The John Innes Centre magazine
Summer 2017

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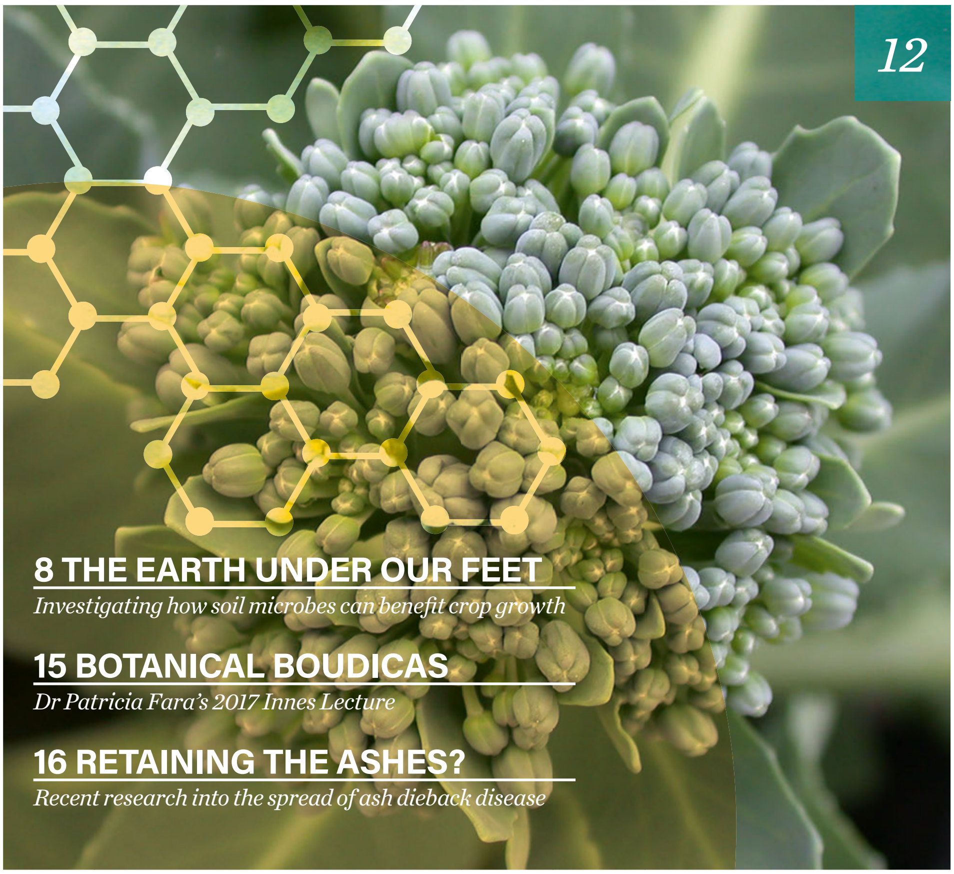
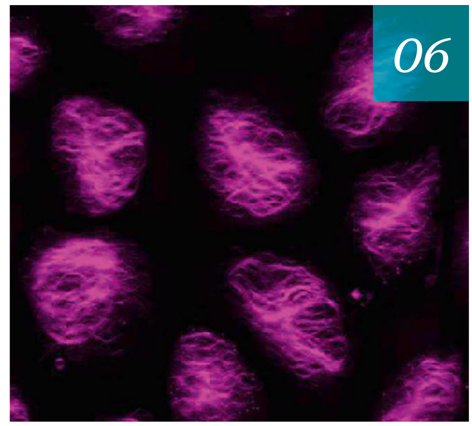
John Innes Centre
Unlocking Nature's Diversity

Advances





Contents Summer 2017

Cover images clockwise from top left: *Brassica oleracea*, anthocyanic vacuolar inclusions in delphinium, AfriPlantSci summer school in Arusha, domatia of the acacia tree, scientists at John Innes Institute circa 1976

Welcome to Advances

Professor Dale Sanders, Director of the John Innes Centre introduces the third issue of the new-look Advances *magazine*

This edition, we are pleased to introduce four new strategic research programmes (p4) funded by the UK Biotechnology and Biological Sciences Research Council (BBSRC). These new strategic programmes represent a significant investment in the future of the John Innes Centre and its world-leading scientists.

Through these new programmes the John Innes Centre will deliver fundamental insights into plant and microbial life and address high-profile national and international challenges in agriculture, the environment and human health. Research at the John Innes Centre spans diverse scientific disciplines from exploring how plants and bacteria produce valuable complex molecules, to developing more resilient and nutritious crops.

For this edition's alumnus interview (p19) we catch up with one of the John Innes Centre's most eminent scientists from the last 50 years, Professor Sir David Hopwood, for some fascinating career insights and how the institute has changed since he first arrived in 1968.

In *The earth under our feet* (p8) we take you into the world of the soil bacteria *Pseudomonas* which fights microscopic battles in the soil, defending plants against pathogens by producing a suite of antibiotic compounds. Meanwhile, new breakthroughs in *Brassica* research (p12) have led to the development of a new line of fast-growing sprouting broccoli.

Through analysing the diversity of the ash dieback fungus, our scientists are investigating what the future holds for the iconic ash tree, and how we can prevent further spread of the disease (p16).

Three John Innes Centre PhD students share the lessons they learned and challenges they faced during the two-week AfriPlantSci summer school earlier in the year at the Nelson Mandela African Institute of Science & Technology in Arusha, Tanzania (p14). Our continued collaboration with the Biosciences eastern and central Africa-International Livestock Research Institute (BecA-ILRI) hub and our support of key events, such as the AfriPlantSci summer school, is part of our wider international endeavours to maximise the translation of our research, to help build capacity and to promote collaborations in Africa and worldwide.

This year we're celebrating 50 years in Norwich with anniversary events throughout the year. We're delighted to invite you to join us at our Open Day on September 16 – it's free to attend, with a range of family-friendly activities to enjoy. You can find out more about this event and some milestones from the John Innes Centre's last five decades on p10.

50 years in Norwich 2017 John Innes Centre

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.

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Four new Institute Strategic Programmes

Our core research areas are funded by the UK Biotechnology and Biological Sciences Research Council (BBSRC) and directly address food security, human health and industrial biotechnology. To meet those objectives our research is organised into four Institute Strategic Programmes (ISPs)

Plant Health

Led by Professor Richard Morris, the Plant Health ISP will investigate the processes and mechanisms that promote plant health and crop resilience, focusing on advancing understanding of plant interactions with symbionts that benefit nutrient uptake and crop productivity, and pests and pathogens that limit crop yields. The Plant Health ISP brings together leading researchers from the John Innes Centre and The Sainsbury Laboratory to unravel the molecular dialogue between plants and microbes, the establishment of the communication interface, and plant-microbe co-evolution. Building on this knowledge we will develop strategies for reducing crop losses and our reliance on agrochemicals that have negative impacts on the environment, thus enhancing agricultural yield and sustainability.

FEATURED PROJECT – FIELD PATHOGENOMICS

As part of our Plant Health ISP Dr Diane Saunders' lab is studying (re-)emerging plant pathogens that pose a significant threat to UK agriculture. Recently the lab pioneered a revolutionary genomics-based pathogen surveillance technique that uses the latest DNA sequencing technology to rapidly generate high-resolution data for describing the diversity in a pathogen population directly from infected field samples. Using this new technique, and in collaboration with the National Institute for Agricultural Botany (NIAB) in Cambridge, the teams uncovered a dramatic shift in the population of yellow rust in the UK in recent years, largely due to an influx of fungal spores from outside the country. This information is essential to help breeders develop wheat varieties resistant to the range of yellow rust isolates, and will positively impact the sustainability of the UK arable industry.

Genes in the Environment

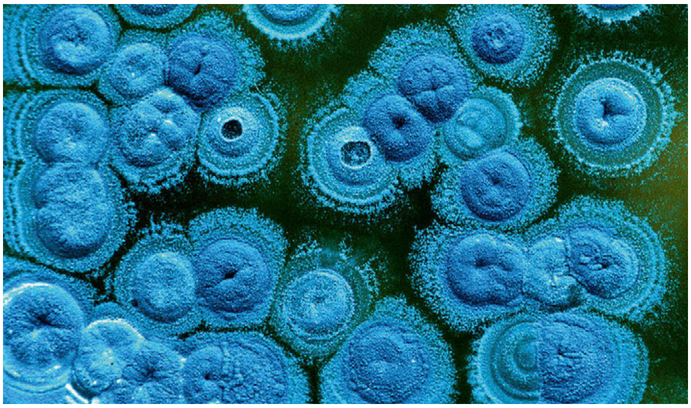
The Genes in the Environment ISP, led by Professor Lars Østergaard, aims to develop a wider and deeper understanding of how the environment influences plant growth and development. This research will provide a deeper knowledge of pathways that enable plants to adapt – over both short and longer evolutionary timescales – to environmental conditions. The research carried out under this ISP will be critically important for improving the stability of crop yields which are strongly influenced by changes in weather and other environmental factors.

FEATURED PROJECT – POD SHATTER

Oilseed rape pods can open in the field and disperse their seeds. This process, known as 'pod shatter,' leads to annual yield losses of around 15 per cent, totalling roughly £165 million every year. Professor Lars Østergaard and his team have studied fruit development in the model plant Arabidopsis. Previously involved in identifying the genes for Arabidopsis fruit opening, since arriving at JIC Professor Østergaard and his team have developed resources to translate knowledge of gene function in this model system to modify certain genes and improve pod shatter in oilseed rape. Recently, in collaboration with Dr Vinod Kumar's group at JIC, his team discovered pod shatter is accelerated at higher temperatures. Their current work is aimed at understanding the genetic mechanisms underlying this effect to inform the development of oilseed rape that is more resilient to climate change.

Molecules from Nature

Our Molecules from Nature ISP, led by Professor Alison Smith, will investigate the vast diversity of chemicals produced by plants and microbes. The chemical products of plants and bacteria already have a multitude of food, therapeutic, agricultural and industrial uses, but a vast wealth of potentially valuable products remains to be discovered and characterised. Our research focuses on biological questions relevant to the discovery and design of new products, the improvement of methods of production and the development of new uses for existing and novel products. These biological questions include the nature of the products made by medicinal plants, the role of bacterial products in the interactions between soil organisms and plants, and the importance for human health of plant products in our diet.



FEATURED PROJECT – PLANTS AS FACTORIES

Professor George Lomonossoff's group focuses on utilising plant viruses in bio- and nano-technology. The group has developed and exploited a highly efficient transient expression system, used to rapidly introduce and express genes of interest in plants, based on their discoveries about how viruses replicate in plants (the CPMV-HT, 'Hyper-trans', system). This system enables the rapid, high-level production of many proteins and chemicals in the leaves of a species of tobacco, that would otherwise be difficult to study and evaluate. These include valuable enzymes, a wide range of plant natural products, antibodies and virus-like particles.

For example, the group has produced virus-like particles (VLPs) that are identical to the 'shells' of disease-causing viruses including the polio virus and the bluetongue virus in sheep. These VLPs cannot cause disease, but they can be used as vaccines against the diseases and for the production of diagnostic tools.

The group is also involved in projects with other Molecules from Nature researchers in which the CPMV-HT system is being used to analyse, manipulate and re-engineer plant biochemical pathways that produce chemicals with therapeutic or industrial uses.

During the next few years, the use of this technology will expand and diversify further. A new company adjacent to JIC on the Norwich Research Park, Leaf Systems International, will scale up the CPMV-HT system to produce far larger quantities of proteins and chemicals than presently possible. This will greatly facilitate research in Molecules from Nature and its translation into commercial products.

Designing Future Wheat

Designing Future Wheat is a Cross-Institute Strategic Programme spanning eight research institutes and universities. Coordinated by Professor Graham Moore, this ISP aims to develop new wheat pre-breeding germplasm characterised for the next generation of key traits. Building on this research these new wheat pre-breeding lines will be provided to crop breeders and the plant science community in a readily accessible and referenced form. Wheat is one of the most important global crops – it currently provides 20 per cent of the total daily calories consumed by humans worldwide. As the global population increases towards 10 billion people, it is anticipated that the world will need to produce 60 per cent more wheat by 2050 to meet requirements. The demand for wheat is such that total production over the next 50 years will need to exceed the total wheat produced by humanity in the 10,000 years since agriculture began. Since it takes between 15 and 20 years for current research to improve wheat varieties grown in farmers' fields, it is imperative that we act now to address problems facing us in the future.

The Designing Future Wheat ISP is a fully integrated, cohesive national UK wheat research programme involving more than 30 groups of scientists across Rothamsted Research, the John Innes Centre, the Quadram Institute, Earlham Institute, the National Institute of Agricultural Botany, Cambridge, the European Bioinformatics Institute, Cambridge and the Universities of Bristol and Nottingham.

Science Research Spotlight

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

New way to target drug-resistant bacteria

Professor Tony Maxwell's team are among an international consortium who have discovered a new class of compounds that target bacteria in a unique way. The team, along with scientists from GlaxoSmithKline and Sanofi, reported that the new compounds inhibit a bacterial enzyme called DNA gyrase. DNA gyrase controls the winding and unwinding of DNA that is required for bacteria to replicate. Inhibiting DNA gyrase is lethal for bacteria, meaning it is an ideal target for antibiotics.

The new compounds have been shown to be effective against a number of drug-resistant bacteria strains in the laboratory. The collaborative research was facilitated by the ENABLE (European Gram-negative Antibacterial Engine) consortium, part of the EU-funded Innovative Medicines Initiative's 'New Drugs for Bad Bugs' (ND4BB) programme.

+ *The paper* ***Thiophene antibacterials that allosterically stabilise DNA-cleavage complexes with DNA gyrase*** *was published in the journal* The Proceedings of the National Academy of Science.

DOI: 10.1073/pnas.1700721114

New antibiotic from bacteria found on African ants

Researchers from Professor Barrie Wilkinson's group at the John Innes Centre and Professor Matt Hutchings's group at the University of East Anglia have discovered a new antibiotic, called formicamycin, produced by a newly-discovered bacterium. This new bacterium, found on the African fungus-growing plant-ant *Tetraponera penzigi*, is part of the *Streptomyces* genus and has been named *Streptomyces formicae*.

Kenyan plant-ants live in symbiosis with thorny acacia trees. They live and breed in domatia – hollowed out structures which the plant evolved to house them – and grow fungus inside for food. In return, the ants protect the plants from large herbivores, including elephants.

After isolating a number of bacterial strains from the ants and sequencing a selection of these, one particular strain caught the scientist's attention. Further investigation found it to be a new species, and the antibiotic compounds it produced showed promising activity in early tests against disease-causing bacteria.

Lab tests have shown that formicamycin is effective against methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE), bacteria which are resistant to a number of common antibiotics and can cause life-threatening infections.

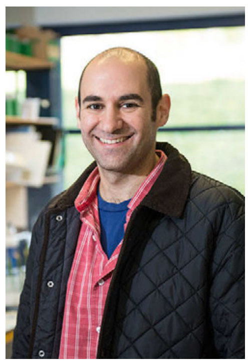
+ *The paper* ***Formicamycins, antibacterial polyketides produced by*** **Streptomyces formicae** ***isolated from African*** **Tetraponera** ***plant-ants*** *was published in the journal* Chemical Science.

DOI: 10.1039/C6SC04265A

Wheat genome breakthrough to benefit breeders and farmers

Scientists at the John Innes Centre, the Earlham Institute, The Sainsbury Laboratory and the European Bioinformatics Institute have completed the most accurate and complete DNA sequence analyses of the wheat genome to date. This comprehensive resource is already helping breeding programmes worldwide by providing a framework for selecting lines with improved characteristics, such as yield and disease resistance, so wheat breeders can develop new superior wheat varieties faster than ever before.

Dr Cristobal Uauy, a Project Leader at JIC which co-leads the project said, "The methods developed by Earlham Institute and JIC scientists have enabled several important UK wheat varieties to be sequenced. Working with breeders, we are now using the DNA sequences to see how previous breeding shaped the genetic make-up of their best performing lines. With this information, they will soon be able to accurately predict which lines to breed from, and to directly identify the most promising progeny. This could save years when making new varieties and accelerate the delivery of scientific discovery to farmers."



The paper ***An improved assembly and annotation of the allohexaploid wheat genome identifies complete families of agronomic genes and provides genomic evidence for chromosomal translocations*** *was published in the journal* Genome Research.
DOI: 10.1101/gr.217117.116

New evidence that plant tissues have a sense of direction

New research from Dr Alexandra Rebocho (pictured) and colleagues in Professor Enrico Coen's lab suggests that plant tissues can have a preferred growth direction, and that this is an important component of complex plant shape development. This builds on the theory of 'tissue conflict resolution'. Genes program how tissues grow, but when adjoining tissues are programmed to grow in different ways a conflict occurs and the tissues deform to a compromise state. Through these interactions plants can develop highly complex shapes. There are three proposed types of tissue conflict: areal, surface and directional. This development provides evidence for directional conflict where tissues can have a set of directions, or 'polarity field', caused by asymmetrical distribution of proteins within cells.

Much like surface and areal conflicts, adjoining tissues with differing specified directions of growth will lead to conflicts. When combined, the resolution of the three types of conflict can produce vastly diverse and complex shapes. This research moves us one step closer to understanding how genes can influence the remarkably intricate and beautiful plant shapes we see all around us.

The paper ***Generation of shape complexity through tissue conflict resolution*** *was published in the journal* eLife.
DOI: 10.7554/eLife.20156

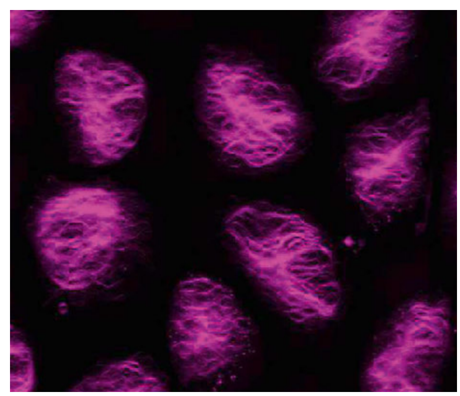
Solving a colourful mystery

A long-standing mystery of how and why colourful structures called 'anthocyanic vacuolar inclusions' (AVIs) occur in some plants has been solved. The research was carried out by scientists in Professor Cathie Martin's group, including first author Dr Kalyani Kallam, Dr Ingo Appelhagen, and collaborators from China, New Zealand and Norway.

A colourful plant pigment, called anthocyanin, usually accumulates uniformly in plant vacuoles. However, previous research has noted that, in some plants, distinct dense clusters of anthocyanins can form within vacuoles. (Pictured far right: AVIs in delphinium)

The team modified tobacco plants to produce the vacuole-soluble form of anthocyanins by introducing genes from the magenta-coloured snapdragon flower. Dr Kalyani Kallam said, "By crossing this modified tobacco with tobacco that expresses proteins from plants that modify anthocyanins, we generated offspring that formed AVIs. Experimenting with different genes and conditions we could work out the chemical steps in forming AVIs. We also deduced that AVIs are not bound by a membrane, they are formed when anthocyanins precipitate out of solution in the vacuole, dependent upon pH."

Dr Ingo Appelhagen, Professor Cathie Martin and Dr Kalyani Kallam



Professor Cathie Martin elaborates, "In many plants the formation of AVIs is most likely an unavoidable chemical behaviour of specific anthocyanins under certain conditions. However, in some plants AVIs may help to increase the intensity of pigmentation to help attract pollinators."

The paper ***Aromatic Decoration Determines the Formation of Anthocyanic Vacuolar Inclusions*** *was published in* Current Biology.
DOI: 10.1016/j.cub.2017.02.027

The earth under our feet

To the naked eye it seems lifeless, but the earth under our feet is a battleground on a microscopic scale. Every handful of soil harbours around 30,000 species of bacteria all fighting for precedence. Dr Jacob Malone is working to understand and influence these microbial battles for the benefit of our crops

Soil bacteria in the genus *Pseudomonas* are constantly competing with other microbes to colonise the roots of host plants, fighting them off with a suite of antibiotic compounds. But far from being noble defenders, they gain life-giving energy and nutrients from their host plants and simply don't want to share.

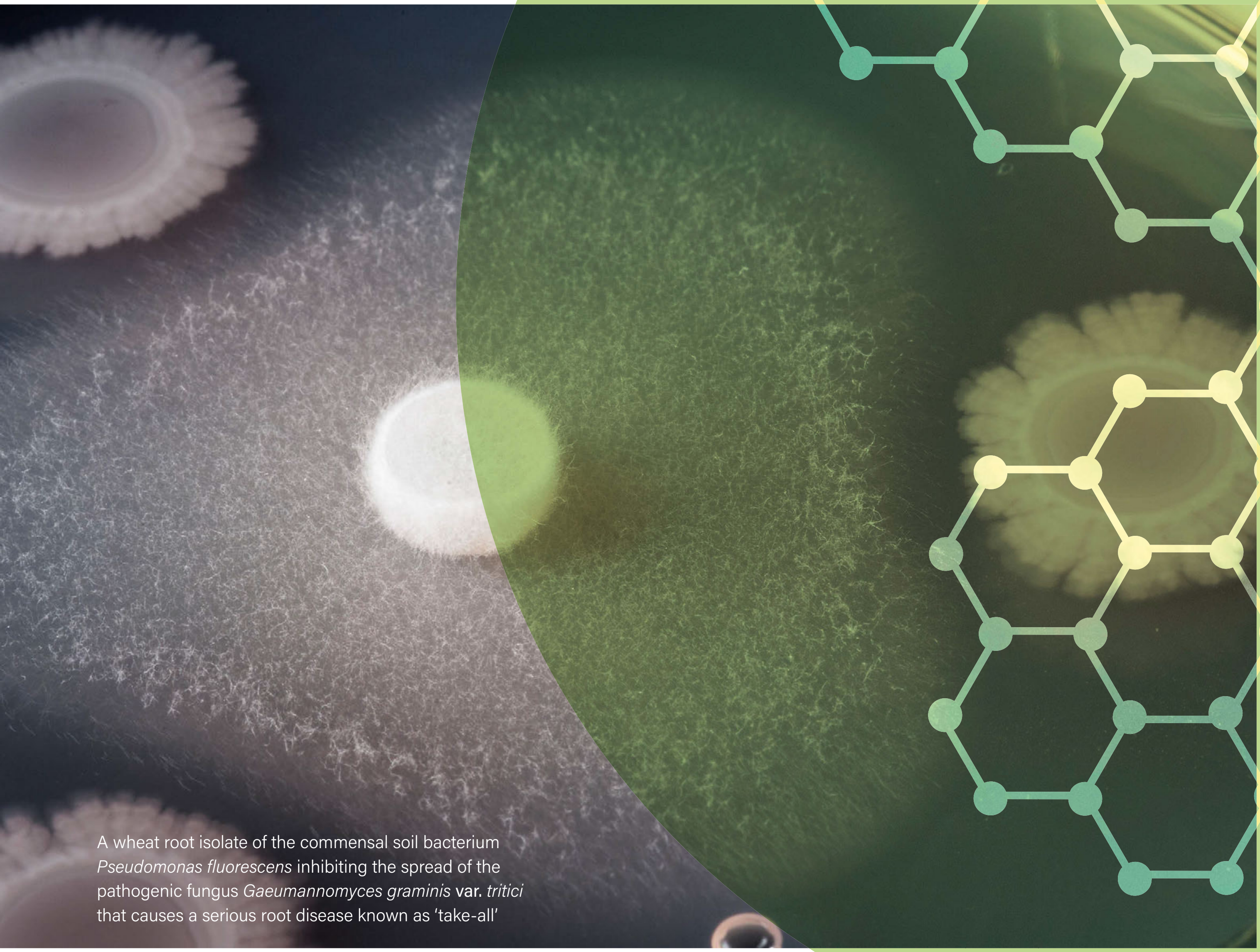
Dr Malone explains, "Pseudomonads are out for themselves. Sometimes what they want coincides with what a plant wants, so they will fight off plant infections and protect the plant against stress, but ultimately they do it for their own gain."

In the context of agriculture what they do is very useful. For instance, *Pseudomonas fluorescens* is capable of suppressing some important fungal and bacterial infections in crop plants, including potato scab, powdery mildew and take-all, a disease that can devastate wheat yields. Dr Malone's current research focuses on establishing exactly which of *Pseudomonas*' characteristics are important for its agriculturally beneficial interactions in the soil microbiome. A key challenge of this research is the vast genetic diversity seen within a single species; as little as 20 per cent of the *Pseudomonas* genome is made up of 'core' genes, which control the basic systems common to all members of the genus. The huge number of 'accessory' genes vary drastically from strain to strain, conferring the ability to adapt to different environments and compete with different microbes.

The diversity of *Pseudomonas* populations in the soil can influence their ability to suppress crop diseases, although this relationship is not yet well understood. Recent work from Dr Malone and collaborators at Rothamsted Research suggests that wheat fields with lower levels of *Pseudomonas* diversity suffer less infection by take-all. It is not known why this correlation occurs yet, but Dr Malone speculates, "It could be that in *Pseudomonas* populations with low diversity, the most effective strains have somehow managed to reach precedence, while in more diverse populations these strains are outcompeted." Interestingly, research in both wheat and other crops suggests that *Pseudomonas* strains that are better at defending plants against one particular pathogen also provide more protection against other diseases. Dr Malone continues, "The *Pseudomonas* strains selected by the more hostile environments appear to have a suite of more aggressive genes, containing effective tools for killing fungi as well as other bacteria."

Just as changes in the soil microbiome affect crop health, different crops can also alter their surrounding microbial communities. Dr Malone and his collaborators recently showed that different cultivars of wheat have a substantial

> We could potentially reduce our reliance on chemical spraying to fight crop disease



A wheat root isolate of the commensal soil bacterium *Pseudomonas fluorescens* inhibiting the spread of the pathogenic fungus *Gaeumannomyces graminis* var. *tritici* that causes a serious root disease known as 'take-all'

impact on the amount and the genetic diversity of *Pseudomonas* in the soil. "By picking one cultivar of wheat over another, farmers could be unknowingly influencing the outcomes of the microscopic battles going on in the soil, and potentially altering the health of their crops."

Dr Malone hopes that the systems and principles he uncovers in these bacteria could be applicable to a broad spectrum of plant-microbe interactions, and *Pseudomonas* is one piece of this complex web of microbial interactions. Dr Malone says, "Understanding these bacteria and their surprising influence over crop health could inform new farming practices to fine tune beneficial microbial communities. By improving the effectiveness of these natural guardians, we could potentially reduce our reliance on chemical spraying to fight crop disease."

WHEN IS AN ENVIRONMENTAL MICROBIOLOGIST NOT AN ENVIRONMENTAL MICROBIOLOGIST?

As a post-doctoral researcher investigating human infectious diseases, Dr Jacob Malone may not have foreseen that his research would lead to the John Innes Centre. His career transitioned when he was invited to speak at JIC's annual Young Microbiologist Symposium, which attracts rising stars from a variety of related fields.

He explains, "I presented my work on infections by the bacterium *Pseudomonas aeruginosa* in cystic fibrosis patients, and they said, 'This is great, but could you adapt this work to involve plants?' Fortunately, *Pseudomonas* is a diverse genus of bacteria and so I was able to turn my attention to different species that can influence plant growth."

As a newly appointed Synergy Lecturer at UEA, based at JIC, Dr Malone began to investigate *Pseudomonas fluorescens*, one of around 30,000 species of bacteria found in every handful of soil. Coming from a molecular biology background has been a strength to this multidisciplinary work, says Dr Malone, "We have developed some fairly complex mixtures of techniques to pick apart bacterial systems. Anyone coming into a field that isn't their conventional research area will do some things differently, and I think that's where our strength lies. I've learned an incredible amount and the new perspectives I've experienced have been illuminating."

Fifty years of research at the John Innes Centre

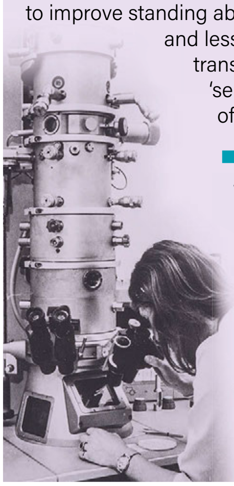
Our Outreach Curator, Dr Sarah Wilmot, takes you on a journey through some key milestones from five decades of cutting-edge research at the John Innes Centre

1967-1980

- Established in Merton in 1910, the institute made its home in Norwich in 1967.
- Research on soil bacteria, called *Streptomyces*, revealed a way to utilise the bacterial equivalent of sexual reproduction to enhance genetic variation. This work laid the foundation for future work on *Streptomyces*, which has since become a major area of research.

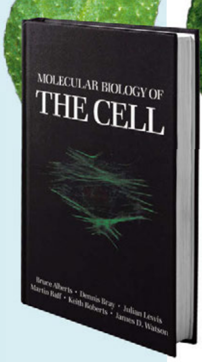
Streptomycetes are the source of over half of clinically useful antibiotics worldwide

- 'Semi-leafless' peas bred at the institute changed pea architecture to improve standing ability in the field, leading to easier harvests and less risk of damage from fungal attack. This transformed the UK pea industry, and today 'semi-leafless' accounts for 100 per cent of dried pea varieties.
- New GM techniques were developed for *Streptomyces* research, and the discovery that genes for antibiotic production are clustered, greatly enhanced prospects for finding the next generation of antibiotics.
- Ground-breaking bio-imaging techniques including electron microscopy were used to study the structure of plant cell walls and viruses.



1980s

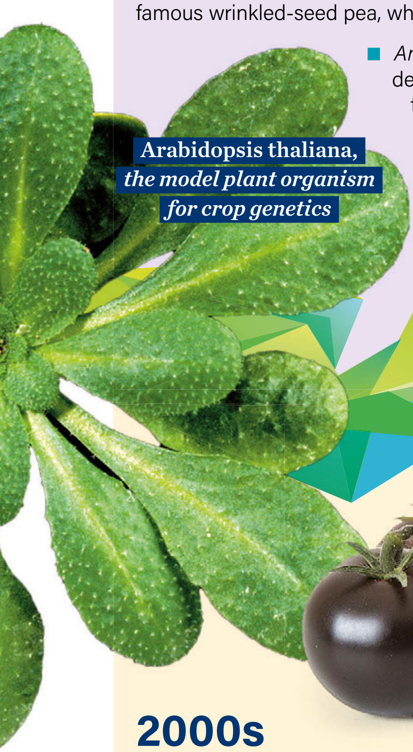
- JIC made major contributions to improving ornamental plants such as Cape primroses, carnations and anemones.
- New disease-resistant cherry varieties were brought to market including the black dessert cherry 'Colney'.
- A major milestone was reached in *Streptomyces* research as scientists isolated and expressed a complete antibiotic biosynthetic pathway in a new host for the first time. They also produced the first 'hybrid' antibiotic using genetic engineering.



- To this day students benefit from the classic text book, *Molecular Biology of the Cell* (1983). Now in its 6th edition, it was co-authored by a JIC scientist.
- The molecular era of *Antirrhinum* genetics began after publishing one of the first examples of transposon tagging to identify genes. This significantly impacted our understanding of how plants produce an array of pigments.

1990s

- Staff were part of an international collaboration that sequenced the first plant genome from the tiny weed *Arabidopsis thaliana*, which became the model plant organism for crop genetics and has influenced generations of plant biologists.
- JIC scientists showed that the order of certain regions of the rice genome is shared among other cereals. 'Synteny', has been at the heart of breeding and cereal research around the world ever since.
- Pea genetic studies led to the discovery of the gene responsible for Gregor Mendel's famous wrinkled-seed pea, which is the most widely consumed type of pea.
- *Antirrhinum* research identified genes that control flower development, including the genes that 'switch' growing shoots to produce flowers.
- JIC furthered understanding of the genetic basis of nitrogen fixation and produced the first 'engineered' nitrogen-fixing microbe.



Arabidopsis thaliana, ***the model plant organism for crop genetics***

PUBLIC OPEN DAY

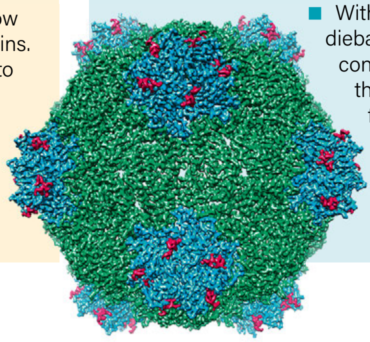
To celebrate 50 years in Norwich, the John Innes Centre is opening its doors to the public. On 16 September from 10am-4pm all are welcome for a family-friendly day of activities, site tours and exciting exhibits. Join the hunt for new antibiotics, explore our labs and greenhouses, find out what's in the food you eat and admire the priceless rare book collection. Free entry – no booking required.

2000s

- Research on plant flowering mechanisms in *A. thaliana* provided clues to how crops can be improved to cope with climate change.
- Advances in our understanding of how wheat chromosomes pair helped breeders to cross commercial and wild varieties to improve agronomic characteristics, eg. drought tolerance.
- JIC oversaw the sequencing of the complete genome of the soil bacterium *Streptomyces coelicolor*, demonstrating for the first time that *Streptomyces* genomes are very large and rich with gene clusters for potentially interesting metabolites, including antibiotics.
- Scientists expressed genes from *Antirrhinum* in tomatoes to grow purple tomatoes with higher levels of health-protecting anthocyanins. This was one of the first examples of plant metabolic engineering to offer the potential to promote human health through diet.
- Oats were found to have enzymes in their roots that make anti-fungal compounds. Work began to identify the 12 steps for the biosynthesis of these compounds, providing possibilities for protecting wheat and other cereals from serious fungal diseases.

2010-2017

- The first analysis of the large and complex wheat genome was carried out, which will help the breeding of better wheat varieties.
- Using genetics to control the protein composition of peas, JIC developed a pea with protein predicted to be more easily digested. The 'super pea' has potential as a high protein food source.
- The discovery that the genes for synthesising diverse natural products are organised in clusters, opens up opportunities to harness the chemical diversity of plants for a new generation of drugs and high-value compounds.
- A new broccoli variety, Beneforté, with high levels of glucoraphanin, thought to reduce chronic disease risk, was released by Marks & Spencer having been developed in collaboration with the Institute of Food Research (now the Quadram Institute).
- With UK ash trees threatened by ash dieback, JIC spearheaded an international consortium to fight back by sequencing the fungal pathogen and identifying fungus-tolerant ash trees.
- A breakthrough turns plants into factories for rapidly producing high value proteins, such as vaccines.



Brilliant brassicas

Significant advances over the past 18 months by John Innes Centre scientists mean some brassica vegetables could be grown throughout the year – despite an increasingly unpredictable UK climate

Brassica species encompass a diverse range of economically important crops worth in excess of $20 billion worldwide. Brassica research at the John Innes Centre is thriving, in no small part due to the close links with the teams studying vernalisation, the need for some plants to undergo a period of cold weather before they can flower. Research by JIC scientists using broccoli and the reference plant *Arabidopsis thaliana* demonstrated that differences in broccoli genotypes that required longer or shorter periods of cold prior to flowering could be mapped back to small variations in a gene called *FLOWERING LOCUS C* (*FLC*).

Earlier research by Professor Dame Caroline Dean showed that variation of the *FLC* gene enables Arabidopsis (a wild relative of brassica crops and in the same family) to adapt to different climates. Working with Dr Judith Irwin (pictured), the team has now shown that these principles also apply to broccoli. The developments are part of a wider project at JIC funded by the Biotechnology and Biological Sciences Research Council (BBSRC) to increase crop productivity and reduce the vulnerability of our food supply chain to fluctuations in climate. Working with Professor Dean, Dr Irwin's lab translates understanding in the reference plant Arabidopsis into more strategically relevant, and genetically more complex, brassica crops.

This spring the team at JIC announced the development of a new line of fast-growing sprouting broccoli that effectively removes the requirement for vernalisation. The new line, developed using conventional breeding techniques, takes just 8-10 weeks to go from seed to flower (the part of the broccoli we eat is the flower buds) and has the potential to deliver two full crops a season in-field.

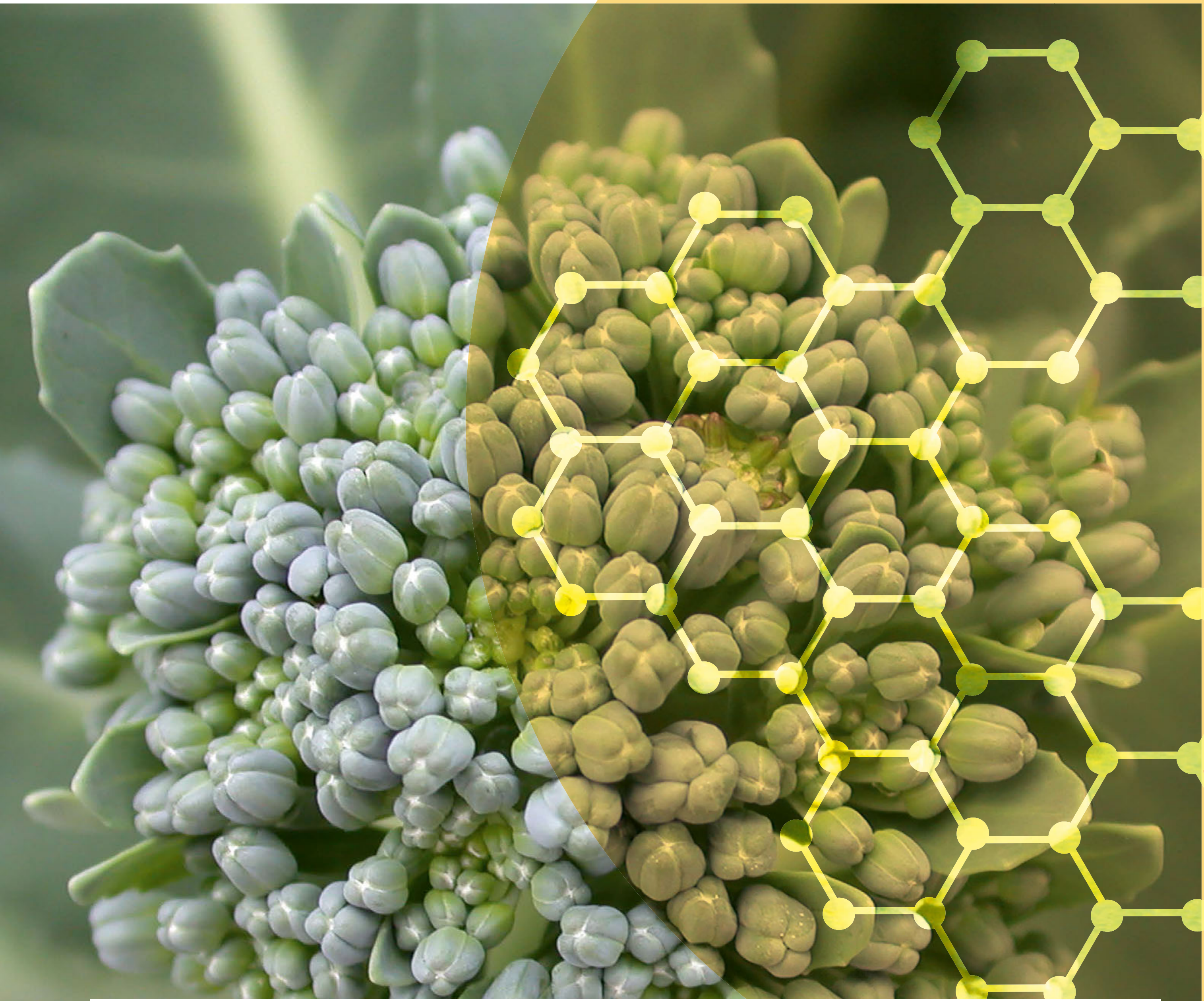
Even more promising, Dr Irwin believes that the new line can be grown year-round in protected conditions. "We could grow two crops a year in a field. But if we grew them in a protected environment – and this is what we are so excited about – we think you could grow four or five crops and grow on demand to meet supply," said Dr Irwin. "There are lots of things to consider in terms of the economics of farming in protected conditions, but you could grow them in a greenhouse, vertical farm or even a poly tunnel."

Grown under such protected conditions, the new line would allow growers to set themselves up locally, close to centres of distribution, reducing food miles at a time when the UK's reliance on imported vegetables is particularly acute, with just 23 per cent of our fruit and vegetables grown at home.

> We could grow two crops a year in a field. In a protected environment you could grow four or five crops on demand to meet supply

THE *BRASSICA* GENUS

The *Brassica* genus contains a range of diverse and economically important species, including: *Brassica oleracea* of which broccoli, cauliflower, cabbages, Brussels sprouts, kohlrabi and kale are all subspecies, and *Brassica rapa* which includes pak choi and Chinese cabbage, and which is also grown as an oil crop in countries such as Bangladesh. Another example, *Brassica napus*, familiar to all as the yellow fields of oilseed rape, is an allotetraploid hybrid of *B. oleracea* and *B. rapa* (containing the genetic information from both parental species) making it even more genetically complex.



BRAVO! A PIPELINE FROM LAB TO FIELD

Another exciting collaboration involving JIC scientists, breeders and growers, Brassica Rapeseed And Vegetable Optimisation (BBSRC BRAVO) is a five-year partnership programme that offers a joined-up response to the challenge of climate change.

Led by Professor Lars Østergaard, BRAVO provides a means of applying fundamental science by bringing together stakeholders from all sectors to create a pipeline from lab to field. It includes representatives from six academic partners along with the breeding industry, the National Farmers Union (NFU) and AgriTech East.

“We consulted with farmers, growers and plant breeders to find out what is important to them. They will be exposed to the science all the way through the five-year programme to help take it forward,” said Professor Østergaard. High on the breeder wish list are synchronised flowering, better seedling vigour and establishment, less pod shatter and higher yields. Some of the outcomes may be years away: applying knowledge from the model plant Arabidopsis and transferring it to more genetically complicated brassicas when looking for traits is not straight-forward.

Another longer-term ambition is the possibility of combining genetics and gene expression data with environmental data to create more sophisticated agronomic models that take a holistic view of crop production. BRAVO Project Manager, Dr Rachel Wells, said, “It would be great to be able to plug in where your field is in the country and say, ‘This is my latitude, my longitude, this is the variety I’m going to use, it has this type of genetics in it, this is when it’s going to flower based on our weather forecasts.’”

Dr Wells added, “The more strategic work you do… the more it drives you in that direction. It is nice to know that what you are doing is going to go on and have an impact in the real world.”

BRAVO
Brassica Rapeseed And Vegetable Optimisation

From Arusha with love

New challenges, fresh perspectives and engaging science; three John Innes Centre PhD scientists reflect upon a memorable two-week AfriPlantSci summer school

A visit to the Nelson Mandela African Institute of Science & Technology in Arusha, Tanzania, offered JIC scientists a chance to forge new international friendships and experience the routine realities faced by their peers in sub-Saharan Africa.

"There is a lot we take for granted here at JIC – in Arusha, the temperature in the lab got up to 38°C and we were meant to be doing a room temperature incubation!" said Jenny Walton, a fourth year PhD student reflecting on the experience at the AfriPlantSci summer school. "It was fun and fostered a creative atmosphere and it was really great to see how engaged all the African students were. I came back with a renewed optimism in science."

Jenny was joined by Javier Galdon-Armero and Eleanor Fearnley, both third year PhD students, who gained places on the BBSRC-funded summer school on Plant Metabolism for Improved Nutrition and Health. The summer school brought together a group of masters and PhD students from countries across sub-Saharan Africa with the aim of building networks among peers and trainers. Organised by Professor Giles Oldroyd, a project leader in the department of Cell and Developmental Biology at JIC, the event aimed to cover the 'breadth and depth' of plant metabolism and how it applies to the improvement of plant and human nutrition.

John Innes Centre project leaders in Arusha included Director Professor Dale Sanders, Professor Alison Smith, Professor Sarah O'Connor, Dr Janneke Balk and Professor Cathie Martin. These leaders gave lectures followed by journal clubs and hands-on practical sessions.

The chance to network with project leaders and fellow scientists from Africa was particularly welcomed by the John Innes Centre PhD students. "Giles said at the beginning that he wanted to break down the barriers between project leaders and the students and I think that really helped," said Eleanor.

The visit highlighted the daily challenges faced by their fellow participants. "We were lucky because it is one of the top biological science institutions in Africa. When you talk to the participants from other institutes they say they have even less equipment," said Javier. "I talked to someone who said they have so many power-cuts that they cannot have any growth rooms. Something as basic as that – we just assume we will have a room where we can grow our plants. They don't."

Eleanor, Javier and Jenny all work on fundamental research in which the end product may be years away whereas at the summer school, young African scientists stressed the need for quick results for farmers.

Photos by Nathan Sukhnandan

"I do mostly basic science on developmental biology," said Javier. "In Africa I was trying to explain why it was important and they would say, 'but how is that going to help us and the farmers here?'"

Talking to African students lent perspective to the work back home at JIC said Eleanor, "Every student you spoke to worked on projects that were much more applied than what we do. It felt like they were duty-bound to solve the problem now rather than years down the line and it did put our work into perspective. It makes you think about where the end use is."

The course lived up to its promise to provide a 'buzzing atmosphere' and left a lasting impression, "My lab partner from Arusha is still emailing me and it's really good we made those connections," said Jenny. "I would recommend the summer school to everyone."

ABOUT THE JIC DELEGATES: Alongside the JIC participants Eleanor, Javier and Jenny, a number of other JIC scientists were involved in bringing the event together. Among the organisational team in Arusha were PhD students Eleni Vikeli and Josie Maidment, post-doctoral scientist Dr Tilly Eldridge and research scientist Dr Anne Edwards, who worked tirelessly over the two weeks to deliver an exciting schedule.

Botanical Boudicas

The First World War is often thought of as a watershed in the history of women in the workforce. This was the subject of the 2017 Innes Lecture – an annual history of science talk given to the Friends of John Innes Centre and the public, supported by the John Innes Foundation

Dr Patricia Fara took as her title, 'Botanical Boudicas and Scientific Soldiers: Struggles past and present'.

While it has been argued that the war 'found them serfs, and left them free' (Millicent Fawcett), Dr Fara's research explores women's struggle in scientific careers after the war, into the 21st century. It was not until the late 19th century that women were permitted to attend university, and even then they were often restricted to segregated, women-only colleges. The first UK university to award degrees to women was London in 1880 when four women received BAs, but some resisted change until well into the 20th century – Cambridge University did not award women full degrees until 1948, and many laboratories were closed to women, so women's colleges had to provide their own laboratory facilities.

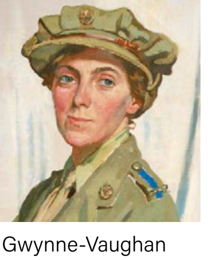
The exclusion of women extended into scientific societies, which had been run as gentlemen's clubs. In 1904, Hertha Ayrton became the first woman to gain entry into the Royal Society to read a scientific paper. In the same year, the Linnaean Society elected women fellows for the first time. Among these fellows was Marie Stopes, the first female botany lecturer at the University of Manchester, who was once prevented from exhibiting her Japanese specimens, being told that her butler or another man could do it for her.

Dame Helen Gwynne-Vaughan, a heroine of WWI as first controller of the Women's Auxiliary Army Corps in France, was hindered early in her botany career because it was considered 'improper' for a woman to lecture to a mixed audience. After the war Gwynne-Vaughan was more fortunate than many: she successfully retained her job as Head of Botany at Birkbeck College, London. Elsewhere women were expected to return to the home, and married women were specifically barred from certain jobs, such as in the Civil Service and Post Office, for years to come. Science, along with many other occupations, was recruiting women on unequal terms with their male counterparts. At universities and organisations such as the British Museum for Natural History, women were 'second class' employees on lower pay.

Despite an impressive record of contributions to science and medicine during WWI, conventional hierarchies that placed men above women were re-established after the Armistice. Almost a century later, the current statistics on women in STEMM (Science Technology, Engineering, Maths and Medicine) careers show that although significant progress has been made towards gender equality in these fields, there is still plenty of room for improvement.

For more information on these statistics, please visit, http://bit.ly/WISE_stats. Dr Patricia Fara is a Fellow of Clare College Cambridge and President of the British Society for the History of Science. Her books include the prize-winning Science: A Four Thousand Year History.





FROM LEFT TO RIGHT: Rose Scott-Moncrieff, Marie Stopes and Dame Helen Gwynne-Vaughan

SCOTT-MONCRIEFF LECTURE

The John Innes Centre is one of many institutes pushing for equal opportunities and was the first independent UK research institute to be awarded the Silver Athena Swan Award. JIC will also be introducing the 'Scott-Moncrieff Lecture' to its 'Named Lecture' series in honour of the talented biochemist, Rose Scott-Moncrieff. The first in the series acknowledges the incredible scientific contribution of our alumnae.

Retaining the ashes?

A survival struggle is taking place in British woodlands, the outcome of which could change the nature of our landscape

Five years on from the discovery of ash dieback disease in Britain and the future of the tree lauded as the 'Venus of the Woods' remains in the balance.

An epidemic on the scale of ash dieback could have seen the iconic ash wiped from our landscape and into folklore. Fortunately, Britain's third most common tree species seems destined to avoid the worst possible outcome and remain part of our much-loved woodlands. This can be largely attributed to the genetic diversity that exists in the ash population with up to five per cent of trees having good resistance to the *Hymenoscyphus fraxineus* fungus that causes ash dieback (pictured above: a resistant tree next to a susceptible tree). One outcome of an epidemic such as ash dieback is that the host and pathogen, over the course of successive generations, reach an equilibrium that alters the ecology of the host but fails to exterminate it.

"Because there is genetic variation in the host plant we would expect to arrive at that equilibrium. But we don't yet know much about variation in the fungus," said Professor James Brown, Head of Crop Genetics at the John Innes Centre. "We know that the fungus is a very aggressive pathogen in Europe, and we know that on ash species native to East Asia it reproduces prolifically but is not a destructive pathogen there. So one of the questions is 'What is likely to happen to this disease in Europe and Britain specifically?' And to answer that we need to understand how natural selection operates in the fungus."

Symptoms of ash dieback are premature shedding of leaves at the top of the crown, small necrotic spots and lesions on stems and branches and perennial cankers on branches.

The first European cases of the pathogen were recorded in 1992 in Poland and by 2012 it had spread through most of the continent, including Britain. Based on what is known about the epidemic and the scale of infection, Dr Joan Webber at Forest Research has estimated that the fungus could have been in this country for around 15 years before it was discovered in natural woodland by JIC scientist Dr Anne Edwards in Ashwellthorpe Woods, Norfolk. Recent research by scientists at

> The work we are doing will help us to understand how quickly the ash will be restored as a keystone species in Britain

JIC and collaborators at Forest Research has revealed how different sources of the invasive fungus have influenced its spread and proliferation across Britain.*

Their study compared pathogen diversity in British ash trees infected from two distinct sources: some woodlands had been planted with imported saplings that were already infected with the ash dieback fungus; whereas other ancient woodlands were infected by the wind-borne spores, which the dieback fungus produces in profusion, carried on the wind from the continent (pictured above right: fallen leaf stalks with the dieback fungus).

"We've found there is considerable genetic diversity in the two types of population," said Professor Brown. "What our results show is that the disease would have arrived in Britain via wind-borne spores, but its spread beyond the east coast of England would have been much slower without the imports."

Dr Elizabeth Orton, a post-doctoral scientist who is working on the project, said her research highlights the importance of preventing further spread of new genetic variants of the dieback fungus from East Asia into Europe. "We need to restrict world-wide movement of ash trees that may carry the disease," said Dr Orton. "This would prevent more diverse, possibly more pathogenic strains of dieback reaching Europe because we've shown their descendants can come to the UK as wind-borne spores." Professor Brown added, "For such a policy to be effective, disease controls need to be implemented at a continental scale not just by individual countries."

In the next stage of their research, Dr Orton and Professor Brown are studying how natural selection is acting on the dieback fungus in British ash woods. They aim to predict whether the fungus will remain highly aggressive, or will evolve to achieve co-existence with its host population.

"The work we are doing will help us to understand how quickly the ash will be restored as a keystone species in the British landscape and at what level it will be restored," said Professor Brown. "Will it become, like the elm, a small hedgerow shrub, or will it become, once again, an important large tree with a lifespan of hundreds of years?"

Funding: Tree Health and Plant Biosecurity Initiative. Collaborators: Dr Joan Webber and Professor Clive Brasier, Forest Research, Hampshire. Journal: Plant Pathology

Awards & achievements

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

Professor Cathie Martin

Fellow of the American Society of Plant Biologists

Professor Cathie Martin has been elected as a Fellow of the American Society of Plant Biologists (ASPB). Only 16 scientists world-wide were awarded fellowship in 2017, and only two from outside of North America.

Professor Martin has had a long and active role in ASPB, most notably sitting on the editorial board for the prestigious ASPB journal *The Plant Cell* from 2000-2014, and becoming the first female and first non-American editor-in-chief from 2008-2014. She has been an associate editor for *Plant Physiology* since 2015.

Professor Allan Downie

Awarded Adam Kondorosi Prize

Professor Allan Downie has been awarded the Adam Kondorosi Prize for his valuable contribution to research on symbiotic nitrogen fixation in legumes. Named after the late Adam Kondorosi, the award recognises landmark research in symbiosis and related fields that make a significant impact on our understanding of plant-microbe interactions. Professor Downie has had a long and distinguished career at the John Innes Centre with recent research focusing on rhizobial infection of legume roots and investigating ash dieback in the European ash tree.

Professor Graham Moore

Jointly awarded 2018 Rank Prize in Nutrition

Professor Graham Moore and the University of Bristol's Professor Keith Edwards have been jointly awarded the 2018 Rank Prize in Nutrition (Human and Animal Nutrition and Crop Husbandry) for "their pioneering research", "which has enabled plant breeders to exploit cereal genomics to develop improved wheat cultivars".

Professor Moore has had a long and distinguished career in wheat research, and this prize recognises three of his major breakthroughs: the pioneering concept of cereal 'synteny' which facilitated improved interaction between scientists working on different cereal species; the use of the synteny concept to characterise the Ph1 locus that allows wheat to have multiple copies of its genome; and the proposal and subsequent coordination of the WISP wheat pre-breeding programme.

Jemima Brinton

MonoGram Early Career Excellence Award

Final year PhD student, Jemima Brinton, has been awarded the MonoGram Early Career Excellence Award (MECEA).

Awarded annually to two PhD or early-career postdoctoral researchers in the field of small grain cereal and grass research in the UK, the MECEA award recognises outstanding contributions in both basic and more applied disciplines, as well as scientific outreach.

Jemima's research focuses on the mechanisms that control grain length and width in bread wheat with a view to increasing final yield. Her research has contributed to the characterisation of the genomic loci which quantitatively affect grain weight in wheat.

Dr Cristobal Uauy

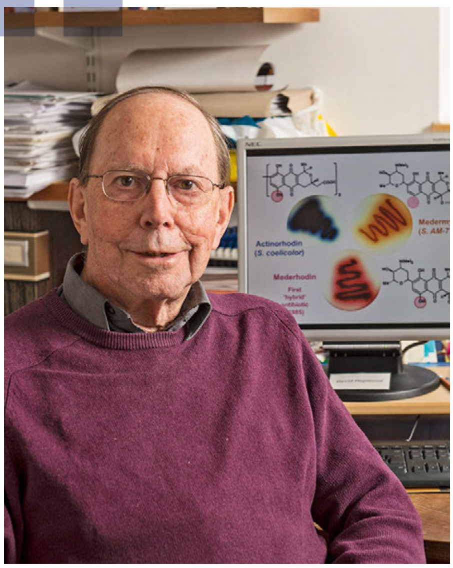
BBSRC Innovator of the Year 2017 Finalist

Dr Cristobal Uauy received national recognition as a finalist in the BBSRC 2017 Innovator of the Year Award.

Dr Uauy was nominated in the social impact category, won by Professor Juliet Osborne of Exeter University, recognising his success in using his research to create a "positive impact on society". Employing modern molecular genetic techniques to investigate wheat productivity traits such as grain size, nutritional quality and nutrient remobilisation, Dr Uauy's research has helped to identify genes that can be incorporated into global wheat breeding programmes.

Recently, working in partnership with colleagues from The Sainsbury Laboratory, the Earlham Institute and the European Bioinformatics Institute, Dr Uauy and colleagues at the John Innes Centre reported the most accurate and complete DNA sequence analyses of the wheat genome to date.

Dr Uauy's group have also spearheaded a movement to introduce practical training resources for breeders and tools to improve the accessibility of important data and methods.



Professor David Hopwood

We caught up with Professor Sir David Hopwood, one of the John Innes Centre's most eminent scientists over the last 50 years

Sir David joined the institute in 1968, less than a year after it moved from Bayfordbury to its home in Norwich. His illustrious career has produced some startling breakthroughs, and his dogged determination and passion has shaped the rise of the field of *Streptomyces* research.

What was your abiding first memory of the John Innes Institute when you arrived?

I thought that things needed changing. Well, first of all there was no media kitchen [for sterile glassware and media] or 'stores'. There was a room in which you could go and rummage – obviously, everybody realised there had to be stores. And we put a stop to the idea that the institute would finish at 3.45 on a Friday, it was so inconvenient! People would phone up and there'd be nobody around. It wasn't terribly popular, but it had to go that way.

There were also virtually no graduate students and, if you like, an ageing population. So I set out to change this, to make it as much as possible like a university department by encouraging other people in the institute to take on graduate students and give a few lectures, because I think that everybody benefits by doing a bit of teaching. The students benefit because they get access to cutting-edge research, and I'm quite sure that it is a symbiotic relationship.

Did you ever have to fight to justify your research?

Very soon after arriving at John Innes there was an ARC (Agricultural Research Council) visiting group and I certainly wasn't prepared for it. I went in there very much exposed and they produced a very damning report on what I was doing. And it turned out that the future of the Genetics Department, in particular, was uncertain – it might be transferred to Biological Sciences at UEA. But pretty soon I managed to correct this.

While I was interested in bacterial genetics, the institute was very much concerned with plants, so the idea was to start some projects where bacteria were doing interesting things with plants, so I chose to hire people to work on rhizobium, agrobacterium, which were then just very small interests in a couple of labs in the world, and plant mycoplasmas, which are wall-less bacteria. And then *Streptomyces* – they were free living but surely they had an agricultural interest. So this approach began to work and the department began to flourish. At the next ARC visiting group the department came out very well.

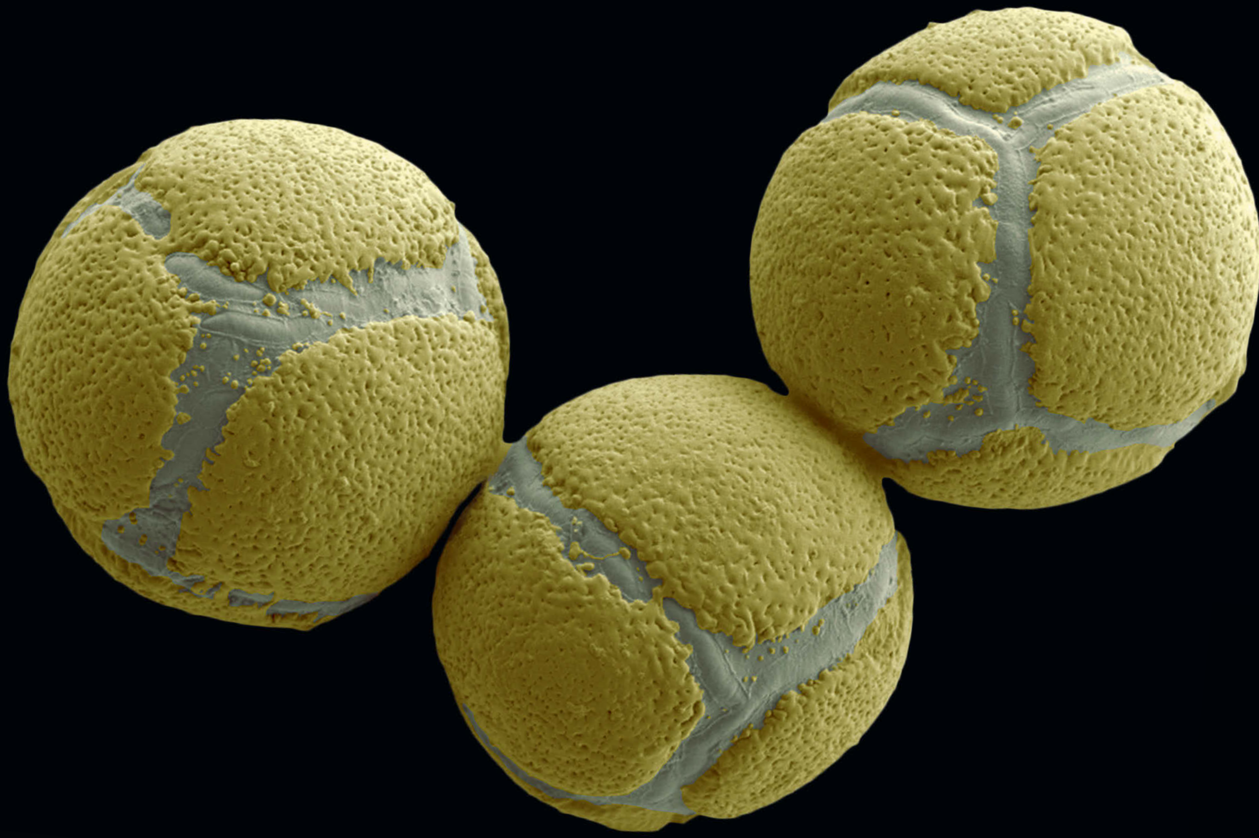
> The hybrid antibiotic stands out, because that was a sort of eureka moment

What was the most significant breakthrough during your career?

In terms of science, the hybrid antibiotic stands out, because that was a sort of eureka moment. We had the blue *Streptomyces coelicolor* and the brown strain that made medermycin, and made this purple recombinant making mederrhodin. And that did cause a stir… it was a watershed moment.

I don't claim that we've changed the world of antibiotic production, because it's extremely hard to discover or to develop novel antibiotics that are better than what nature has already produced, but the genetic manipulation of antibiotic production has certainly become a very promising field. What I do think had a more immediate effect was our discovery of protoplast fusion, where you strip the cell walls off two strains to make protoplasts and then fuse them together with polyethylene glycol and you get a complete mixing of the genotypes – incredibly high recombination frequencies, so people interested in strain improvement could take two divergent lines and very easily mix them together, and get strains that were better.

There's no doubt that was used in industry, I think to quite a degree, but of course it's never published, so you never hear about it. A company isn't going to patent that because that would mean releasing details they want to keep as know-how, and in any case it would probably be hard to patent. We published, and we sent strains if they wanted to try out experiments, knowing full well that the world wouldn't necessarily know about how successful it was.



New balls, please!

Pollen from the flowers of *Mahonia aquifolium* (Oregon grape), imaged using a Zeiss scanning electron microscope in the JIC Bioimaging facility, coloured using Photoshop. The sample was collected by Clare Jarret, a local artist, imaged and coloured by Kim Findlay, senior scientist and head of the Bioimaging facility, as part of a small outreach project combining art and science. The image was also featured in a Royal Microscopical Society calendar for the month of June, with the title 'New balls, please'!

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