduced to the unfamiliar world of science policy on a Professional Internship for PhD Students (PIPS) during her studies, Rachel is now preparing to join the Civil Service Fast Stream

What were you researching at JIC?
I worked with Professor Mike Bevan on understanding how one particular gene, called DA1, controls organ size in *Arabidopsis* (thale cress). DA1 controls the timing of the arrest of cell proliferation, at least that was what was previously thought. My research showed that, as with everything, it isn't quite that simple.

What was your experience on the PIPS placement?
I joined the Research Service, in the Environment and Transport team at the National Assembly of Wales. They take you on as a member of the team and you do what they do which is writing blog posts, guides and briefing documents and dealing with enquiries. You'd get a call or email from an Assembly Member who'd say, 'I'm giving a speech next week, I need this information' and you'd just have to produce it. It was fast-paced and unpredictable; exciting compared to the more long-range view of a PhD.

Did the experience contribute to your decision to apply for the Civil Service Fast Stream after your PhD was finished?
Definitely. I applied for policy officer roles at several charities, and learned societies and that kind of thing. But I concluded that these organisations were often just lobbying not contributing to actual decision-making. With government policy, your work hopefully contributes to ministers making policy decisions. During my internship, the office building was attached to the Assembly building and you could go and sit in the gallery to see the person who you'd written a briefing for stand up and talk. So that's why I decided on government: because it was exciting being close to the action.

Why is it important to have academia involved in government policy?
We need people who decide where the funding goes to understand that we're doing useful work. Often if I talk about my PhD, people say, 'why should we care what *Arabidopsis* does, we only care about wheat', because wheat is what we eat. And that could easily be a commonly held opinion among people who choose where the money goes. So it's important for us so that we can continue doing the work that we need to do.

If you don't have somebody advocating for science and ensuring that what we're coming up with is getting used, then what's the point? Fundamental research is important but it's all to support the improvement of society and unless it can get through to decision makers like ministers, then it's getting lost in translation.

> If you don't have somebody advocating for science then what's the point?

What's the Civil Service Fast Stream about?
The government call it their flagship leadership programme. Essentially you go in at a level that would be slightly up from an undergraduate position. Then you're given training and opportunities to accelerate your development over three or four years. It's a rotation programme, so you get to try out a range of departments. And at the end of the three years you're guaranteed a job in the Civil Service.

Do you feel like doing a PhD has prepared you for a career in the Civil Service?
I can definitely say that I would not have got onto the Fast Stream without a PhD – people do the Fast Stream without a PhD all the time, but for me I think doing one made me much more self-aware. Experience of having to make decisions and self-motivate really helped me during the application process. Having to write a PhD thesis also means writing documents doesn't seem overwhelming. The independence that you develop during a PhD is useful in any work place not just a policy-related one. You have to make a lot of decisions during your PhD about the direction of your project, which gives confidence in your ability to make decisions.

Any final thoughts?
I really recommend that PhD students apply for PIPS. A few people that I persuaded to do it thought differently about their career path subsequently. Just applying for the Civil Service was a valuable experience. If you get to the assessment centre they give you the most amazing feedback. Basically, I can't recommend either of them highly enough.

Spike in demand?

Research at the John Innes Centre has uncovered the genetic mechanism that controls a mutant trait in bread wheat known as paired spikelets. Seen here in purple, this occurs where a wheat inflorescence is formed of two spikelets instead of the usual one. Diversity of floral architecture has been exploited by generations of crop breeders to increase yields. Greater understanding of the genetics behind key traits such as this has the potential to boost grain production in one of the world's most important crops.

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