NIAB

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Landmark

Researching and discovering cereal crop genetics

In this Issue

News from NIAB

Congratulations to NIAB's pre-breeding team who were finalists in the 'Food Innovation' category of the 2022 BBC Food and Farming Awards for their work using novel plant breeding techniques to help find new genetic diversity in wheat that could help overcome the challenges of food security and climate change. Pictured are Dr Phil Howell, Dr Sigrid Heuer, Richard Horsnell, Dr Fiona Leigh and Professor Mario Caccamo who all attended the Award Ceremony in Cardiff in late November 2022. The eventual winner was TastEd, a food education charity.

We welcomed Professors Tina Barsby and Wayne Powell back to NIAB with the renaming of two of our main buildings to mark the achievements our past chief executives, pictured here with NIAB project manager David Neill who oversaw the construction project. The Barsby Building and The Powell Building are part of NIAB's recently redeveloped Park Farm site on the outskirts of Cambridge. Opened in 2019 the buildings contain research laboratories and offices, crop and seed cold storage facilities, and analytical services laboratories. They are also home to the Agronomy and Farming Systems specialists in arable, field vegetables and potatoes, the Official Seed Testing Station, and the crop characterisation, NIAB LabTest, and crop transformation teams.

NIAB has welcomed PepsiCo to its Park Farm site in Cambridge with the opening of its first UK oat testing laboratory, which aims to help growers boost yields and build future resilience of oat production. Opening the new Pepsico oat quality laboratory at NIAB included (from left to right) NIAB Head of Analytical Services Helen Appleyard, PepsiCo Research Director Professor Ian Puddephat, PepsiCo R&D Director Mac McWilliam, NIAB CEO Professor Mario Caccamo and PepsiCo Senior Scientist Peter Bright.

Mario Caccamo, Chief Executive, NIAB

Old and new approaches to crop genetic innovation

Professor Mario Caccamo is NIAB Chief Executive appointed in October 2021. He originally joined NIAB as the Head of Crop Bioinformatics in 2015 before taking the position of Managing Director of NIAB EMR in 2017. A computer scientist by training, Mario has over 20 years' experience in life science research and big data, including specific projects to apply the latest DNA sequencing technologies and bioinformatics methods to advance scientific understanding of crop genetics and the interaction of agricultural crops with their environment.

A reliable supply of home-grown food is essential to maintain a stable and prosperous economy. The normalisation of irregular climate patterns and the instability that wars and social unrest bring to world food markets have brought into sharp relief how vulnerable we are to global shocks in food supply. I find it compelling to look at these challenges, and the critical contribution of crop genetic innovation, through the perspective of NIAB's 100 year history.

NIAB was founded in 1919 in response to the post-war food crisis when there were serious shortages of seed, fertiliser and equipment to cultivate large areas of newly ploughed fields. Although the underlying reasons might be different, the food supply challenges of today remind us of what the country was facing in the years following the Great War.

Then, one of NIAB's early priorities was the design and implementation of a seed testing system, with the primary aim of assuring quality for domestic and imported seed. In 1921, the Official Seed Testing Station became a member of the International Seed Testing Association, which to this day continues to ensure common standards for testing methods and data collection are maintained across the world for seed testing.

In this context, NIAB's early work in variety and seed testing has provided the basis to define plant breeders' intellectual property through the award of Plant Breeders' Rights, which today supports variety registration and consumer protection through the National List system. In the early 1920s NIAB also established a system of performance trials to compare new crop varieties to existing ones. Over time, this led to the establishment of the 'Descriptive' and 'Recommended' Lists, which are designed to allow growers to select with confidence independently assessed crop varieties.

This two-tier approach highlights the robustness of the underlying regulatory framework for crop varietal registration, testing and certification for seed marketing, built largely under policies promoting food security and consumer protection. This winter edition of Landmark gives an update on many of the activities we deliver at NIAB to support this process for well-established crops as well as some underutilised ones.

I recently co-authored a book[1] chapter with former colleague Dr Richard Harrison exploring the historical development of the UK's regulatory framework for crops. We discuss the important role that transparency plays in the management of information related to crop performance and safety in the context of regulation and the definition of plant breeders' rights.

As we explain in detail, the evidence shows that the UK has a very robust and product-focused regulatory scheme that delivers safe and fit-for-purpose plant varieties. The current regulatory framework is also flexible to incorporate new breeding technologies such as genome editing. In the interests of transparency, organisations such as the

[1] *Towards Responsible Plant Data Linkage: Data Challenges for Agricultural Research and Development* – doi.org/10.1007/978-3-031-13276-6_3

NIAB's early work in variety and seed testing provided the basis to define plant breeders' intellectual property through the award of Plant Breeders' Rights

British Society of Plant Breeders (BSPB) have also proposed to establish a public register for all crop varieties that have been developed using precision breeding technologies, which will only strengthen the current regulatory framework.

Those who claim that new breeding technologies would be left unregulated under the new Genetic Technology Bill ignore the solid system that is already in place. This is a framework with an impeccable track record that over more than a hundred years has evolved to enable safe and sustainable innovation in the sector.

As the Genetic Technology Bill progresses through Parliament, we have already heard calls for the legislation to enforce statutory labelling of products that might include ingredients from crops generated using new breeding technologies. This is an unnecessary requirement that contradicts the rationale of the proposed new legislation that the products of precision breeding technologies are indistinguishable from conventional ones. It would also increase costs to consumers, and in practice would be impossible to enforce precisely because the products are indistinguishable.

The summary data for the summer of 2022 shows that this year was defined by a drought and heat that was more intense than previous comparable heatwaves, including the first time we experienced temperatures of 40°C in the country with records also set for high overnight temperatures. Although most cereal crops fared relatively well, the unusual hot weather accelerated their harvest season, in which yields for legumes, root and horticultural crops were severely reduced.

The challenging weather conditions we experienced this summer, not just in the UK but across Europe, bring to the fore the need to fast-track the delivery of novel crop varieties that could be enabled by new breeding methods. Indeed, the target to maintain global rising temperatures within 1.5°C is unlikely and therefore adapting to climate change is more urgent. New breeding technologies such as genome editing can provide greater access to solutions to generate crops that are resistant to new emerging diseases, can produce good yields under water stress conditions and that can also utilise fertilisers more efficiently.

At NIAB we have contributed with innovation to support the development of more resilient and climate-ready crops that could still yield the expected outputs under greater extremes of climate stress. This is demonstrated by several of the articles in this Landmark issue that are focused on climate-change traits and the deployment of advanced technologies that we can use to monitor the impact of new varieties and specialised agronomy practices.

We were invited to attend the BBC Food and Farming Awards this year after NIAB was nominated as a finalist in the Food Innovation category. NIAB's nomination recognised our work in supporting the development of wheat breeding through the collaborations we have developed over the years with UK and global research organisations. NIAB's investment in infrastructure and skills in cereal crop genetics in the last 15 years has been transformational, and we were thrilled to see this contribution recognised at such a level.

CEREAL GENETICS SPECIAL

Jiemeng Xu, Rothamsted Research

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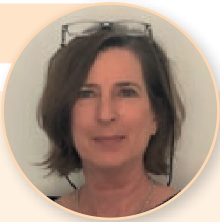
Some like it hot

Currently the global average temperature is estimated to have increased by 1.15°C above pre-industrial times (1850-1900 average) (Figure 1). As a consequence, since 2015 we have experienced the warmest seven years ever recorded, with 2022 well on track to be number eight.

If you like it hot, you will have fond memories of last summer, which reached the highest temperature ever recorded in the UK – a blistering 40.3°C in Lincolnshire and record-breaking temperatures elsewhere across the country. With the world heading towards an average 1.5°C increase in global temperature, chances are that we will see more of that in the future.

Due to the high temperatures and low rainfall, parts of the UK and most of Europe experienced a serious drought in August (Figure 2), causing yield losses and reduced quality for vegetables and fruits, and forage. However, according to the Defra statistics (October 2022) there were also some real winners – with higher yields per hectare reported for barley, wheat (11%), oats (4.5%) and oilseed rape (19%). This was at least partly due to a lucky escape since the heatwave occurred after the critical crop developmental stages and actually helped drying down the crop. Across Europe the situation was not as favourable; France saw a 20% reduction in wheat yield and non-irrigated maize by 30%. Similarly, a heat wave in Denmark in 2016 caused a 30% reduction in wheat yield.

So, whilst plants love it when it is warm, with a clear, sunny sky (and high



Dr Sigrid Heuer is head of pre-breeding at NIAB, developing climate resilient crops, with an emphasis on high temperature stress and drought, alongside enhancing nutrient-use efficiency in crops to reduce fertiliser use.

CO_2) maximising the effectiveness of sugar generation via photosynthesis, they have their limits. In wheat, for instance, under experimental conditions, leaves showed stress systems already at 24°C and leaf photosynthesis is significantly reduced at 27°C. This negatively affects spike number per plant and thereby final yield. Later on, during the grain filling stage, heat stress negatively affects grain/fruit quality and size, thereby reducing yield.

Most plants, including wheat and beans, are very sensitive to high temperatures during pollen development. In wheat, this occurs during booting, when the spike is still hidden within the stem. When temperatures exceed 34°C, pollen development is disrupted and there is no pollen on the stigma, or pollen cannot germinate for fertilisation (Figure 3). This is causing seed sterility and lack of grain development. In India, an unusually hot event in 2022 during that stage caused a 10% reduction in yield and caused an export ban on wheat to secure national supplies.

The good news is that naturally heat tolerant genotypes are available that we can use to breed for heat tolerant crops. In ongoing projects at NIAB, in partnership with international research centres in Mexico (CIMMYT) and Colombia (CIAT), heat tolerant wheat and common bean material is being validated and is now making its way into breeding programmes. Likewise, work on identifying drought tolerant material and understanding the underlying mechanisms is ongoing at NIAB and a research and breeding priority across the globe.

Within the Crop Science Centre, NIAB's new partnership with the University of Cambridge, a new project has just started to develop heat- and drought-tolerant and disease-resistant legumes for Africa. NIAB is now also engaging internationally in order to maximise the value and impact of our tremendous genetic resource comprising >10,000 different wheat lines, in support of a global effort to make our staple crops more climate resilient and increase food security for all.

Figure 1. Increase in average global temperature
Source: Earth Observatory NASA.gov

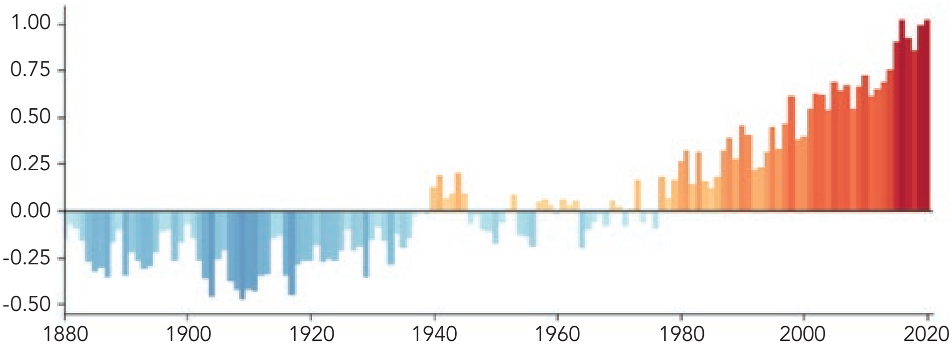


Figure 2. Drought in Europe (August 2022)
Source: Global Drought Observatory

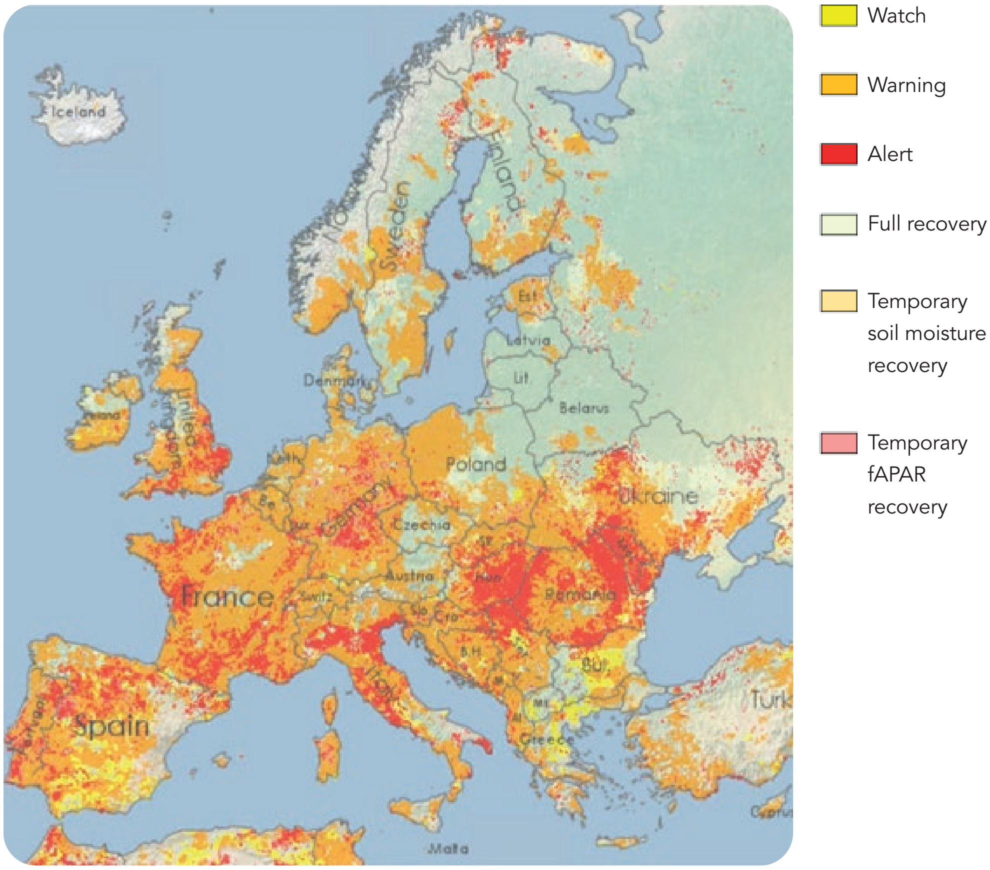
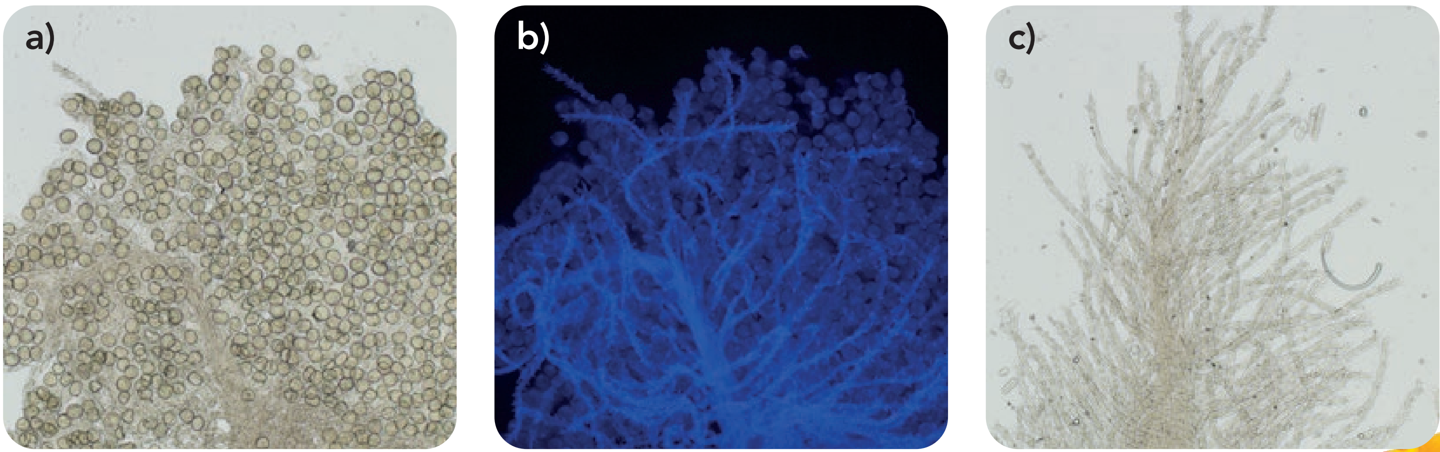


Figure 3. Pollen on the stigma a) and germinating b) under control conditions. Under heat stress c) pollen development is disrupted and there is no pollen on the stigma



Nick Fradgley • nick.fradgley@niab.com

Working towards a diverse UK wheat landscape

Nick Fradgley researches the role of plant breeding in improving the sustainability and productivity of crops across a range of management systems. His PhD project investigates the genetic architecture of milling and baking, as well as nutritional quality, and how these traits can be predicted.

There are concerns that modern arable farming systems have become too uniform and homogeneous and that this leaves our cropping systems vulnerable to unpredictable environmental shocks. Although almost all wheat varieties in the UK are pure lines, ie all plants grown in a field are genetically almost identical, the diversity of wheat varieties grown across the whole landscape is more important when considering the productivity of a nation rather than just a single field. In theory, each wheat variety (genotype) will be adapted to a particular range of environments and be sensitive to different biotic and abiotic stresses. Having a greater diversity of wheat genotypes across the whole landscape should help hedge our bets to any environmental stresses future years may bring, and allow for selection of high yielding varieties adapted to the range of soil and climatic conditions available throughout the UK.

As a clear example of how a variety has historically suffered from an unexpected environmental shock, the variety Moulin, bred by the Plant Breeding Institute (PBI), was released in 1985 but by the following year was found to have drastically low yields and ear sterility due to cold weather at flowering. Some yields were reduced by as much as 70% and growers even took legal action against seed merchants and PBI. Many varieties were subsequently bred from Moulin and concern remained that these associated issues would persist in the later varieties.

Plant breeding is often credited for achieving significant genetic gain in important traits like grain yield and disease resistance, but is also criticised for eroding genetic diversity by continually selecting and recombining material from within a finite genepool.

But how has the landscape of UK wheat varieties evolved since then and is it becoming too much of a monoculture that is sensitive to these environmental shocks? To investigate these trends, data on the areas of varieties grown across England each year, as well as the pedigrees of these varieties, were analysed. A measure of relatedness based on shared parentage among varieties (kinship) can be calculated and this was then weighted by the

Figure 1a. Trends in landscape diversity of wheat grown in England since 1990

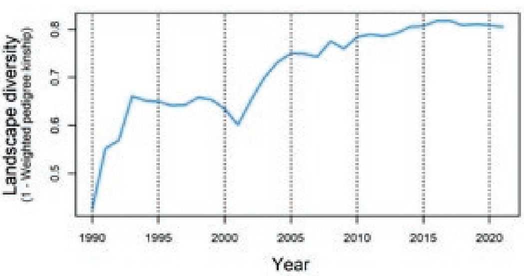


Figure 1c. Dendrogram of wheat varieties relatedness based on pedigree kinship

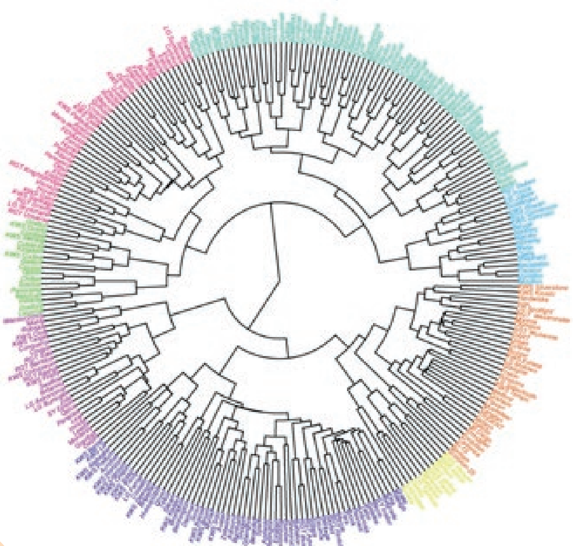
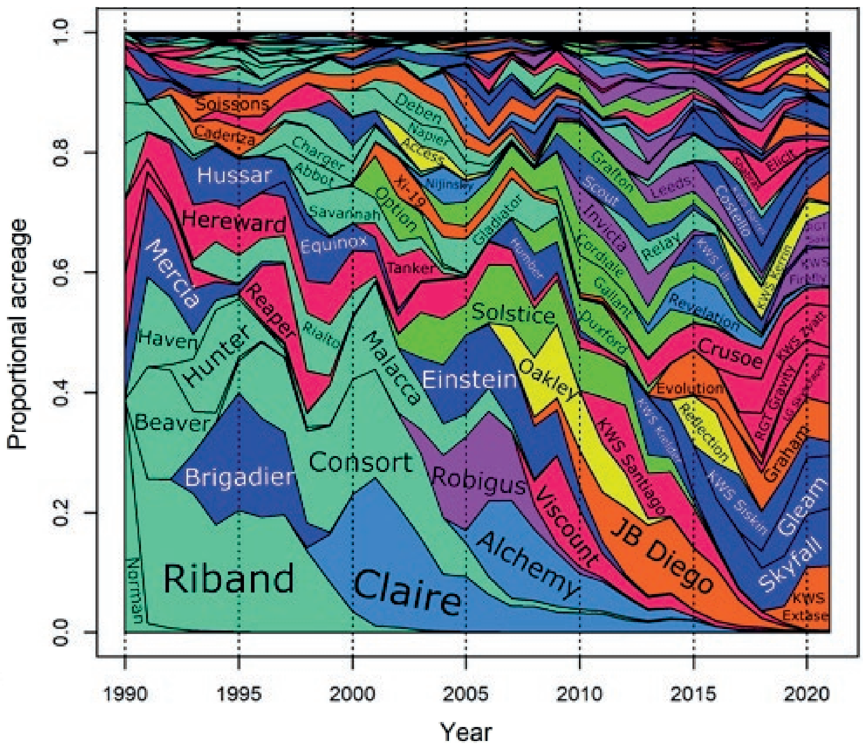


Figure 1b. Proportional area of wheat varieties based on data from NIAB SeedStats service



proportional acreage of varieties grown each year to get an index of landscape diversity. This indicates, on average, how closely related wheat in two randomly selected fields would likely be.

Results showed that there has been an increasing trend in landscape diversity since 1990 as closely related varieties are less likely to be grown in the same year (Figure 1a). The most obvious trend is that there are now fewer varieties that take up such a large market share. Whereas varieties such as Riband and Claire each occupied almost 25% of the wheat area, now only a few milling wheat varieties, such as Skyfall and KWS Extase, achieve more than 10% market share.

Although the dataset only goes back as far as 1990, historically there was even clearer dominance of a few highly successful varieties. At its peak in 1962 Cappelle Desprez was grown on 82% of the UK wheat area and was used as a parent for many PBI-bred varieties. Similarly, the highly acclaimed variety Marquis was grown on over 80% of the Canadian wheat area in 1918.

However, looking even further back to the early 20th Century when heterogeneously diverse cereal landraces were replaced by pure-line bred varieties, landscape diversity would likely have been even greater among a much larger number of localised landraces. While fewer single varieties now have a large market share, many of the popular varieties before 2005 were also relatively closely related, shown by the same colour in Figures 1b and c. Norman, Riband, Beaver, Haven, Hunter, Consort, Rialto and Malacca all share a similar pedigree (Figure 2), and were grown over large areas at a similar period. All these varieties, with the exception of Malacca, were bred at PBI, which closed in 1987 just before the start of this dataset. With increased competition among a greater number of private breeding companies, a greater diversity of wheat varieties have been bred and grown over the last few decades.

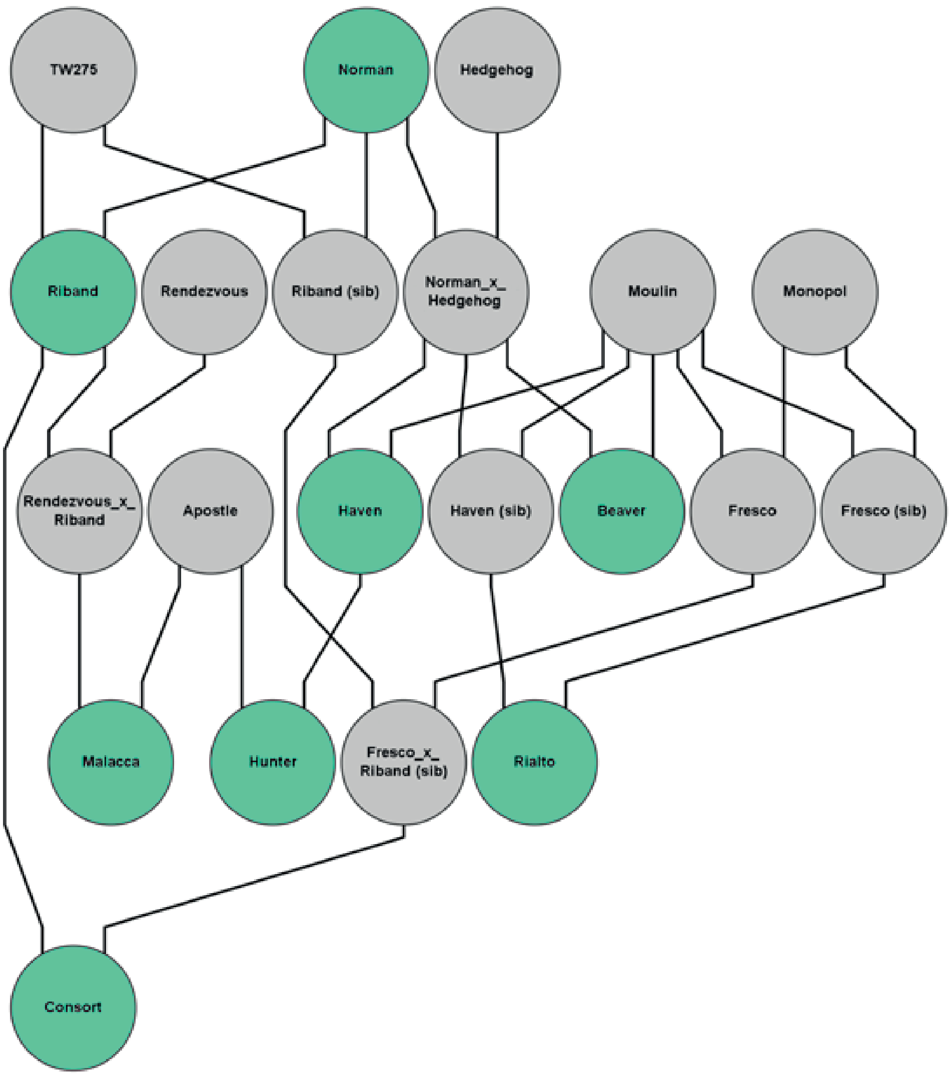
The variety Robigus was released in 2000 and is thought to include some particularly novel genetics derived from a distant wheat wild relative. It represented a distinct increase in yield potential and was commonly used as a parent for subsequently released varieties, such as Leeds, Cougar and Invicta; a large proportion of current non-milling wheat varieties have Robigus somewhere in their pedigree. However, the introduction of Robigus does not seem to coincide with a drop in landscape diversity because the novel diversity introduced by Robigus has been effectively recombined with the existing elite wheat genepool.

Apart from the odd step change, such as the introduction of the reduced height dwarfing genes that clearly increase yield in optimum environments, the majority of genetic gain in yield has been due to steady accumulation of many small genetic effects. It is therefore remarkable that the breeders have achieved continued genetic gains in wheat yield potential without apparently depleting the genetic variance in genepool.

NIAB's pre-breeding work has been operating a large re-synthesised wheat breeding programme which is mobilising a huge resource of genetic diversity from wheat wild progenitor species that are feeding into commercial wheat breeding programmes. Similar to the introduction of Robigus, this input of new useful genetic variability is key to topping up the fuel tank of genetic variance that can be used to keep yield potential increasing and maintain the diversity of UK wheat at a landscape level.

Climate change will present increasingly unpredictable challenges to UK farmers. New races of wheat diseases are evolving to overcome varietal resistances at ever faster rates. However, the recent increases in wheat landscape diversity suggests that this is likely driven by changes in weather patterns that bring in new virulent races each year rather than lack of wheat diversity. Nevertheless, ensuring a diverse and resilient wheat landscape will be even more important in the future and will rely upon continued innovations, such as from NIAB's pre-breeding programme.

Figure 2. Pedigree showing close relationships among several popular varieties between 1990 and 2005



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World-class cereal rust and mildew research comes to Cambridge

The latest scientific advances in research on cereal rusts and powdery mildews and moves to ensure globally sustainable disease management were centre stage at an international conference held in Cambridge.

The 16th International Cereal Rust and Powdery Mildew Conference (ICRPMC) was organised by NIAB on behalf of the European and Mediterranean Cereal Rusts Foundation (EMCRF). The hybrid conference, held at Clare College, Cambridge from 31st August-2nd September 2022, attracted 100 in-person participants and 35 online delegates from across the globe. The two-day conference covered four broad topic areas; pathogen genomics and epidemiology, integrated disease control and breeding for resistance, molecular and cell biology of plant-pathogen interactions, and the global landscapes of cereal rust and powdery mildew fungi. It followed on from a two-day final meeting of the European H2020 'RustWatch' project, making the week a major forum for cereal rust and powdery mildew researchers.

Professor Annemarie Fejer Justesen, from Aarhus University in Denmark, presented the work from Rustwatch, a four-year European Commission project involving partners from across Europe and beyond. Its work supported previous opinion that while yellow rust is capable of undergoing sexual reproduction, a process that increases the chance of new race emergence, this does not appear to be the norm for yellow rust populations across Europe. There are no indications of sexual recombination in the European yellow rust population and the pathogen has not been detected on surveyed barberry (the alternative host) bushes in Europe. However, several barberry species present in Europe have proven susceptible under experimental conditions.

Stem rust is continuing to increase in prevalence across Europe. Since the appearance of stem rust at epidemic scales in Sicily in 2016, the disease has emerged in several European countries with increasing prevalence. Three genetic groups of stem rust have been detected in Europe, and in 2022 significant outbreaks of stem rust were detected in the UK on untreated wheat trials.

While sexual reproduction in yellow rust populations within Europe has not been detected, sexual reproduction in stem rust appears common. Local, sexual recombining populations with the potential of infecting cereals have been observed.

The results of Project Yellowhammer, a four-year study of yellow rust resistance in over 400 winter wheat varieties bred for UK and Northern European

Dr Charlotte Nellist is a group leader in pathology with interests in disease resistance characterisation on a wide range of crops and understanding how pathogens interact with hosts. She manages the UK Cereal Pathogen Virulence Survey (UKCPVS).

Dr Lesley Boyd is an internationally recognised expert on wheat-rust genetics, leading research on the genetics and biology of wheat/rust interactions. Additional research interests include the study of ergot in cereals and the relationship between multiple nutritional traits in cereals, with a primary focus on phenolic compounds.

CRPMC2022
16th International Cereal Rusts and Powdery Mildew
CONFERENCE 2022

The NIAB team that helped organise and run the ICRPMC 2022 Conference environments, was presented by NIAB's Dr Camila Zanella. While a large number of resistance genes were identified, many sources of resistance appear to be race-specific, with the same limited number of resistances being used by most wheat breeding companies.

Early Career Researchers

It is always important to help support the attendance of the next generation of scientists at conferences, with funding provided for six Early Career Researcher (ECR) awards at the ICRPMC. Three were supported by the British Society of Plant Pathology (BSPP), two by the Borlaug Global Rust Initiative, specifically supporting ECRs from ODA (official development assistance) countries and one was supported by EMCRF. The EMCRF award was named in honour of Patrick Schweizer who contributed significantly to the field of powdery mildew research and passed away in 2018. The BSPP awardees were Julian Rodriguez Algaba (Aarhus University, Denmark), Diana Gomez de la Cruz (The Sainsbury Laboratory) and Tyler Frailie (Indiana University, USA), the BGRI awardees were Martin Chemonges (University of the Free State, South Africa) and Niranjana Murukan (Indian Agricultural Research Institute) and the Patrick Schweizer award went to Zoe Bernasconi (University of Zürich).

Advanced molecular genetic studies in barley powdery mildew highlight just how clever fungal pathogens are at generating new genetic variation that underpins race diversity. Dr Stefan Kusch, from RWTH in Aachen, Germany, indicated that the barley powdery mildew pathogen dynamically regulates its numerous transposable elements (piece of DNA that can move within a genome) via complex mechanisms of epigenetics, RNA interference and antisense lncRNAs. Antisense lncRNAs could be a mechanism to repurpose transposable elements and give rise to novel genes. So, transposable elements are the likely key drivers of adaptive evolution in cereal powdery mildew fungi.

Although hundreds of disease resistance genes have been genetically characterised in the wheat gene pool, only a handful of them have been cloned. The large and repeat-rich genome of wheat (the modern wheat genome is five times larger than the human genome) has represented a major hurdle for the rapid and efficient cloning of disease resistance genes.

Over the past five years Professor Simon Krattinger, from KAUST in Saudi Arabia, has developed several gene cloning approaches for wheat. These are based on chromosome sequencing, whole genome sequencing, and transcriptomics sequencing.

The cloning of the yellow rust resistance gene *Yr27* indicated that *Yr27* is allelic to the wheat leaf rust resistance gene *Lr13*, showing 97% sequence identity. This is the first example where alleles of a single-copy gene confer resistance against two different rust species of wheat, which raises interesting questions about how the protein receptors encodes by these two genes function.

Dr Jérôme Enjalbert from INRAE (the French National Research institute for Agriculture, Food and the Environment) presented the results of a spatio-temporal study of changes in varietal resistance over the period from 1985 to 2018 in 54 French administrative districts by using a set of relevant indicators weighted by the relative varietal areas. This analysis revealed an increase in varietal resistance over decades that would be due to the accumulation of both quantitative resistance and different race-specific resistance genes, despite the successive breakdown of major resistance genes. This illustrates the effect of variety turnover, resistant varieties rapidly replacing the newly susceptible ones, but also the global increase of durable resistance in the European germplasm.

ICRPMC 2022 Conference delegates at Clare College, Cambridge

Kay Trafford • kay.trafford@niab.com

Cereal starch and grain quality

The most abundant component of cereal grains is starch. It is starch, a carbohydrate, that makes cereal grains so filling. This is why we eat a large amount of cereals in our diets.

Dr Kay Trafford is a project leader in crop research at NIAB. During her career, she has studied starch-accumulating crop plants, particularly cereals. Using natural variation, she has shown how plants control the amount and nature of the starch that they make with a view to improving crop yield and quality.

Starch structure

Starch molecules are very large and consist of glucose molecules chemically-bonded together into long, occasionally-branched chains. Unlike free glucose molecules, starch molecules are insoluble and exist in plants in the form of granules. Although starch molecules are very similar in all plants, the shape, size and number of granules vary enormously between species. Even amongst closely related cereals, the starch from different species is very distinctive. This alone makes starch very interesting for biologists to study but starch granule shape and size also influences the end-uses of cereals, both for food and non-food. It affects things like viscosity, digestibility, and for human food, what is called 'mouth-feel' which is whether it feels gritty or smooth.

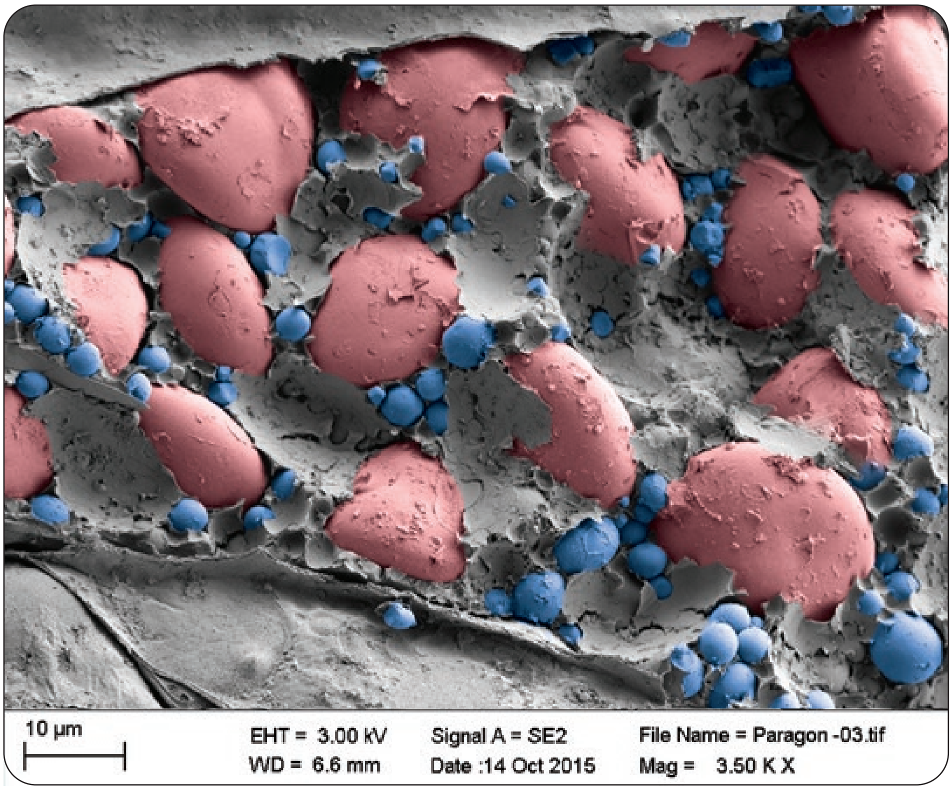
New wheat starch

Recently, NIAB successfully developed a new type of wheat with a larger average starch granule size. This type of starch existed previously but only in some wild-grass relatives of wheat. By studying the wild relative, NIAB discovered the gene responsible for its unusual starch and transferred this trait to modern wheat varieties, e.g. Paragon and Cadenza and the pasta wheat Kronos. The expectation is that the new wheat might be more suitable for making beer and whisky, and possibly less susceptible to yield-fluctuation in changing climates. However, these expectations are still being tested. What we do know is that the amount of starch is the same, or very nearly, to the original. So changing the starch granule size does not affect yield very much, if at all. This probably explains why there is so much variation between plant species in their starch granule shapes – because variation in granule shape and size has no negative impact on plant biology and so it is not constrained by natural selection.

Starch genetics and genomics

Since the dawn of agriculture, humans have shaped the starch content of cereal grains, mostly unconsciously, by selecting plants with lots of plump, starch-rich grains and this has led to higher yields. Of course, there is a downside to high starch content: the starch dilutes out the less abundant, but nutritionally important components such as proteins, fats, vitamins and minerals. By studying how starch and starch granules are made, NIAB has accumulated knowledge of how to improve starch structure whilst maintaining yield, as the new wheat starch story above illustrates. Another of our aims is improving grain quality through an understanding of and conscious selection for genes that influence grain nutritional value without compromising yield.

Very soon, the global scientific community expects a huge increase in the number of publicly-available wheat genome sequences. This will allows us to find new genetic variation, even genetic variation that is hidden because it does not lead to visible changes. At NIAB, we are gearing-up to exploit existing genetic variation in wheat landraces and elite cultivars. We have been identifying and analysing genes relating to starch structure and nutritional value in wheat to provide cereal breeders with tools and information to allow the continued production of new, high-quality and high-yielding varieties.



Inside a wheat grain. Starch consists of large and small granules (coloured red and blue, respectively)

James Cockram • james.cockram@niab.com

In wheat, size really does matter

Dr James Cockram is a group leader working on trait genetics at NIAB. After completing a PhD and post-doctoral position at the John Innes Centre, he has worked at NIAB as a Programme Leader since 2013. His research focuses on the application of plant molecular genetics, genomics, to investigate the genetic control of yield, yield components, disease resistance and quality traits in cereal crops, with particular focus on wheat and multi-founder advanced generation inter-cross (MAGIC) populations.

Wheat is a ubiquitous feature across much of the UK farmed landscape, grown across 1.8 million ha with an annual grain yield of around 14 million tonnes. These are big numbers for a crop with such humble origins – having evolved in Neolithic farmers' fields somewhere in the Middle East via a rare hybridisation between the progenitor of pasta wheat and a small grassy wild relative called 'goat grass'.

Early farmers clearly saw potential in these newly evolved wheat plants, which were associated with better performance and improved yield. What they could not have realised was that they were now dealing with a crop with a supersized genome, encoded by an astonishing 16 million individual characters of the four-letter 'DNA alphabet'. To put this in context, this makes the modern wheat genome over five times the size of the human genome, and forty times that of the related crop rice (which, for pre-history buffs, had been domesticated around 4,000 years earlier in the Yangtze River Valley region of modern-day China) (Figure 1).

The many hundreds of generations of on-farm selection that subsequently occurred from Neolithic times up until the end of the 1800s resulted in the many locally adapted wheat 'landraces' that were grown over this period across Europe and beyond. Industrial breeding approaches that first started at the end of the 19th Century exploited these sources of wheat genetic diversity by systematically selecting and evaluating these landraces, as well as the crosses made between them. The outcomes of this rich history are still evident in modern UK wheats (Figure 2) – for example, NIAB has shown that in a collection of over 180 modern UK varieties released since the year 2000, almost 90% include genetic contributions from the old Ukrainian landrace Ostka-Galicyjska and the Mediterranean landrace from which the early UK variety Squarehead was developed.

Fast forwarding to the modern day, wheat breeders now mix established approaches (making crosses and selecting progeny based on their performance for traits such as yield and disease resistance) with new approaches that exploit the use of molecular DNA methodologies. Indeed, 17 years after release of the human genome, the advances in DNA sequencing technologies that helped deliver this milestone enabled the sequencing of the large, complex, wheat genome. Since then, with sequencing technologies continuing to develop apace, it took just two more years before an additional 14 wheat genome sequence assemblies were published, late in 2020. This included two recently popular UK winter wheat varieties, Robigus and Claire, that had also been selected as founders for NIAB's multi-founder advanced generation inter-cross (MAGIC) experimental population, due to their prominence in modern UK wheat pedigrees.

Consisting of over 1,000 progeny lines created by intercrossing eight parents, the MAGIC population was developed as a powerful resource to investigate the genetics controlling agronomic traits relevant to UK wheat. Via a collaborative project between three additional UK academic partners, collectively we have recently completed genome assemblies for the remaining six MAGIC founder wheat varieties, which when released will increase the number of sequenced wheat genomes available by 40%.

Most recently, we have used the MAGIC population to investigate the genetics controlling the size of the uppermost wheat leaf (the flag leaf), which plays a major role in supplying nutrients to the developing

Figure 1. Illustration of comparative genome sizes – the wheat genome is over five times the size of the human genome, and forty times that of rice

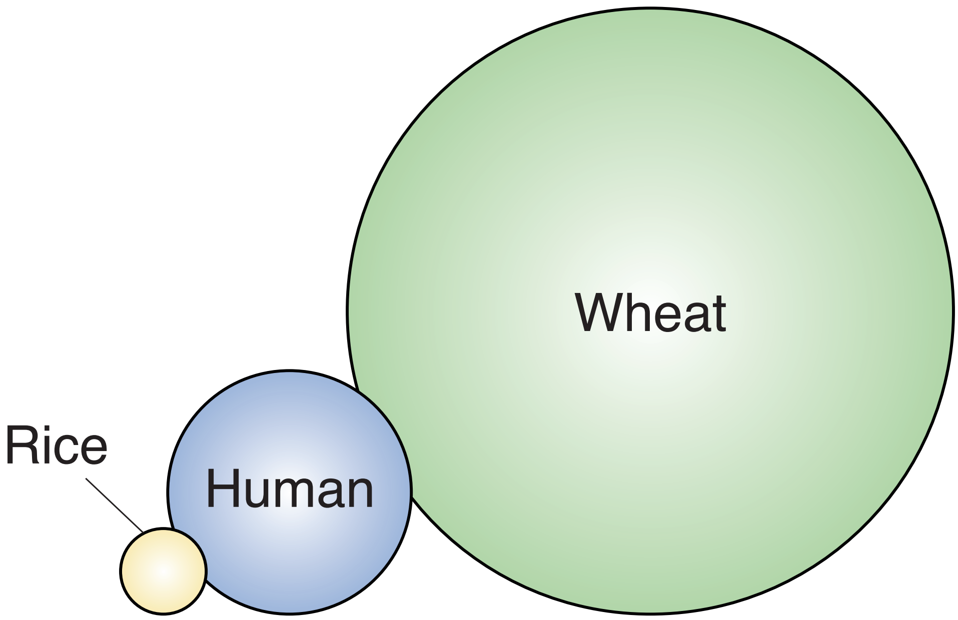
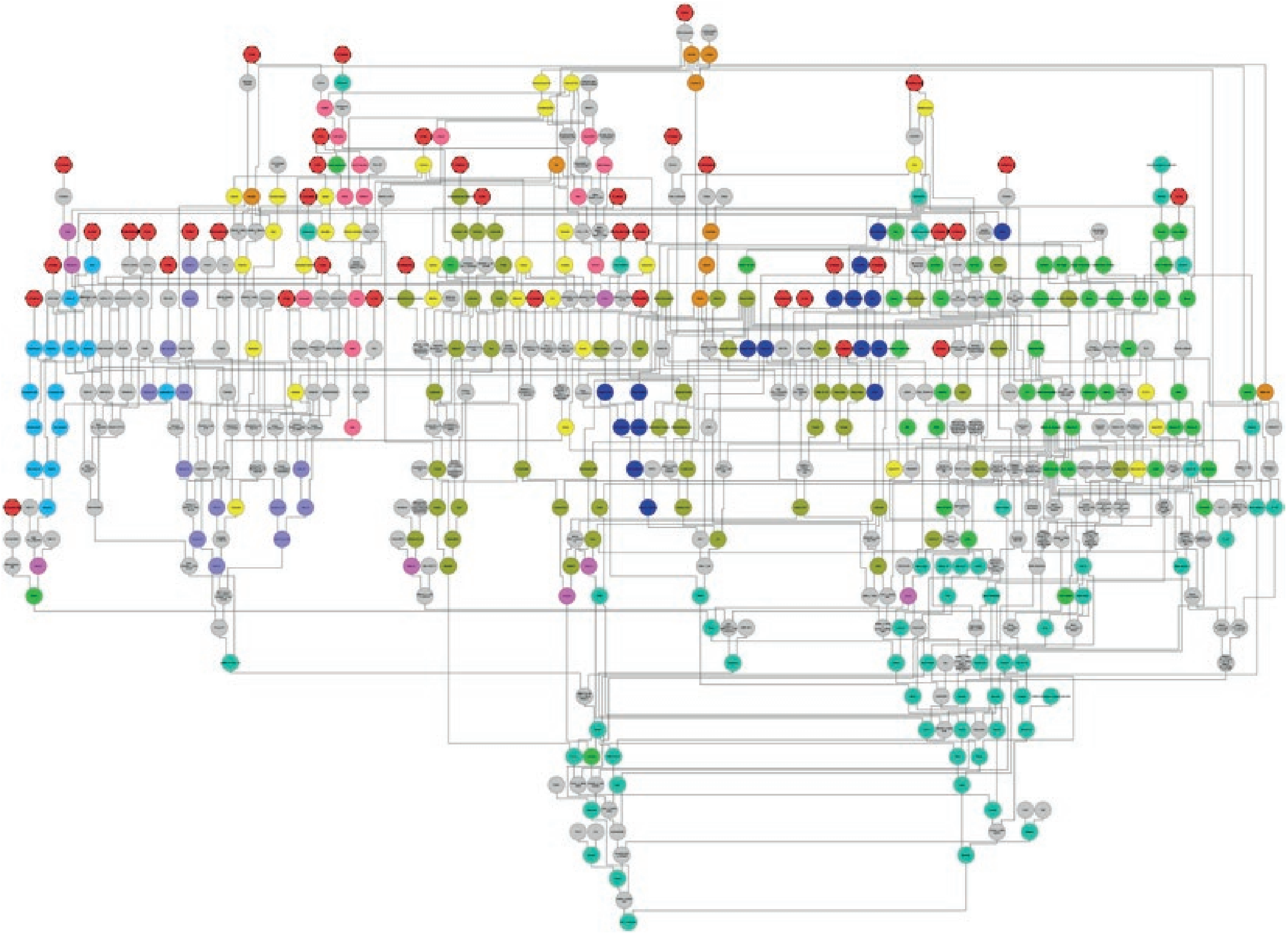


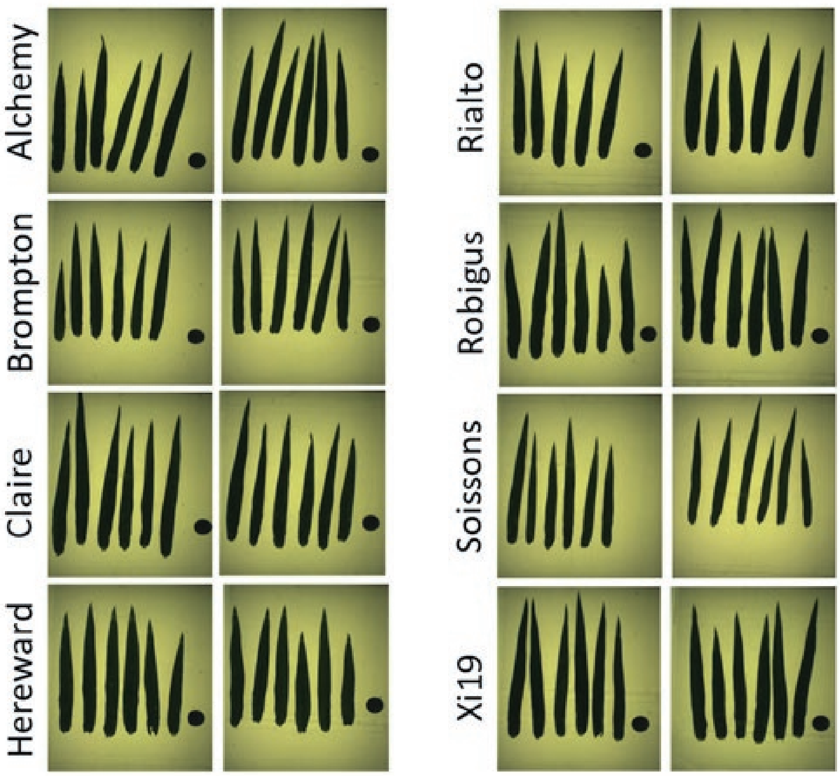
Figure 2. The large and complex pedigree of a single UK wheat variety (RGT Conversion, bottom of image in turquoise), and the contribution of landraces (red) within its history



grain during late season crop development (Figure 3). While we found the genetic control of flag leaf size to be complex, by isolating one of these genetic loci we showed that the increase in size it controlled was associated with larger stomata – the small adjustable openings across the leaf surface that allow exchange of the water, carbon dioxide and oxygen the plant needs to photosynthesise and develop. However, this increase in stomata size was associated with lower stomata density, which could affect the photosynthetic efficiency of the plant. This might be especially true when passing clouds cause transient fluctuations in light, where smaller faster responding stomata are thought to perform better.

In summary, while the modern wheat genome is unarguably huge, in a timely reminder that bigger is not always better, larger leaves may not prove all they make out to be for crop performance in the field.

Figure 3. Example of flag leaf size in the eight wheat varieties that represent the parents of the NIAB MAGIC experimental population



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Harnessing the power of NIAB's diversity-enriched wheat

Climate change and population increase are two fundamental issues for the wheat breeding community to address. More mouths to feed will require higher yielding varieties and changing climatic conditions will require these to be adapted to more extreme weather conditions.

A series of groundbreaking, multi-partner BBSRC-funded research projects, including the Wheat Improvement Strategic Programme (WISP) and its successor Designing Future Wheat (DFW), provided NIAB with the opportunity to undertake pioneering research to help address this.

Our first approach was to generate 50 novel Synthetic Hexaploid Wheat (SHW) lines. Figure 1 illustrates how these lines are created using classical breeding techniques. These SHW are lines that contain unique genetic diversity from the progenitor species *Aegilops tauschii* which is also known as goatgrass. *Ae. tauschii* contributed one third of modern wheat's genetic material as the 'D sub-genome'.

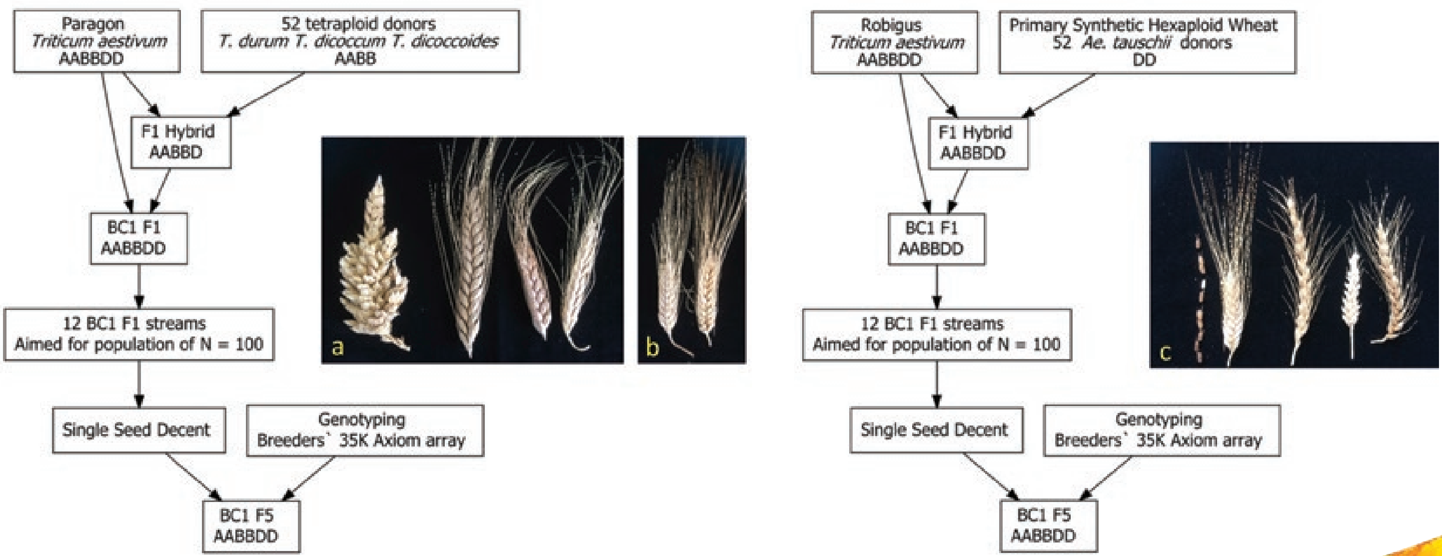
After developing the SHW lines, NIAB was able to cross them into the wheat varieties Robigus and Paragon to produce over 9,000 pre-breeding lines. The second approach taken was to target diversity improvement across the other sub-genomes that form modern wheat, the A and the B genomes. By making direct crosses with tetraploid wheat species, including wild emmer wheat *Triticum dicoccoides* and *T. durum* or pasta wheat, to those same varieties Robigus and Paragon, NIAB produced over 3,000 pre-breeding lines incorporating unique tetraploid diversity. These progenitor species used in the crossing programmes are well adapted to a diverse range of environments; by backcrossing them into current commercial wheat varieties NIAB has created an oven-ready source

Dr Tally Wright is leading a group in quantitative genetics within the pre-breeding department at NIAB. The group explores statistical genetics, experimental design, data analysis and methods of diversity capture from wild relatives of modern crops.

Dr Fiona Leigh is a senior research scientist at NIAB. With over 20 years' experience of characterising genetic diversity of crop plants using molecular markers, Fiona is part of the pre-breeding team, capturing diversity from wheat relatives in order to augment the traits available to the wheat breeding community.

Richard Horsnell is a research scientist working on exploiting genetic diversity from wild relatives of wheat. Richard has generated over 50 novel synthetic wheat lines capturing genetic diversity from the ancestral wheat progenitor species *A.tauschii*. Nearly 10,000 synthetic wheat derived pre-breeding lines have been developed, providing both scientists and breeders with a valuable resource to explore novel sources of genetic diversity.

Figure 1. The capture of diversity



of improvement. Figure 2 shows an example of the range of ear traits captured in one cross between Robigus and an emmer wheat.

Via these crossing approaches NIAB has created a library of thousands of diversity-enriched wheat pre-breeding lines that harbour potentially game-changing ancestral genes. In 2022 we grew NIAB's largest ever winter wheat nursery to evaluate the potential of these diverse pre-breeding lines; 4,000 of the diversity-enriched Robigus lines were grown in small plots in a single field trial alongside control varieties. We were able to assess each line for traits including yellow rust susceptibility, flowering time and height. Drone mounted cameras were used to capture images of the wheat lines in the trial as they grew throughout the 2021-2022 season. Figure 3 shows an overhead image of the trial alongside an example of the raw images captured. To complement our fieldwork we then generated high density genetic marker data for each line. By combining the genetic and trait data, we can identify and map points of the genome that contain novel genes from ancestral wheat backgrounds that are not present in modern wheat varieties. This work is ongoing with results and publications on the research available soon.

The scale of the 2022 field trial and the plethora of diversity on show attracted many researchers and visitors to the field site this year. These visits included an interview with *The Times* that looked at our material in relation to adapting wheat varieties to climate change, and a segment filmed for the BBC television programme *Countryfile* in January 2023. We were also recent finalists in the BBC Food and Farming Awards in the Food Innovation category.

The impact of this diversity-enriched wheat stretches further than just with the media. Through projects like DFW, representatives from seven of the UK's biggest wheat breeding companies have been visiting our trials for the past eight years, selecting promising material to incorporate into their own breeding programmes. The interactions that NIAB has with the DFW partners and the wheat industry are illustrated in Figure 4. Through feedback with these companies we know that some of this material is progressing well through their breeding programmes and offers new and interesting combinations of traits. The diversity-enriched wheat library contains segments of diversity that had previously been lost to wheat growers and breeders, and the off-the-shelf format provides an accessible way to rapidly respond to changes in the agricultural landscape. NIAB has made a significant contribution to forming a resource that could contribute to overcoming the diversity bottleneck in the modern wheat gene pool; our focus going forward will be to ensure this resource is utilised in breeding for changing climates and the future challenges that lie ahead.

Figure 2. The parent lines Robigus and Emmer wheat (left and second left) and resulting BC1F5 ears from one cross (four ears on the right)

Figure 3. Aerial images and photos from the large diversity-enriched wheat field trial grown in 2022, with 5,000 entries. The pre-breeding group collaborated with NIAB's Data Sciences Department to take aerial images for high throughput trait analysis and genetic mapping

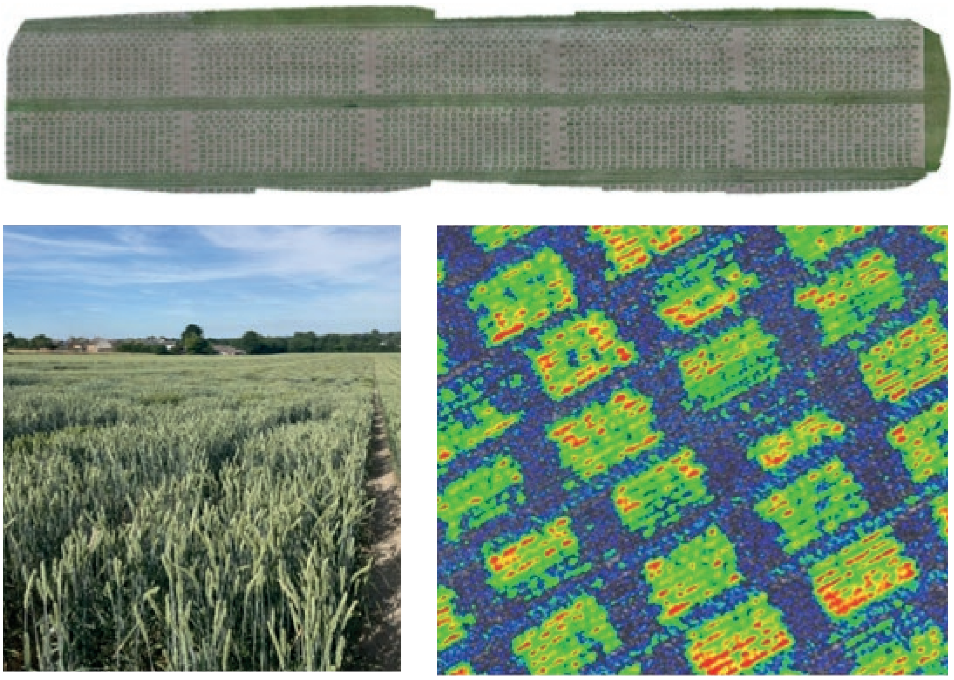
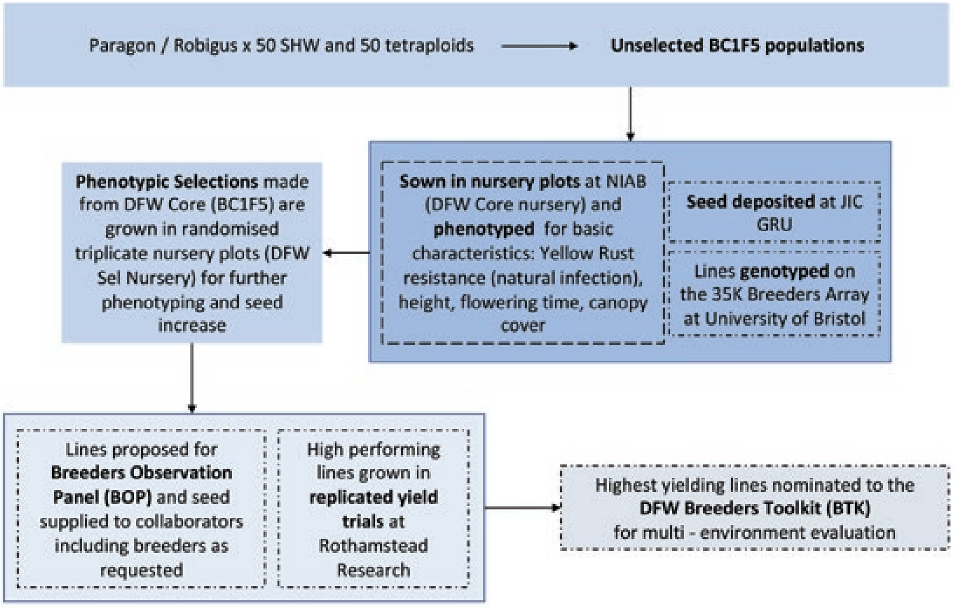


Figure 4. Evaluation of NIAB DFW material



The Science Behind Superwheat

https://youtu.be/M7bN2C1Pjs0

An animated short video where NIAB's Richard Horsnell explains how synthetic hexaploid wheat is created and how it could offer new sources of genetic diversity to improve wheat crops in the UK and Europe.

CEREAL GENETICS SPECIAL

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Accelerating cereal crop breeding through enhanced trait reassortment

Cereals (wheat, rice, maize, oat and barley) are crops of global importance for human consumption and animal feed. Breeders are constantly working to improve cereal crop varieties to increase grain yields and quality and reduce yield losses from abiotic (extreme temperature, drought) and biotic (pest and pathogen) stresses by improving crop stress resilience. Domestication of cereal crops has narrowed their genetic diversity, or the number of agronomically valuable traits that can improve existing varieties. However, wild cereal crop relatives have a reservoir of untapped traits conferring abiotic and biotic stress resilience. Introgressing these traits into new commercial varieties through breeding is one of the major routes for crop improvement.

Studies suggest that the current pace of cereal crop improvement through conventional breeding is insufficient and needs to be doubled to meet projected food demands of the growing world population by 2050. To improve existing varieties, breeders select novel combinations of agronomically valuable traits that result from trait reassortment, or crossover recombination, during meiosis, a specialised cell division in eukaryotes to produce, gametes, eggs and sperm (pollen). Despite its importance for breeding, crossover recombination is limiting, because recombination events are rare, i.e. one to three per chromosome, and highly uneven. This creates a bottleneck in breeding resulting in lengthy (decades-long) breeding programmes due to a large proportion of traits unavailable or 'locked' for breeding, and 'linkage drag' or co-inheritance of agronomically valuable and undesired traits.

Fundamental and translational advances in crossover recombination control over the past 15 years have identified ways to enhance trait reassortment and, therefore, opened up routes to overcome the bottleneck in conventional cereal crop breeding. The University of Cambridge (Department of Plant Sciences) and the Crop Science Centre, the alliance between NIAB and the University, are carrying out fundamental work on enhancing recombination using model plants; the University is using wheat, and here at the Crop Science Centre we are using legumes. NIAB is collaborating with the University of Leicester on enhancing recombination in wheat.

This article discusses these recent advances by looking at three case studies in wheat, barley and rice. The research organisations carrying out this research in these examples include the John Innes Centre, the Universities of Leicester, Bristol and Dundee, and in France INRAE (National Research iNstitute for Agriculture, Food and Environment) and CNRS (the French National Centre for Scientific Research).

1. Enhanced crossover recombination between wheat and its wild relatives (Figure 1)

Modern wheat has resulted from hybridisation of three species; *Triticum urartu*, a species closely related to *Aegilops speltoides* and *Aegilops tauschii*. During wheat meiosis crossover recombination and, therefore, exchange of genetic material can only occur between chromosomes coming from the same species. For example, no crossovers occur between *T. urartu* and *A. tauschii* chromosomes in modern wheat. This prevents introgression of agronomically valuable traits from wild relatives into wheat as there is no crossover-mediated exchange of genetic material between wheat and its wild relatives in hybrids. Recently, two research groups in the UK and France have made a breakthrough. They identified two wheat genes, named *TaMSH7-3D* and *TaZIP4-B2*, that inhibit exchange of genetic material between chromosomes coming from different species. Researchers and breeders are currently looking into knocking out *TaMSH7-3D* and *TaZIP4-B2* genes in wheat varieties and believe that this would make a step-change in wheat improvement through introgressing valuable agronomic traits from wild wheat relatives into new commercial varieties.

2. Enhanced crossover recombination in rice and barley

During plant sexual reproduction, crossovers are key to ensure accurate inheritance of genetic material from a maternal cell to four daughter gametes, each of which contains half of the maternal genetic material. A single crossover per chromosome is sufficient to ensure that each daughter cell receives a correct genetic make-up, and it has been always thought that enhancing crossover recombination, or increasing overall crossover numbers, would be detrimental to plant fitness. However, recent studies, first in a model plant Arabidopsis and then in cereal and dicot crops demonstrated that this is not the case. A research group in France has identified several anti-crossover factors, including *RECQ4*, *FANCM* and *FIGL1* which knockouts massively enhance trait reassortment. *RECQ4* appears to be a universal anti-crossover factor – its knockouts in multiple crops, including rice and barley, as shown by independent research groups in France and the UK, boost crossover recombination up to three-fold and result in healthy offspring. This is especially good news for pre-breeding where enhanced crossover recombination can lead to increased number of novel trait combinations, therefore, reducing the time and cost of generating novel plant material for breeders' selection.

3. Harnessing temperature to 'unlock' novel traits

In wheat, barley and rye, crossover recombination occurs in chromosome parts that are rich in protein-coding genes. However, this leaves up to a third of protein-coding genes located in recombination-suppressed chromosome regions unavailable, or 'locked' for breeding. Due to a lack of recombination around these genes, it is difficult to study these chromosome regions and accurately assess their agronomic potential. However, an example of barley *Yd2* gene located in a crossover-suppressed region and responsible for yellow dwarf virus resistance, a cause of serious cereal losses worldwide, indicates that crossover-suppressed regions can potentially harbour a reservoir of agronomically valuable traits. Anti-crossover factors, for example, *RECQ4* (described earlier), suppress recombination in crossover-active regions, but *RECQ4* knockouts cannot 'unlock' crossover-suppressed chromosome parts.

However, two research groups in the UK found that elevated temperatures can shift recombination to crossover-suppressed regions. Although at this stage increases in trait reassortment in crossover-suppressed regions under elevated temperatures are modest, this area remains exciting. Firstly, the approach is extremely simple – in order to shift crossovers to crossover-suppressed regions, barley or wheat plants need to be exposed to 28-30°C during flowering. Secondly, it is possible, but remains to be explored, whether combining elevated temperatures with genetic factors that control recombination can lead to stronger effects.

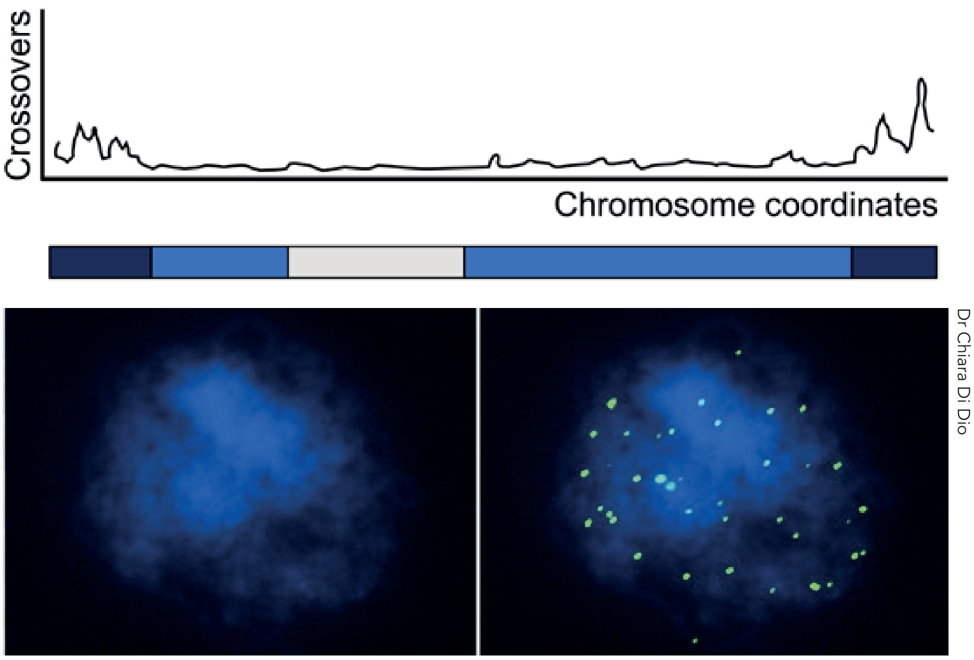
Summary

Trait reassortment during crop sexual reproduction has been key for crop breeding throughout the times, however, its natural limitations have created a bottleneck in the modern-day breeding due to faster population growth and increased food demands. Recent years have seen multiple fundamental advances that allowed to enhance trait reassortment. This fundamental knowledge has great potential to overcome current limitations in crop breeding. We are now at the dawn of developing pioneering technologies that can expedite breeding programmes and deliver positive impact for breeders, farmers, and society in general, in the next decades.

Figure 1. Crossover recombination in wheat

Top panel: schematic representation of uneven crossover distribution (y-axis) along a wheat chromosome (x-axis) summed up over hundreds of cells undergoing meiosis. Coloured bars (middle panel) show chromosome regions with crossover recombination (dark blue), as opposed low or suppressed recombination regions (light blue/grey).

Bottom panel: wheat DNA (blue, left) and crossover sites on wheat DNA (green dots, right).



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Getting to the root of lodging resistance in tef

Increasing the diversity of crop species on which we rely for food security implies growing more varied species on UK farms as well as improving the performance of neglected or underutilised crops elsewhere.

Dr Stéphanie Swarbreck is NIAB's group leader for crop molecular physiology, studying how plants integrate and respond to different environmental conditions such as nutrient availability and the presence of neighbours, for example black-grass.

In Ethiopia, tef (*Eragrostis tef* Zucc.) is a major crop cultivated by smallholder farmers, both for grain production and for fodder. It is a culturally important crop. Tef flour is used in a range of different preparations, the main one being injeras (large, thin and fermented pancakes), which are the basis of many meals. The grains can also be used to make a local beer. Tef flour is relevant to people's diet in the UK and across the world, since the grains hold a high percentage of proteins, and micronutrient (e.g. calcium, iron and zinc), and do not include gluten (which makes it suitable to coeliac patients).

In Ethiopia, tef is cultivated on 2.8 million ha, representing 30% of the total cereal area cultivated and it is a staple crop for about 70 million people. Despite its relevance to food security in the horn of Africa, tef remains a low yielding crop that is considered neglected or underutilised. In areas, where maize can reach 3.2 t/ha, tef yield remains very low at 1.5 t/ha. Though tef has not yet benefited from the breeding improvement brought to wheat, rice or maize, there is a growing community of researchers interested in improving this crop.

Tef is well adapted to local conditions in Ethiopia, including waterlogging experienced early in the season after the rain, and drought later on in the season. One of the main constraints of tef production is its high susceptibility to lodging. A large proportion of the harvest can be lost or spoilt because the plants have lodged during the season, as the stem breaks or bends. Root lodging, where the root system breaks under the pressure of the bending stem, can also cause yield loss. One of the solutions is the selection of shorter varieties with stronger stems. However, this is problematic as local farmers value the thin straw for animal feed.

At NIAB, we have explored the possibility that a stronger root system may reduce the risk of lodging in tef through projects funded by the Cambridge-Africa ALBORADA funds, and Innovate UK. We have analysed the crop's root system architecture to identify specific traits that may better support the very tall tef plants and prevent lodging. So far, NIAB researchers have adapted a clear pot method, originally developed for wheat plants, to screen for interesting root traits across a population of around 3,000 tef lines, each holding many mutations. We are particularly interested in plants that have a wider root angle which has been shown to offer better protection against root lodging, and we will also look at additional traits such as the roots thickness and root system complexity, using high throughput analyses available at NIAB. Our work has been conducted in collaboration with researchers in Ethiopia, especially Dr Kebebew Assefa at the Ethiopian Institute of Agricultural Research (EIAR), and ultimately the new lines will be tested under field conditions in Ethiopia.

Tef crop in Ethiopia

Panicles of the crop tef

Checking out the 2023 cereal variety options

With the new AHDB Recommended Lists released in early December 2022 it is time to review which varieties made it, what they might offer and how they compare to what we already have available. With some nice varieties recently hitting the market will these varieties offer enough to gain space on farm?

Clare Leaman has worked in variety evaluation at NIAB for nearly 30 years, mainly with combinable crops and more recently focused on cereals. Much of Clare's work revolves around knowledge transfer within the industry both through the NIAB membership as well as to a much wider audience. Translating data and trial information into a digestible format for the growers and agronomists to use on the front line is a high priority. She is widely regarded as a key source of independent variety advice to growers.

Wheat

Starting with winter wheat there are five new additions spread across all end use groups to consider. Whilst there are no new UKFM Group 1 varieties we do have a new Group 2 variety; **KWS Ultimatum** (KWS) joins the List, positioned neatly between KWS Extase and KWS Palladium. With respectable yields treated and untreated, it offers relatively good straw characters, the option of slightly later maturity and promising resistance to sprouting. Good yellow rust resistance is included but the septoria resistance, whilst not poor, is the least good of this group of varieties. Quality wise it is early days, but the grain quality looks good, and export is an additional option.

RGT Wilkinson (RAGT) widens the UKFM Group 3 choice still further. Its treated yield has not moved things on, but does equal the best of the group, and the untreated yield is up with the best. The variety has short, stiff straw and a moderate disease profile. It is suitable for all Group 3 markets, but its specific weight is at the lower end.

There is no doubt that **LG Redwald** (Limagrain), one of the new soft feed varieties, offers top yield potential. It tops this group by a clear 4% and has just crept above Champion on treated yield, whilst also having a high untreated yield. It is, however, a variety that will need good agronomic management regarding its straw strength and large crop biomass – drilling date, on farm positioning and seed rate should all be key considerations for getting the best out of this variety on farm. LG Redwald has a relatively sound disease profile but has a specific weight towards the lower end of the range. From a market perspective it also offers medium distilling quality.

Another variety with suitability for distilling is **KWS Zealum** (KWS), a new Recommendation for the north. It has treated and untreated yields similar to those of LG Skyscraper but has given a better response to plant growth regulators, has excellent resistance to yellow rust and is moderate for septoria.

One new hard feed variety, **Oxford** (DSV), joins the competitive UKFM Group 4. Its treated yield is similar to that of KWS Dawsum, but the untreated yield is not quite as good. It has moderate straw strength and appears to respond well to plant growth regulators. At 6.4 Oxford's septoria rating is reasonable and it has excellent resistance to yellow rust, alongside the added advantage of orange wheat blossom midge resistance. At first glance Oxford may not stand out in this group, but it has a very useful combination of characters, and should certainly not be ignored.

Spring wheat has seen plenty of recent new additions and this year is no different,

with another new UKFM Group 1 joining the List plus two Group 2 choices. **KWS Harsum** (KWS) adds further choice to Group 1 with a yield matching that of KWS Ladum and 7% above Mulika. It offers reasonable disease resistance and has the benefit of orange wheat blossom midge resistance on top of its high yield. **KWS Alicium** (KWS) is a high yielding Group 2 variety with early maturity, a high specific weight and solid disease resistance. **KWS Lightum** (KWS) has a similar yield to KWS Cochise and also offers a well-rounded set characteristic.

Barley

The winter barley AHDB Recommended List offers new choices across all three groupings. **Buccaneer** (Sejet/Saaten Union) is an exciting new malting prospect offering a step up in yield as well as improved disease resistance. It is, however, still under test for malting, but we should have progress on this before autumn 2023 drilling.

LG Caravelle (Limagrain), an exciting two-row feed variety, has continued to live up to the promise of high yields. With yields 3% higher than those of KWS Tardis and equal to the best of the six-row varieties, as well as a specific weight second only to KWS Cassia, LG Caravelle is rightly going to attract attention. Its agronomic and disease characteristics offer no reason for concern.

Bolivia (Nordic Seed/Agrii), whilst offering a slightly lower yield than LG Caravelle, is still a high yielding option of interest with the benefit of stiff straw and a solid disease profile. **SY Nephin** (Syngenta) a new six-row hybrid. While it does not offer an improvement in yield it has improved resistance to Rhynchosporium as well as a good specific weight.

There are seven new spring barley varieties in total, six with malting potential and one feed. Whilst this may seem a lot, it is worth pointing out that the quality testing has a slight lag. Not all these will make it through and may vanish quite quickly, as with the six varieties removed from the List this year.

Florence (Breun/Senova), **Sun King** (Secobra/Agrii) and **SY Signet** (Syngenta) are all under test for brewing. They have similar high yields to that of Skyway and limited data suggests that Florence has the best Rhynchosporium rating at a 6 whilst Sun King and SY Signet sit on a 4 and 5, respectively. **SY Tennyson** (Syngenta) and **KWS Curtis** (KWS) are both under test for brewing as well as malt distilling and offer improved yields over Laureate and LG Diablo, although the specific weight of SY Tennyson is on the low side, as is the Rhynchosporium rating based on limited data. Conversely the same limited data is suggesting a good Rhynchosporium rating for KWS Curtis. The final new malting variety is **Diviner** (Secobra/Agrii) which is under test for malt distilling. It offers competitive yields but again is potentially susceptible to Rhynchosporium.

Hurler (Secobra/Agrii) is a new high yielding feed variety, and the first for a while that has taken yields above those of the malting varieties. It has very short stiff straw, good resistance to brackling and a moderate disease profile. The specific weight is towards the lower end which might not suit all.

Oats

At long last we have a new winter oat variety to consider. **Cromwell** (IBERS/Senova) offers yields 7% above those of Mascani as well as a good kernel content and specific weight. Its characteristics all look promising for milling, although as with all quality varieties, it is still early days. It is susceptible to mildew and has some susceptibility to crown rust but on balance Cromwell is still a variety of interest depending on the millers' verdict.

We also have one new spring oat. **RGT Vaughan** (RAGT) offers moderate yields combined with good grain quality. It has good resistance to mildew but is susceptible to crown rust. As with Cromwell the future of this variety will lie with its quality and the verdict of the millers.

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Oilseeds and pulse varieties for 2023

Colin Peters is NIAB's break crop specialist, providing specialist technical and scientific knowledge on the evaluation, selection and management of crop varieties, focusing on break crops including oilseed rape, linseed, pulses, sugar beet and other minor crops.

Winter oilseed rape

The 2021/22 cropping year will probably be remembered for the drought, the heatwave peaking in excess of 40°C in some areas and a very early/dry harvest. From a winter oilseed rape perspective, establishment in autumn 2021 was better than recent years with many good crops established across the country and a decent range of variety trials enabling NIAB to test new varieties properly. Establishing oilseed rape trials is a tricky business as we generally do not see the seed until, at the earliest, late August and, since Brexit, this has been compounded by seed having to be checked in at Customs which can, in some cases, add several days to what used to be an overnight delivery system.

There are potentially seven new winter oilseed rape varieties added to the 2023/24 AHDB Recommended List. At the time of writing, we are waiting for confirmation that Turing will be added to the RL following registration (19 December, 2022). **Turing** (LS Plant Breeding) is a hybrid variety recommended for the UK. It has given a very high treated gross output of 107% for both the East/West and North regions. An early-flowering variety Turing has a high resistance to light leaf spot but does lack both pod shatter and Turnip Yellows Virus resistance (TuYV).

Attica from Limagrain has matched Turing with 107% gross output for both the East/West and North regions. It shows good stem stiffness and a strong resistance to both light leaf spot and stem canker. It also has pod shatter and TuYV resistance.

Beatrix CL (DSV) is a new Clearfield® hybrid variety for the North. Like Matrix CL, its sister in the DSV camp, it has resistance to pod shatter and TuYV. This is an exciting step for the CL range as they are starting to compete against the other RL varieties that do not have the benefit of herbicide resistance. Beatrix CL also has a very good oil content at

45.9%. For those who want to make use of this trait, growers are advised to go to the BASF website, agricentre.basf.co.uk, for more information about Clearfield® management and husbandry.

LG Wagner from Limagrain is another new variety to the List. A hybrid variety recommended for the North region it has a commendable gross output score of 108% for this region. With good resistance to light leaf spot and resistant to TuYV LG Wagner also has resistance to pod shatter but is not very early to mature.

Murray (LS Plant Breeding) is another good addition to the RL. It is a hybrid variety recommended for the East/West, scoring 106% for gross output. It has good disease resistance, with an impressive 8 for stem canker, but it does however lack genetic resistance for both pod shatter and TuYV.

Also new to this year's List is **Tom** (Frontier Agriculture), a conventional, open-pollinated variety recommended for all regions in the UK. At 102% Tom has the highest treated gross output in the East/West region for a conventional variety on the 2023/24 Recommended Lists. It is great to see new conventional varieties appear on the List, but we must see how this variety delivers in the field.

The final new variety on the List this year is **Vegas** from LS Plant Breeding. Solid gross output scores with 106% for the East/West and 103% for the North. Like Fleming and Tennyson, both added to the 2021/22 RL, the breeder claims Vegas has a different genetic resistance to stem canker, which is great as we do know that reliance on one gene for resistance to this disease will, in the longer term, become an issue.

Spring linseed

There are two new varieties on the 2023 AHDB Descriptive List. **Gilbert** (JTSD) is a yellow seeded variety that has medium short plants with very early maturity and average oil content. We also have **Olympe** (Limagain) which does show a low yield, at 84%, albeit with limited data. It has medium short plants that flower medium-early, but the variety matures very early and has an average oil content.

Pulses

The Processors and Growers Research Organisation (PGRO) 2023 Descriptive List (DL) has added six new combining pea varieties and one winter bean variety. Potentially, there are four new spring bean varieties, but these have yet to pass National Listing and will be added to the DL later if they are successful.

Glam (Senova) and **LG Ajax** (Limagrain) are two new yellow combining pea varieties. Glam has very good yields, generally produced from moderately tall plants which, despite being very late maturing, have good standing ability at harvest. It is resistant to pea wilt (Race 1) but moderately susceptible to downy mildew and susceptible to powdery mildew. LG Ajax has moderate yields for this group but performs well yield wise across the DL. It produces medium height plants with good standing ability, has moderately good resistance to downy mildew and is highly resistant to powdery mildew as well as resistant to pea wilt (Race 1).

Butterfly (LS Plant Breeding) is one of the new green-type varieties which is second in the group for yield. It is early maturing with good standing ability at harvest. The variety is moderately resistant to downy mildew but susceptible to powdery mildew and resistant to pea wilt (Race 1). **KWS Gotham** (KWS) is a solid yielding green-type, producing tall plants with moderate standing ability and late maturity. Moderately susceptible to downy mildew its powdery mildew and pea wilt resistance status is unknown at this point. The third new green-type to be added is **Kiravi** from Senova. With good yields in trials so far, it has fairly tall plants but a good standing ability and late maturity. The variety is moderately susceptible to downy mildew and resistant to pea wilt (Race 1), but susceptible to powdery mildew.

A new variety of marrowfat pea has made the List; **Takayama** (LS Plant Breeding) has become the highest yielder in that category at 96%. It produces tall plants with moderate standing ability, is moderately susceptible to downy mildew and resistant to pea wilt (Race 1) but is susceptible to powdery mildew.

Bonneville (Senova) is the only new winter bean addition to the 2023 DL, with yields above average at 102% and the second highest protein content on the List.

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Colin Peters – see page 20.

New evidence on OSR flea beetle lifecycle

NIAB has continued work on the *csfbSMART – Sharing Management and Agronomy Research Tools* project with the focus over the past year on the lifecycle of the Cabbage Stem Flea Beetle (Landmark 48, December 2021, pp16). It became clear in the first year of the project, begun in autumn 2020, that previous knowledge about the pest's lifecycle did not match what was being seen in the field. NIAB deployed a new design of emergence traps (Figure 1) into oilseed rape stubbles, straight after combining, to study the timing of CSFB adult emergence from the soil. The literature cited states that CSFB adults all emerge before harvest but, if they are still in the soil after harvest, they may well still be pupae and therefore at a vulnerable stage.

The traps were positioned around the country and monitored through the latter part of the summer into the autumn. Figure 2 shows the data from sites where we would normally expect lower numbers of CSFB adults to be found and this was the case. However, it is clear that many did emerge from the soil much later than the literature suggests. When we moved towards the areas with historically higher numbers, the pattern remained the same with the bulk emerging through September. But, the numbers were far higher; in Cambridgeshire two sites recorded 2.5 and 3.5 million adult beetles per hectare.

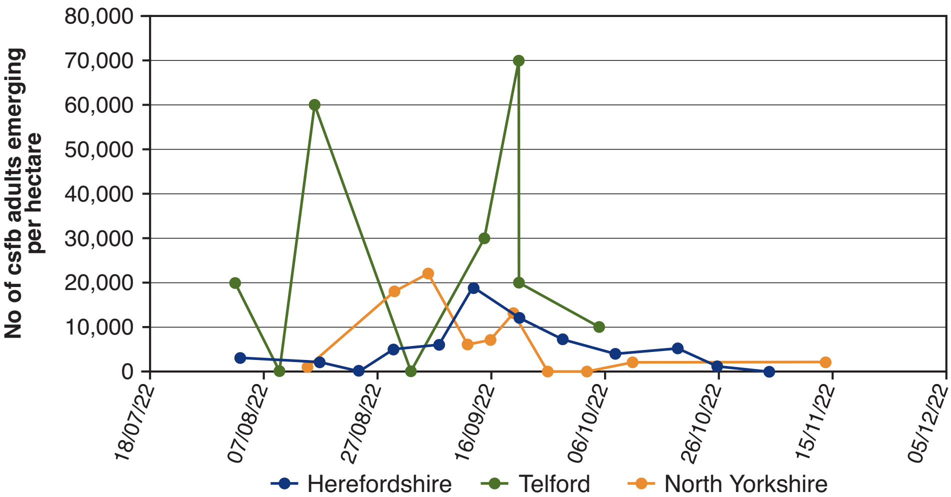
So this does raise the question as to whether we can influence emergence as there may be a vulnerable stage where we have access to the soil after harvest (Figure 3). On two sites in Cambridgeshire, where we expected very high numbers of flea beetle, we placed emergence traps on the stubble after combining and also cultivated some areas which we also trapped.

Figure 4 shows the results of one farm where we lightly cultivated after harvest. The graph shows the difference in emergence numbers from the non-cultivated stubble and the cultivated stubble where the reduction in emerging adult numbers was more than 60%. On another farm in the same region, deeper cultivations led to a reduction of over 90%.

Clearly this is exciting but does need much more investigation. This was only two sites in one year. But, the general picture relating to the lifecycle backs up the limited data from 2021; emergence is much later than originally thought and therefore questions the management of oilseed rape stubbles after harvest. It was also interesting to note that, whilst we were catching large amounts of CSFB adults in emergence traps, we also had

Figure 1. Host farmer David White with emergence traps that collect adult CSFB as they emerge from the soil

Figure 2. CSFB adults emerging from the soil at different locations in late summer 2022



water traps in the same areas catching hardly any adults. This indicates that the beetles were leaving the OSR stubble rather than waiting to feed on emerging volunteers.

NIAB is very grateful to Defra for its support on this project and the injection of funds this year for the construction of new emergence traps. We still have one year of project funding left to target the emergence and cultivation issues, aiming to understand much more about the pest and how we can influence the general population, but also understand the impact that any of our activities will have on other insects including beneficial parasitoids.

Another area being explored is the use of longer-lasting companion crops in OSR crops to combat the beetle. We need to have a multi-pronged approach to this pest as we need to influence the population rather than just try to find ways to establish the crop. This relies on having a nice neighbour with a trap crop to accommodate the feeding adults displaced from our own crop. There has been a lot of good work on establishment, from ADAS and others in the AHDB-funded work, and NIAB is aiming to complement that work – researching the population in general and the stem larval issues. One result that came from our large stem larval count project in 2021 was that longer-lasting companion crops, which are still present through the egg-laying season and into the early spring, do have an impact on stem larval numbers. We are also looking to include OSR into other winter cover crops to act as a trap crop; over this winter, NIAB is studying stem larval numbers in crops with companions in them and also in OSR sown into over-wintered cover crops. Figure 5 shows various OSR companion crops in autumn 2022 which NIAB will be monitoring through this winter and spring to see if they can be used to manage the beetle population.

NIAB is always looking for more sites to use in the study – please contact Colin Peters (colin.peters@niab.com) if growing oilseed rape with a companion.

Figure 3. Timing of adult cabbage stem flea beetle emergence in Cambridgeshire, 2022

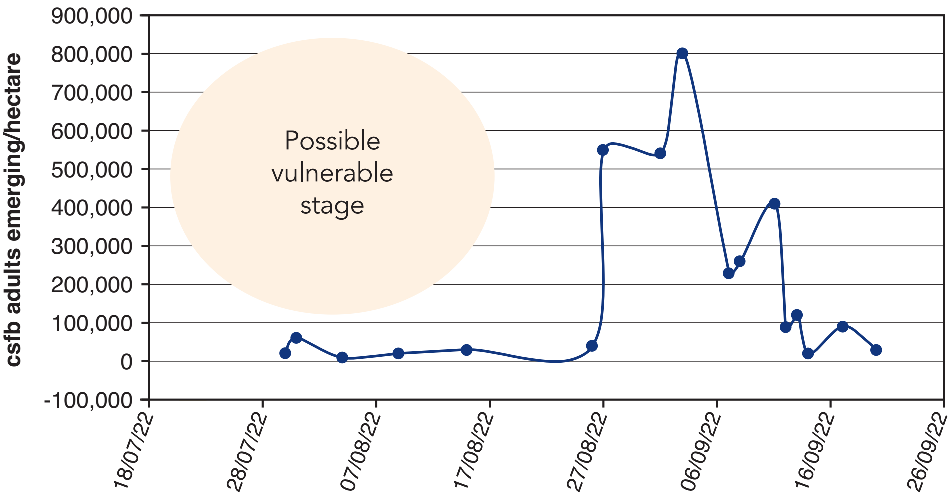


Figure 4. Cabbage stem flea beetle emergence in cultivated and uncultivated OSR stubble in Cambridgeshire, 2022

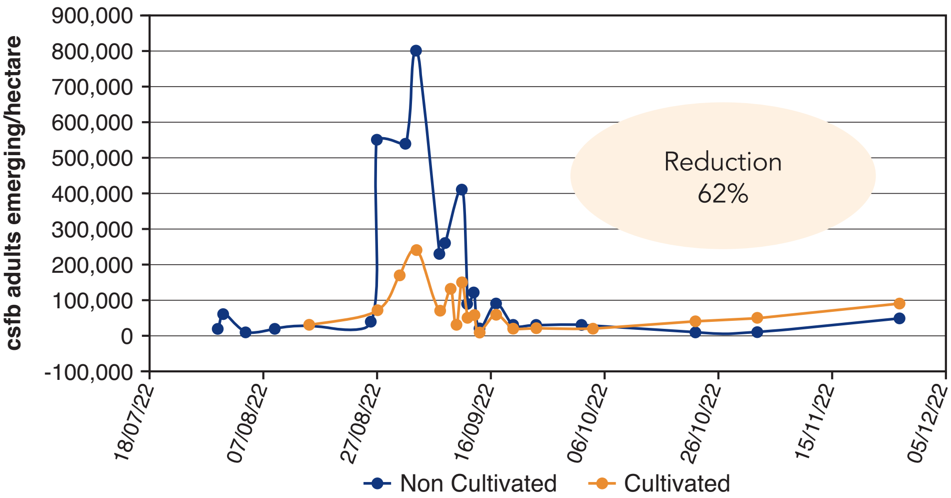


Figure 5. OSR crops with companion crops sown within them

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Underutilised crops: opportunities to diversify UK agriculture and horticulture

The world's food supply is underpinned by a surprisingly small number of crops (about 30) with wheat, maize, rice, potatoes, cassava and soya amongst the biggest contributors. Wheat, barley and oilseed rape together account for 75% of the UK's 4.5 million ha of arable land, whereas grain legumes (mostly field beans and combining peas) occupy less than 5%. Perennial ryegrass is the predominant forage species, with mixed leys much less common. Horticultural production is more varied, but strawberry, apple, carrot, onion, cauliflower and broccoli are the major crops.

The dependence of agri-food systems on relatively few crops, globally and in the UK, is a risk to food security. Climate change, weather extremes (such as the drought and heat of 2022), intractable weeds, pests and diseases, market volatility (as seen with the conflict in Ukraine), and the need for sustainable land management to protect the environment, collectively mean that changes to cropping systems are needed. Whether currently grown but underutilised, or novel to the UK, alternative crops could contribute to more resilient agriculture.

Diverse cropping has the potential, for example, to ease crop protection difficulties. However, even with Integrated Pest Management (IPM) access to effective plant protection products will be necessary. With the economic and environmental challenges posed by nitrogen (N) fertilisers, legumes that fix atmospheric N are an underutilised resource. As soil management practices continue to adjust, and reduced tillage increases, fast-growing, deep-rooting species, or those suited to semi-permanent cropping, can deliver biocultivation, greater soil carbon capture, and enhanced water infiltration and storage.

A recently completed review by NIAB for Defra examined the wide range of food, forage or pharmaceutical crops that exist, including their scope for cultivation within UK agriculture or horticulture; potential productivity benefits and risks; sustainability and climate resilience; knowledge gaps, and research or investment needs. The review was delivered through literature search, expert knowledge, and engagement with growers, advisers, plant breeders, seed suppliers, traders, processors, end-users, and researchers.

From an initial assembly of more than 400 species, a long-list of 192 candidate crops was identified, comprising 38 cereals/grains, 19 oilseeds/seeds, 22 grain legumes, 29 forage crops, 52 vegetables or tubers, and 32 fruits, nuts or vines. The crops spanned 44 plant families, with 135 having food as their primary use, 40 feed/forage, 16 pharmaceutical, and one fibre. 140 were field crops, 24 orchard, 21 outdoor or protected, and seven protected-only crops.

To derive a shortlist, 15 criteria in five categories were established with stakeholder input:

- Crop suitability (climate; soil or growing medium; cropping/production system);
- Ease of cultivation (variety/seed/plant accessibility; agronomy; machinery and storage);
- Economic potential (outputs; markets and utilisation; costs, margins and returns);
- Knowledge and resources (state of knowledge; state of resources);
- Environmental impact (climate change; biodiversity; pollution; soil health/ protection).

Candidates were assessed against these criteria, in comparison to existing crops they might replace. Informed by this process, but ensuring a diversity of types and features, about ten were selected for each crop group to form a draft shortlist. Following a series of workshops, a final shortlist was compiled (Table 1). Some crops that did not make the shortlist may still come to the fore as circumstances change; with the review highlighting examples such as Phaseolus beans, lupins and opium poppy.

Rye and triticale are already grown

Deputy Director of NIAB, with a background in agronomy, Stuart Knight's responsibilities include statutory, technical and membership services. He leads a number of research projects, and his interests include combinable crop husbandry; management of soil and fertiliser nutrients; monitoring and control of cereal fungal diseases; evaluation of new crop protection chemicals; managing within-field variation; decision support; and the impact of farming systems and management practices on farm performance.

A plant ecologist by training, especially in soil-plant microbial interactions and reclamation of land to agricultural use, Dr Lydia Smith has extensive experience in the application of ecological principles to the farming environment. Lydia has a particular interest in diversification of farm species and has sought to foster interactions between academics and business, especially in the East of England. She also manages the Eastern AgriTech Innovation Hub.

Table 1. Shortlisted crops within each crop group

Cereals and grains	Buckwheat, Durum, Grain maize, Quinoa, Rye, Triticale
Oilseed and seeds	Ahiflower®, Hemp, Linseed, Sunflower
Grain legumes/pulses	Chickpea, Lentil, Soya bean, Faba (field) bean, Yellow pea
Forage/forage legumes	Chicory, Festulolium, Lucerne, Red clover, Ribwort plantain, Sainfoin
Vegetable and tubers	Jerusalem artichoke, Kale, Radish, Snap/snow pea, Squash, Swiss chard
Fruits nuts and vines	Apricot, Haskap, Hazelnut, Peach/Nectarine, Table grapes, Walnut

in the UK on a limited area, and are more suited to marginal soils and low inputs than wheat, but reliable end-use market developments are needed. Durum and grain maize have good economic potential and suit future UK climate projections, with plant breeding resources available internationally. Quinoa and buckwheat have potential as high-protein, non-cereal breaks in rotations, with buckwheat a rich pollen and nectar source. For all these, improved varieties and agronomy are required.

Crop genetic improvement for linseed and sunflower is more advanced and both could be more commonly in grown in the UK. They have broad market potential, require comparatively low inputs, and offer environmental advantages over oilseed rape. However, earlier-maturing, high-yielding sunflower varieties are needed. For pharmaceutical and probiotic crops, oversupply often reduces crop value. Ahiflower®, derived from the native weed Corn Gromwell, can replace fish oil as a source of omega-3. Hemp offers good economic returns from relatively low inputs, with expanding markets for industrial and food uses, and potential for increased carbon capture in the soil and in crop-based materials.

The grain legumes shortlist includes both existing UK crops with scope for expansion, and those with little current production. Increased use of faba bean in animal feeds and developing markets as a high-protein food ingredient could support a trebling of the current area. There is similar demand for yellow pea for high-protein, gluten-free flour. Soya (Figure 1) has potential to be a major crop, but more especially for premium human-consumption markets. A limited area is already produced in England, but the growing season is short, and harvest can be late. Despite genetic improvements, UK varieties with better early-season cold tolerance and earlier maturity are needed. Chickpea and lentil have potential as minor UK crops, grown for specialist uses. Chickpea is sensitive to frosts and waterlogging, failing to mature in cool, wet summers, so better-adapted varieties would be required. Lentils (Figure 2) are cold tolerant and more suited to UK soil conditions.

Forage crops include a wide species range. Red clover, sainfoin (Figure 3) and lucerne are perennial legumes, offering an opportunity to reduce N-fertiliser use in livestock production. They are valuable protein sources that can be grown in mixed swards. Their deep roots confer drought tolerance, and they support insect biodiversity. Festulolium offers high yields and improved stress tolerance within grassland swards for ruminants. The perennial herbs ribwort plantain and chicory can be grown in mixed grazing leys for sheep or cattle, increasing drought tolerance. For all these forage crops, more agronomic information is needed on how to integrate and manage them within grazing or conservation swards to improve utilisation.

The land area occupied by most vegetable crops is small, but their value to UK horticulture is significant. New kale types could diversify markets currently dominated by cauliflower and broccoli.

Figure 1. Soya bean

Figure 2. Lentils

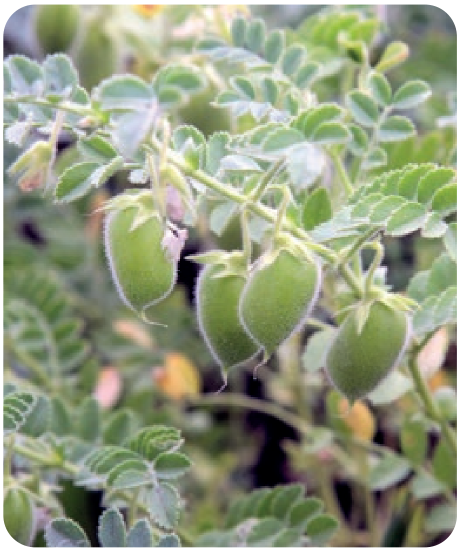


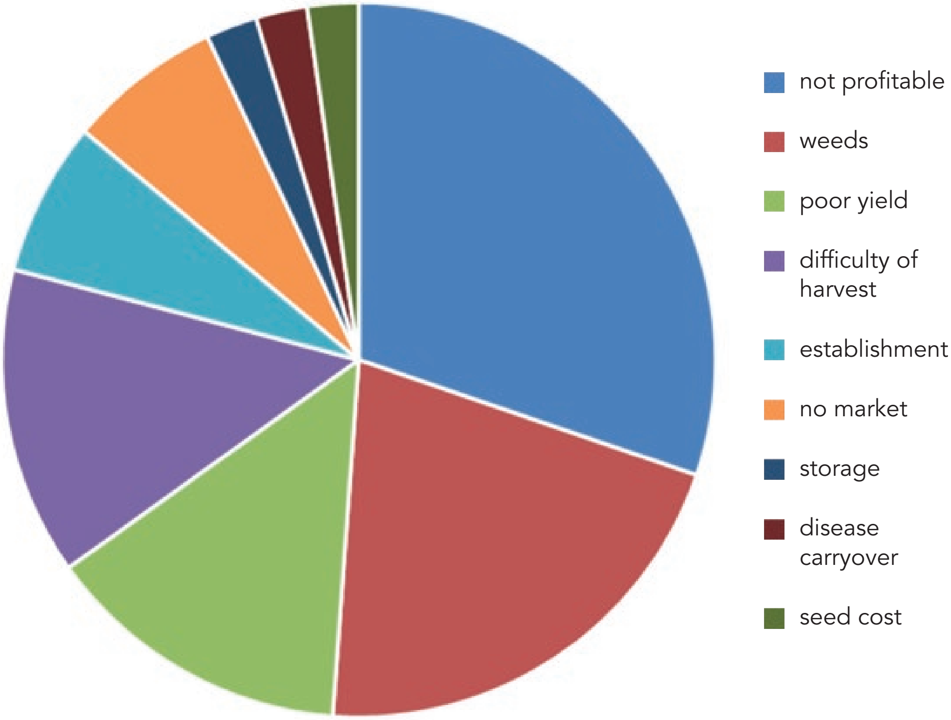
Figure 3. Sainfoin

There is scope to improve the flavour and range of radishes, and extend the UK season. Swiss chard adds diversity to fresh green produce, but investment is needed in mechanical harvesting. Jerusalem artichoke is a hardy crop well suited to UK conditions. The tubers represent a healthy option, but their quality needs improving. Increasing the range of snap and snow pea varieties could extend the UK season, but harvesting costs are a barrier, with research required into mechanical harvesting. Whilst courgettes and pumpkins are widely grown, there is little production of other squash types in the UK. Improved storability would reduce waste and increase economic potential.

In Table 1 three of the fruit and nut crops are well adapted to the UK climate and have limited labour and agrochemical requirement, but their markets are not fully developed. Haskaps (Figure 4) are small, edible honeysuckle berries, mainly used in processing. Sweeter varieties are needed to improve acceptability as fresh berries. Hazelnut plantings are ideal for poor soil areas. Product development is needed to expand premium uses; such as in snack bars and as a substitute milk. Walnut is fast-growing, and carbon-offsetting schemes could help to cover costs prior to first cropping. Three protected crops (apricots, peaches/nectarines and table grapes) have robust markets and UK production would aim to replace imports. However, they require significant investment at farm level (tunnels, netting, irrigation) and by the breeding industry. Without grants to offset establishment costs, expansion of UK production of these crops is unlikely to be economic. Premium home-grown brands may be one route to market.

Figure 4. Haskap berries or honeyberries

Figure 5. Main barriers to growing alternative crops (proportion of survey respondents)



A producer survey revealed that most growers are willing to consider alternative crops, many of which are seen as having additional potential to improve soil health, climate resilience, and agronomic sustainability. Profitability was the main reason given for not persisting with a crop tried previously, along with late harvest and lack of weed control options (Figure 5).

Stakeholder discussions highlighted concern that price premiums diminish once the market for a crop becomes saturated. Equally, the market must be large enough to gain commercial interest in sustaining UK production from the outset, otherwise crops will remain niche or may disappear. Those grown on a modest scale often present the most difficulty, with a lack of UK processing capacity suitable for crops that are larger than niche, but not commodities. There is therefore a need for a focus on the value-chain as well as how to grow a crop successfully. Traceability is vital to expanding export potential. For new crops, the growing component should be readily encompassed within Farm Assurance schemes, but for processing and storage it may be harder to avoid contamination, bringing added costs and risk.

Acknowledgements

This project was delivered by NIAB – including Stuart Knight, Lydia Smith, Ian Midgley, Phil Howell, Jane Thomas, Colin Peters, Bruce Napier, Ellie Sweetman, Feli Fernandez and Elizabeth Scott, with Kairsty Topp and Christine Watson at SRUC. It was funded by Defra, with support from 'Legumes Translated'.

The full report '*Review of opportunities for diversifying UK agriculture through investment in underutilised crops*' is available online on the Defra 'Science Searc' website https://randd.defra.gov.uk/

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Nutrient management planning and inhibitors

Nutrient management planning has been an important part of sustainable fertiliser use and compliance for some time. It does however have a renewed importance in the light of high fertiliser prices, limitations on availability, changes in farm practices, carbon footprints and legislative change. There have been two key areas of legislation seeing revision or clarification in 2022, these relating the urea inhibitors and the Farming Rules for Water (FRfW).

Nitrogen is the primary nutrient of discussion with prices rising from around 70p/kg N to £2.00/kg N and at some times more. This has the potential to markedly change the economic optima application rate to combinable crops, particularly winter wheat. However, in the case of the 2022 crop which saw values reaching £300/t (although at the time of writing resides much lower around £250/t) the increases in price were well compensated for and, where growers purchased nitrogen early at lower prices, may have even increased the economic optimal dose which is typically around 220 kg N/ha. The outlook for 2023 is less favourable; forward commodity prices are lower (albeit still historically high) and the cost of nitrogen has remained high with a typical cost for autumn delivered nitrogen around £1.70/kg N depending on the source. This is likely to encourage reductions of around 30 kg N/ha from the normal economic optima in winter wheat with no required reduction from normal nitrogen rates for other crops.

High prices have the welcome effect of encouraging growers and agronomists to think carefully about the rates they use and how they might improve the efficiency of use. It is worthwhile considering the form of nitrogen, additions such as inhibitors and biologicals and application technology.

In some cases growers may be using forms of nitrogen in 2023 which they have not had recent experience with. Previous users of ammonium nitrate may have stocks of lower priced urea and some liquid users may have stocks of solid fertilisers. Whilst most nitrogen is still supplied in soil applied forms there is also increasing interest and uptake of foliar nitrogen forms with claims of higher nitrogen use efficiency.

At NIAB we have been looking at nitrogen efficiency for many years including trials comparing urea with ammonium nitrate, trials reviewing the performance of urease inhibitors, nitrogen fixing seed treatments, biologicals and

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Will is NIAB's regional agronomist covering the south west and is also the membership services development lead. He is based in Somerset with his own farm and has experience in a range of technical and commercial organisations.

foliar forms of nitrogen with varying results.

With urea-based fertilisers there has always been concern about the risk of volatilisation of ammonia gas which can result from the process of converting urea into ammonium when the pH rises to a high level around the urea granule. These losses are behind a perception that ammonium nitrate is a more efficient form of nitrogen for crops to use as part of the nitrogen is supplied in the nitrate form. In practice NIAB trials have found no significant difference between the two forms of nitrogen in yield or optimal nitrogen dose rate in winter wheat. Whilst these losses are small and of limited effect at field level the cumulative effect on air quality is much more significant and it is noted that agriculture is a significant emitter of ammonia to the atmosphere, being responsible for 88% of UK ammonia emissions (Defra).

In 2022 Defra consulted on options to mitigate ammonia losses from urea fertilisers including the option of a complete ban. An industry consortium put forward a fourth option, including best practice guidelines and compulsory use of urease inhibitors at certain times with compliance through Red Tractor Assurance schemes. From 1st April until 15th January urea fertilisers will need to be applied with a urease inhibitor. These rules come into place in 2023 but are not fully adopted and enforced within the Red Tractor standards until 1st October 2023, which gives farmers time to adjust. This means for most growers the first time they will be required to use an inhibitor with urea nitrogen will be from 1st April 2024. Where solid urea is used the fertiliser will be treated before supply so growers will need to ensure they have correctly treated stock for use after 1st April 2024. With UAN the situation is slightly different and it will need to be treated as it is applied by mixing the inhibitor with the fertiliser in the sprayer.

If inhibitor use is compulsory between certain dates, will they affect the efficiency of nitrogen use? Theoretically the efficiency of use should rise as the losses are reduced and more nitrogen should be available to the crop. However, in practice the amounts of nitrogen lost are small on a per hectare basis and where use of nitrogen is near to the biological optimum a change of 10-20 kg N/ha available to the crop will be hard to detect in yield or economic effect. In NIAB trials the effects of inhibitors have been marginal and insignificant. Where rates of applied nitrogen are significantly below the crop optima there is more potential for the mitigated losses to affect to uplift yield, however if the applied rate drops, so does the potential for loss and thus reduces the kg N/ha benefit of an inhibitor. So, whilst these are important for overall air quality, we should not be expecting significant improvements in nitrogen use efficiency or crop yield at field level.

The nitrogen dose response curve is well understood to represent diminishing marginal returns and typically 85% of the nitrogen response comes from the first 100 kg N/ha with the next 120 kg N/ha providing 15% of the response at the economic optima. The efficiency of nitrogen conversion to yield can be represented by the inverse curve with efficiency declining as application rate (and yield) rises.

Whether technologies and nitrogen alternatives will affect nitrogen use efficiency will depend where on the nitrogen dose response curve the crop sits. If crops are fertilised at the higher end near the biological optima, then there is little to no scope for alternative sources, biologicals, inhibitors or bio-stimulants to affect yield. As applications of soil applied nitrogen significantly decline below the economic optima the yield losses are large and the opportunities for an alternative technology to improve nitrogen use efficiency rise. Foliar nitrogen products are an interesting case in point, these products are claimed to have extremely high nitrogen use efficiency and typically enable 7-8 kg N in foliar form to replace 40 kg N in soil applied form. We have been evaluating these products in NIAB members trials and work continues. They rely on sufficient canopy being constructed to intercept the foliar nitrogen which means they can only be effective where sufficient soil applied nitrogen is first used. In effect the reason such a small amount of nitrogen in foliar form can replace a large amount in soil form is because the part of the dose response curve where they fit is a part where soil applied nitrogen efficiency has significantly declined. Foliar products are a useful tool but only as a compliment to a base level of soil applied nitrogen.

With the economics of fertiliser use becoming more challenging there is a role for alternative technologies as part of a crop nutrition strategy but we need to be realistic about claims that are made on product performance, have a full understanding of how they work and the dose response curve otherwise there is the potential for expensive errors.

Julian Westaway is General Manager of BCPC and Chairman of the BCPC Advisory Board. He has a strong agricultural and electronic publishing background ideal that fits with BCPC's portfolio of products and activities. With a degree in agricultural science he has previously worked for the Milk Marketing Board, RBI where he set up Farmers Weekly Interactive, Defra and UBM as online commercial manager for the Farmers Guardian Group.

BCPC – promoting the science behind sustainable crop production

January 2023 will see the publication of the 36th edition of the British Crop Production Council's *UK Pesticide Guide*, the authoritative reference for all approved pesticides and adjuvants. With a dedicated editor keeping track of new entrants, changes to approvals and addition of relevant EAMUs, the guide aims to ensure you have all the information at your fingertips to assist in those crop protection decisions.

Among the additions for 2023 is cinmethylin, BASF's new entrant offering a new mode of action against black-grass although its introduction does highlight the implications of Brexit as it is not approved for use in Northern Ireland. Keeping track of approvals, and indeed any removal of approvals, has now become a year-round requirement.

To meet this demand BCPC, which has been part of NIAB since 2018, also produces the online version of the Guide, updated throughout the year, keeping farmers and spray operators up to speed with all the changes while also adding the sophisticated search and compare functionality across fields including formulations, uses, dose rates, maximum total dose and/or latest timing of application, along with the pests or diseases controlled and Extensions of Authorisation for Minor Use (EAMU).

While the *UK Pesticide Guide*, known colloquially across the agricultural and horticultural industries as *The Green Book*, might be BCPC's most widely known product, it is not alone in pulling together the expertise within the industry for crop production and pest and disease control. BCPC also organises its series of invitation-only Expert Reviews.

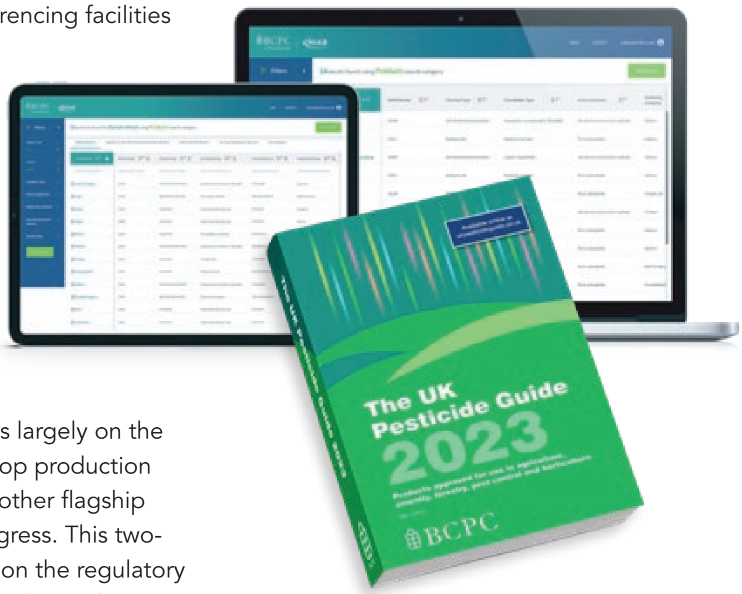
Two of these, the Weeds Review and the Diseases Review, are held at the tail-end of the year, with reports from the 2022 meetings available on the BCPC website www.bcpc.org, while the third covering Pests and Beneficials will next be held at the end of January 2023. The programme for each of these reviews is pulled together by a working group with around 12 subject specialists. While integrated crop management has always been an underlying feature in UK agriculture, it has featured highly in many of the recent presentations in all three reviews.

The Expert Review meetings are held at NIAB where around 70-80 delegates benefit not just from the presentations but also the networking opportunity among a like-minded audience. With the addition of online conferencing facilities these Reviews are now able to extend the invitation to attend still further. To be added to the invitation list for any of the three Expert Reviews email jw@bcpc.org to register interest.

While the Expert Reviews will focus largely on the agronomic aspects of crop production and protection, BCPC's other flagship event is the annual Congress. This two-day conference focuses on the regulatory aspects of the industry, with speakers from Defra, HSE/CRD, Croplife and NFU alongside many others from within the industry.

The 2022 Congress, *Providing policy and regulatory support for multi-functional UK agriculture*, discussed how UK agriculture might best meet its three key deliverables of producing adequate supplies of healthy food to contribute to UK food security; supporting environmental initiatives including biodiversity, conservation, rewilding and environmental land management; and contributing to UK net carbon zero targets.

BCPC



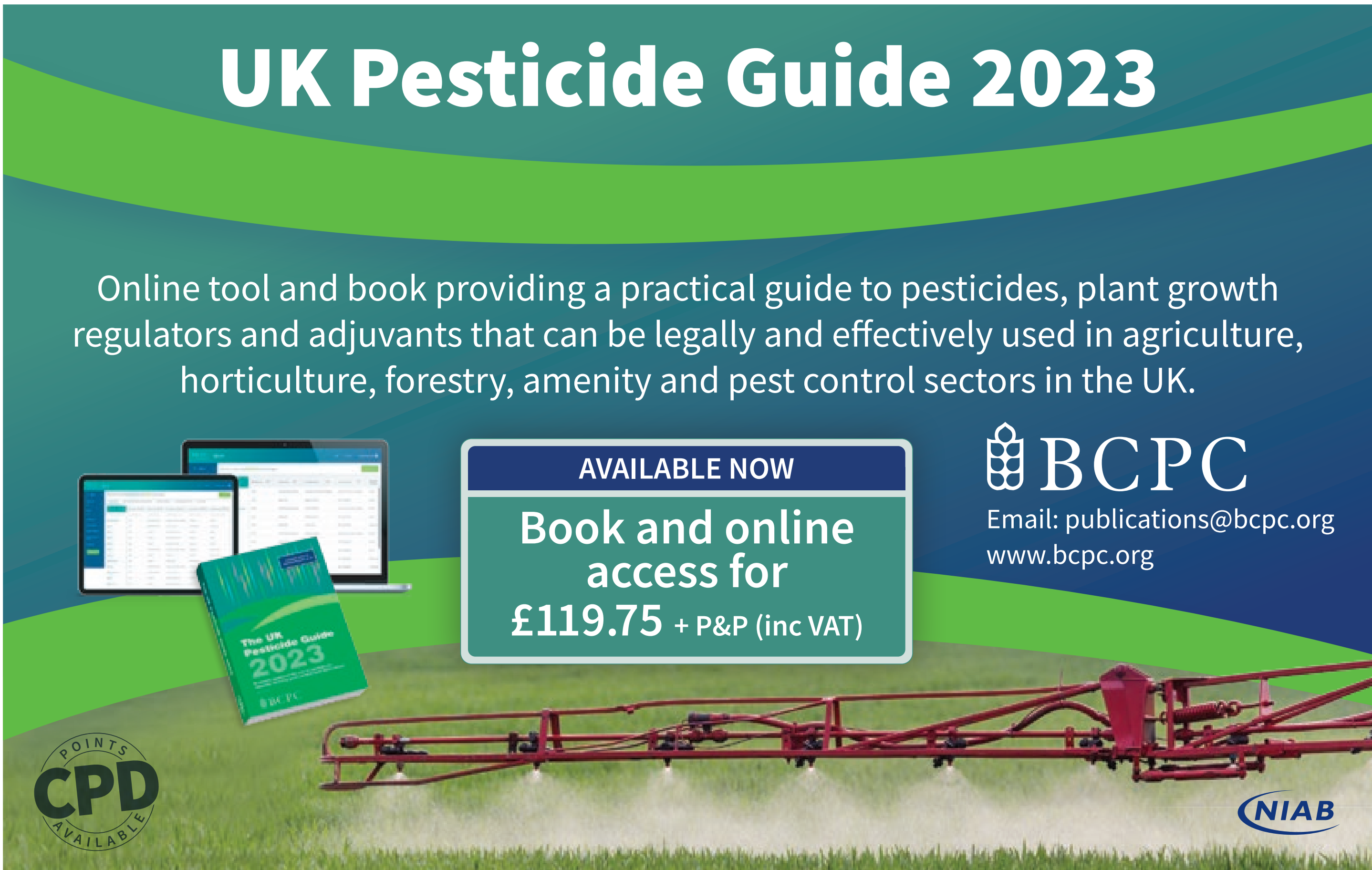
In addition to the two-days of presentations, all of which can be found on the BCPC website www.bcpc.org, delegates benefit from the UK Health and Safety Executive's Chemicals Regulation Division's afternoon workshop. This has now become a regular part of the conference programme and an ideal opportunity for the industry to input the delivery of government policy.

The above activities all sit comfortably within BCPC's key strategic remit of "promoting the science of sustainable agriculture", an area that not only covers pesticides, but all aspects of crop production. It is here that two other BCPC services – its Manual of Biocontrol Agents and its GM/GE Biotech Crops Service – feature. Both these areas are gaining growing relevance as the global agricultural sector comes to terms with meeting the growing biodiversity and food security challenges ahead.

BCPC's GM/GE Biotech Crops Service is a database that includes information on 372 products, on 25 crops worldwide, including GM crops and those produced by non-GM methods such as genetic selection and genome editing. The service also includes monthly e-newsletter, highlighting the latest biotech advances.

The Manual of Biocontrol Agents provides a reference of over 100 marco-organisms, 120-plus micro-organisms, 40-plus botanicals and over 50 semiochemicals used commercially around the world. The biocontrol content originated from one of BCPC's other key services – its Pesticide Manual. This was first published over 50 years ago and provides extensive technical data on over 10,000 product names and over 3,000 discontinued names. This has now evolved into a sophisticated online database, with extensive search features and downloadable data options.

All the above products and services, and more, can be seen on the BCPC website www.bcpc.org.



Scott Raffle • scott.raffle@niab.com

New research talent emerging from the CTP Fruit Crop Research programme

Scott Raffle is NIAB's Senior Knowledge Exchange Manager, raising the profile of the research and commercial activities at NIAB East Malling and improving collaboration between researchers and the fruit and wider horticulture industry.

NIAB's Scott Raffle explains how a new generation of talented fruit researchers is emerging from the Collaborative Training Partnership for Fruit Crop Research programme.

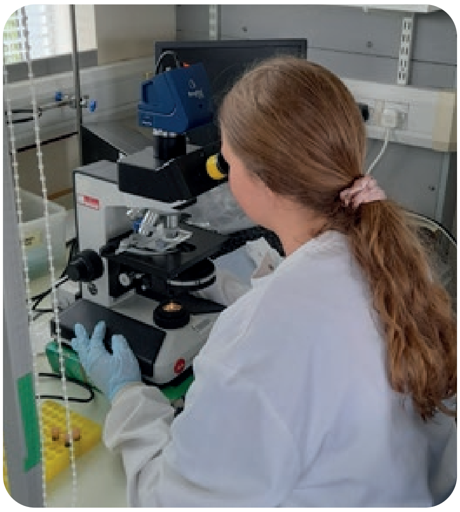
Where were you on 18th and 19th July 2022, when the UK experienced record high temperatures of 40°C and above? That may be a question posed around the drinks tables in pubs and clubs in the coming months and years. In my case, I had a great stroke of luck in that I was booked to attend a two-day conference of the Collaborative Training Partnership for Fruit Crop Research Studentship programme, which happened to take place in the very well-ventilated and cool Conference Centre at East Malling. The delegates and students attending were not only treated to a 'cool' environment, but we were reinvigorated by the talent and enthusiasm displayed by our student presenters.

The Collaborative Training Partnership for Fruit Crop Research (CTP-FCR) was instigated by lead partner Berry Gardens Growers Ltd, in collaboration with NIAB at East Malling, to help develop a new generation of fruit crop researchers to fill the ever-expanding void of young talent coming into the horticulture industry at large. Funded by the Biotechnology and Biological Sciences Research Council (BBSRC) along with industry partners AHDB, Berry Gardens Growers, Marks & Spencer, the National Association of Cider Makers, Worldwide Fruit Ltd and the Worshipful Company of Fruiterers, the programme aims to deliver a high-quality training programme for students, delivering independent, highly-employable scientists in strategically important research and development areas.

The first cohort of students kicked off the programme in 2017 and consecutive intakes continued annually each autumn until 2021; 40 researchers will have been trained by the time the final project is completed in September 2025. The majority of students are working with NIAB at East Malling, with others based at the Universities of Cranfield, Essex, Harper Adams, Lincoln, Nottingham and Reading. Each one is researching a topic of interest selected by the industry partners and within their four-year training period, the students also have the opportunity to experience the sector first hand by spending time with the CTP's industry partners in their businesses in order to widen their knowledge of the industry.

Many of the CTP's research topics are complementing research that is already in progress and the results will be adopted by existing NIAB researchers at East Malling and elsewhere. So what are the students researching and how might they benefit the soft fruit industry? Of the projects currently in progress, 17 have relevance to berry crops and these are grouped into four categories:

- pest and pathogen ecology;
- crop science and production systems;
- genetics;
- artificial intelligence and robotics.



Lauren Farwell is studying the management and control of Cladosporium, a green/black mould that develops on ripening raspberries

Pest and pathogen ecology

Laura Martinez at Harper Adams University is studying why the potato aphid, a common pest of strawberry, is not reliably controlled by aphid parasitoids. So far, she has discovered that there is genetic variability in the populations of the pest, but this does not appear to influence the susceptibility of the aphids to parasitoids. On a related theme, Stuart Edwards at the University of Reading is finishing his research into the influence of climate warming on aphid parasitoid/prey interactions.

Four pathology projects are currently in progress. At NIAB East Malling, Lauren Farwell is studying the management and control of *Cladosporium*, a green/black mould that develops on ripening raspberries. She has found that it only grows on the surface of ripe fruits and not green fruits, that good hygiene is important to reduce infection, and she is now investigating biological control options on the surface of the fruit. The range of pathogenic *Phytophthora* species causing raspberry root rot appears to be increasing and Eithne Browne has been working at Harper Adams University and NIAB East Malling to find out which species are prevalent and which are the most pathogenic. Samantha Lynn has been identifying strawberry genes that confer resistance to powdery mildew, so it is hoped to adopt these findings in the East

Malling strawberry breeding programme. Finlay Bourquin at NIAB Cambridge is investigating both the resistance and susceptibility of strawberries to *Botrytis cinerea*, whilst also understanding the virulence of different pathogenic strains.

Crop science and production systems

As you might expect with industry selected research projects, there are quite a few underway investigating aspects of plant physiology and improving crop production and fruit quality. Sophie Read at the University of Reading has been experimenting with the impact of additional lighting and night-break lighting in a bid to extend the UK strawberry production season between November and February under glass. In 2023, she plans to employ vertical growing systems using different light levels identified from her previous research. Nicholas Doddrell at NIAB East Malling and the University of Reading has worked at NIAB's WET Centre to understand the effect of increasing photosynthesis efficiency on strawberry yields. Measuring photosynthetic active radiation (PAR), he has found that middle rows in tunnels have a higher rate of photosynthesis and subsequent yield than the outside rows. He is now considering if plant genetics might be manipulated to increase strawberry photosynthesis.

At the University of Reading and of Essex respectively, Winnie Swann and Mengjie Fan are working with NIAB's Dr Mark Else at East Malling to optimise light recipes to maximise photosynthesis and yields in strawberry. Winnie has been using supplementary LED lighting and added CO_2 to refine a system for improving yield and fruit quality, while Mengjie is investigating the use of blue light with the intention of boosting yields late in the season.

Back at East Malling, in a project seeking to improve CO_2 uptake by stomata in strawberry crops and increase their yields, William Atkinson is experimenting with light and other environmental cues both to increase stomata density and stomatal opening. Emily Johnstone at the University of Reading is investigating ways to maximise optimum strawberry fruit size for sale to multiple retailers, by manipulating nitrogen input and strawberry growth.

Finally in raspberry, Ece Moustafa is trying to understand the legacy effect of short-term water stress and its impact on fruit size and quality. Importantly, Ece is also determining how quickly raspberry plants recover from water stress, which will be very useful information for growers in the future as our climate becomes warmer.

Genetics

Camila Gonzalez at NIAB at East Malling is working with the genetics and breeding teams, using a combination of genetic mapping and gene editing to understand the control of flowering in strawberries, specifically the Junebearer Malling™ Centenary and the everbearer Calypso. By improving our understanding of what controls flowering, we hope to be able to find ways of creating continuous flower and fruit production through the season.

Artificial intelligence and robotics

Three students at the University of Lincoln are working on projects to inform robotic research and yield forecasting. Justin Le Louedec has been using novel machine learning techniques to teach cameras installed on robotic pickers to identify the correct colour and shape of fruits to pick. Katherine James is creating images of model strawberry plants, which can be used by automated strawberry harvesters to recognise the plants and their fruit traits. Finally George Onoufriou is using yield profile data collected from previous year's harvests, alongside the recorded temperatures and light levels, to build yield forecasting models. These will allow us to use weather forecast data to improve our prediction of yield forecasts for up to three weeks ahead.

Student progress into industry

The success of the CTP programme is not just measured by the output of results, but also by the employment secured by the students at the end of their studies. Three students, from the first intake in 2017, are already working in fruit research roles spanning academia and industry. Carlota Gonzalez Noguer is now a Quantitative Crop Physiologist with NIAB at East Malling and Raymond Kirk is the Chief Technology Officer of a start-up business, FruitCast, who plan to offer a crop forecasting service to strawberry growers in the next few years. Lastly, Christina Conroy is employed as a Technical Account Manager at Berry Gardens. The next generation of fruit research scientists has already landed!

NIAB and Berry Gardens Growers are extremely grateful to the Biotechnology and Biological Sciences Research Council (BBSRC), AHDB and partner universities, for providing grant funding for the CTP-FCR programme as well as the industry funding sponsors.

www.ctp-fcr.org **@ctp_fcr**

Ece Moustafa is trying to understand the legacy effect of short-term water stress and its impact on raspberry fruit size and quality

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Growing Green pilot supports move towards net-zero

NIAB's Scott Raffle and Robert Saville explain how a Growing Kent & Medway-led support programme has assisted Kent fruit growing businesses in their journey towards net-zero.

Scott Raffle – see page 32

Robert Saville is the Innovation Growth Manager for Growing Kent & Medway, based at NIAB East Malling. He works closely with stakeholders across the GKM programme to engage businesses in the region with the facilities, resources and expertise available within the cluster.

The *Growing Green* programme is a government-funded pilot training scheme seeking to provide the knowledge, tools and funding to reduce carbon emissions, helping businesses on their journey towards net-zero. As a pilot programme, the aim has also been to work with businesses to learn and understand what aspects of reaching net-zero they need help and support with, allowing us to put further support programmes together to ensure they reach their ultimate targets.

Funded by the UK Government's Community Renewal Fund (CRF) through Kent County Council, the *Growing Green* programme began in February 2022, recruiting 37 horticultural and plant-based food and drink companies to participate, including several fruit growing operations. The businesses started by quantifying the principal inputs they required, including energy and water, along with the outputs in terms of waste products. They were encouraged to consider how they might reduce both inputs and outputs and what help they needed to achieve this.

Trained practitioners were allocated to each participating business to help to facilitate this process and to develop a decarbonisation plan. Whilst developing these, the businesses were also invited to attend a series of eight interactive training workshops covering topics ranging from 'thinking outside the box', sustainable packaging, resource use, environmental management and waste recycling. This allowed the fruit growers involved to network with other types of businesses, learn from different production processes, and inspire them to implement change.

Businesses are keen to find alternative uses for fruit and vegetable waste

Following the training process, each business developed a bespoke action plan, identifying two or three goals to work towards, implementing changes to achieve reduced inputs or alternative uses for the by-products of their operations, to help the business to get closer to a 'net-zero' target. As part of the pilot project a grant was available to participating businesses to implement one or more of their decarbonisation goals. Following submission to an assessment panel, businesses eligible to receive a financial grant from the community renewal fund, were asked to submit a fully costed proposal. At the time of writing, over £190,000 of grant funding had been committed to fund 26 decarbonisation projects.

The *Growing Green* pilot project concluded in late September and October 2022 with a series of site visits showcasing commercially relevant net-zero technologies and processes in the region.

For the participating horticultural and fruit businesses, the most commonly occurring decarbonisation goals included renewable energy, energy efficiency, water and alternative fuels, with a number of novel approaches being identified.

73% of horticultural businesses targeted more efficient use of water including the installation of rainwater harvesting from farm buildings,

Fruit growers are developing new ways of capturing and storing water for irrigation

Improving energy efficiency for fruit stores was a high priority for fruit growers in the Growing Green programme

polytunnels, natural ponds and low-lying areas of farms. Some sought to install more trickle irrigation with fertiliser dosing, whilst others considered the recycling of water from fruit grading lines. 67% identified techniques to improve cold store energy efficiency, changing processes to be more energy efficient or addressing energy savings in staff accommodation.

A number of horticultural businesses (20%) identified circularity opportunities for by-products from their business operations, such as adding value to cherry waste, finding new markets for cobnut husks, using apple waste as feedstock for insects, composting systems, and development of biochar production from orchard prunings.

The pilot programme concluded in October 2022 with a *Growing Green* wrap-up event, including a tour of one participating business, Communigrow; a charity that teaches people how to grow food, reconnecting them to the outdoor environment it comes from, and the soil it grows in. There were also tours of NIAB's fruit demonstration centres at East Malling where soil health, water use efficiency, and environmental management are the focus of ongoing research.

The event also showcased a fascinating business development at Nim's Fruit Crisps, a Kent-based food business that has benefited from a *Growing Green* grant to valorise its fruit waste. For some time, owner Nimisha Raja has been keen to find a use for the fruit and vegetable waste (such as skins, peels and cores), left over from her processing operation. After learning about the *Growing Green* pilot project, she was able to secure funding to purchase equipment that can grind her dried waste into powders.

Nimisha is now developing new markets for its waste products. Fruit powders can be used as flavouring in gin distilling, for cereals and smoothies, whilst lemon powder is employed in the production of Baklava, a traditional pastry dessert. Ultimately, Nimisha aims to find markets for 30-40 tonnes of dried food each year and plans to reach zero food waste by the end of this year or at the latest, summer 2023.

> *"The Growing Green pilot training programme has acted as a catalyst to change my business and I am now seeking to work more closely with GKM and their research partners to develop ways of storing my food powders and how best to granulate them for my current markets."*
>
> Nimisha Raja, Nim's Fruit Crisps

NIAB's Trevor Wignall welcomes the Growing Green wrap-up event delegates to the NIAB WET Centre

So what has the *Growing Green* pilot training programme achieved? It has worked closely with 37 horticultural, food and drinks businesses in Kent, identifying their most pressing needs to move towards net-zero, provided them with training, and supported and mentored them in developing a total of 30 decarbonisation action plans.

Equally importantly, Growing Kent & Medway has allowed Kent horticultural, food and drinks businesses to network, share ideas and identify areas where they need further support to reach their 'net-zero' target. The team now has an improved understanding of the decarbonisation challenges facing this sector and aims to deliver further resources and events, whilst seeking new funding opportunities. Look out for more developments on www.growingkentandmedway.com.

GROWING KENT & MEDWAY

Growing Kent & Medway is a research, innovation and enterprise cluster, which is funded through the Government's UKRI's Strength in Places Fund. It is investing in sustainable ideas to help the horticultural and plant-based food and drink industry in the Kent and Medway region to thrive. It does so through funding collaborative research and development projects led by NIAB, University of Greenwich and University of Kent, and providing business support through mentoring, food accelerator and networking programmes.

GROWING GREEN

Funded by:
UK Government
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Diploid potatoes are emerging

Potato production in the coming years will radically change when the advances in potato genetics enable the use of true potato seed and F1 hybrid diploids.

A senior research associate in the potato team at NIAB Professor Gerard Bishop has over 30 years' experience carrying out research on tomato, potato and eggplant. He has studied plant growth and development and helped in sequencing the tomato and potato genomes. He is eager to see agronomic and genetic solutions enabling sustainable potato production and the adoption of new technologies and breeding techniques.

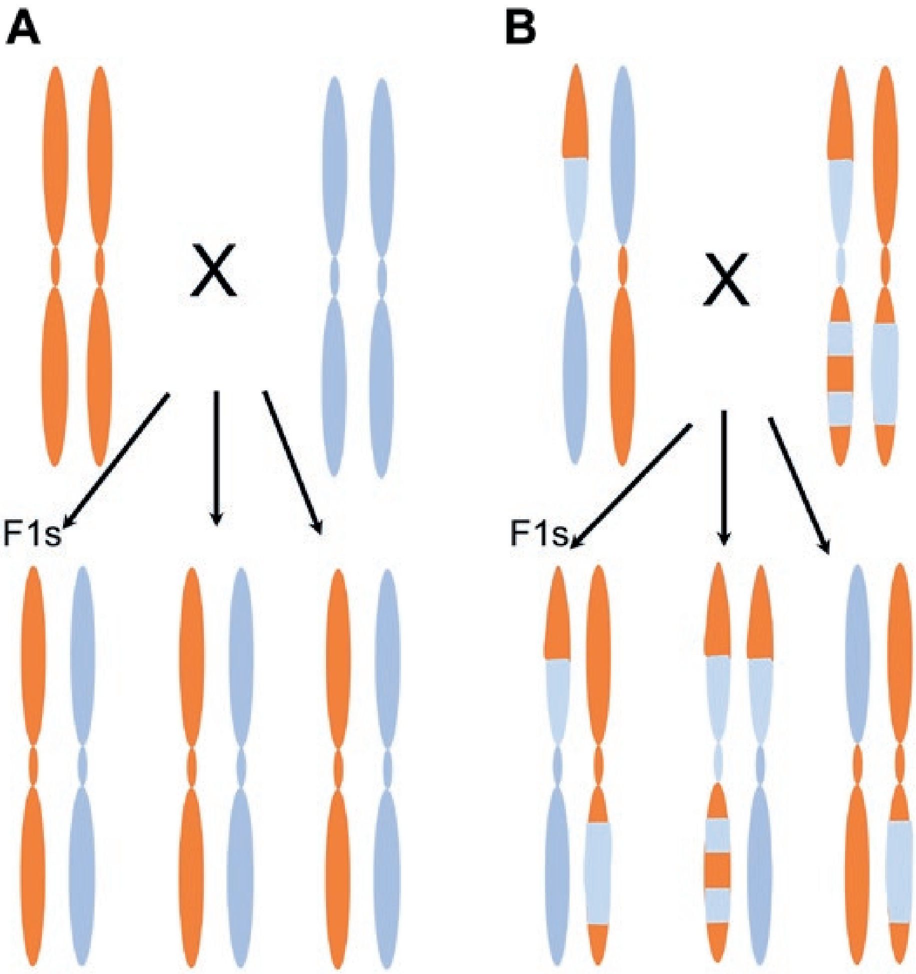
Diploids and tetraploids

The mainstay of potato breeding has been the crossing of elite tetraploid varieties to each other to increase their performance. Tetraploids have four copies of a chromosome in a cell in comparison to diploids that only have two. The advantages of having more chromosomes per cell are enlarged organs and any genes that are mutated on a chromosome will be compensated by a functional gene on another. This however leads to complex genetics especially when breeding in beneficial genes from wild germplasm (that is often diploid) and is a slow process. Diploid potato breeding on the other hand involves less complex genetics but is hampered by germplasm accessions in collections around the world that are self-incompatible and thus unable to set self-seed. This has meant that the numerous diploid accessions from which new beneficial genes can be bred have highly heterogenous (diverse) DNA sequences which brings their own complications in breeding.

Figure 1. Hybrid F1s showing the need for inbreeding to generate homozygous lines so that when crossed together the progeny will have uniform genetics.

A) Shows a pair of chromosomes from inbred parents (homozygous lines) leading to F1 progeny that have uniform chromosomes and plant phenotypes

B) Shows a pair of chromosomes from outbred parents (heterozygous lines) leading to F1 progeny that have heterogeneous chromosomes and plant phenotypes



Sli gene

A key discovery that is aiding the diploid potato revolution has been the characterisation and use of the *S-locus inhibitor (Sli)* gene that allows self-seed to be made in diploids. This has been deployed to make lines that have more homogenous gene sequences (homozygotes) at any given position in the chromosome. The development of such inbred lines enables the generation of more uniform F1 hybrids (Figure 1) that will exhibit hybrid vigour, i.e. the cross-bred line having superior performance in comparison to those of both parents. The outbreeding in wild germplasm has however led to the build-up of many deleterious mutations and these mutations need to be removed to enhance crop performance.

True potato seed

The ability to generate inbred lines in potato enables the use of true potato seed (TPS) from pollinated flowers instead of using seed tubers, as the inbreeding will maintain a uniform variety.

The use of true seed has many advantages over seed tubers including:

- *fewer pests and diseases:* TPS has limited transmission of disease, whereas viral, fungal and bacterial diseases are transmitted between generations of seed tubers and this disease load increases with the number of generations;

- *more rapid multiplication of material:* a single plant can produce thousands of seeds compared to only about 10 tubers. This greatly reduces the time required to generate sufficient material to introduce new cultivars.
- *storage:* less than about 50 g of TPS are sufficient to grow one hectare of potatoes compared to approximately two tonnes of seed tubers. TPS does not require refrigeration and can be stored for many years whereas seed tubers must be kept cool to prevent sprouting and lose vigour if stored for too long;
- *transport:* Seed tubers are normally produced in different regions to where the commercial ware crop is grown to prevent virus entering the seed tubers. This separation requires the shipment of tonnes of seed tubers over distance. In comparison the grams or kilograms of TPS is cheap to transport.

Challenges that remain

TPS is small, approximately 1/10,000 of the weight of an average seed tuber (Figure 2). The lack of resource in a seed in comparison to a tuber means that emergence and growth of plants from tubers is much more vigorous than that from true seed. The rapid growth from seed tubers helps the development of ground cover and thus energy capture that can be converted to yield, and it helps prevent competition from weeds. The small, less vigorous, seedlings from TPS will suffer from competition from weeds and may also be more sensitive to pre-emergence herbicides currently in use. Other challenges in using diploids include the potential production of berries in a ware potato crop. The berries are a resource sink, potentially reducing yield and, depending on timing of harvests, may leave TPS in the field leading to significant volunteer production in future rotations. A key challenge is to improve yields from F1 diploids grown from seed tubers or from TPS. Currently the diploids generate many small tubers in comparison to tetraploid varieties that have fewer larger tubers.

The future

There is much excitement about the possibilities of using diploids with three companies – Aardevo, HZPC and Solynta, all in the Netherlands – and research groups in the USA and China rapidly advancing potato diploids. It is highly unlikely that we will be drilling true seed for potato production anytime soon in the UK. The route to market in countries with established certified seed tuber production systems will most likely be via seed tubers grown from TPS.

However, diploids will make the slow clonal multiplication of seed tubers through many field generations become a thing of the past and many new varieties will potentially enter the market at scale. The speed of genetic improvement suggests it is possible that by the end of the decade diploids will be grown more widely, with niche salad varieties most likely to be the breakthrough product for UK and European markets. Before this, the socio economics will need to favour their introduction, which will require the diploids to have significant advantages over the current varieties, some of which have been around for over 50 (Maris Piper) or 100 (International Kidney/Jersey Royal) years. History suggests that changing customers preferences will be challenging. However, the use of true seed and hybrid diploids will have a significant impact where infrastructure in potato seed production is poor, for example in African countries. These countries already benefit from using apical cutting transplants in potato production and generating transplants from TPS will be straightforward.

Figure 2. Potato true potato seed (TPS) and seed tuber

Staff news

Helen Appleyard now leads NIAB's Analytical Services department and has been appointed Chief Officer for the Official Seed Testing Station (OSTS) for England and Wales. She takes over from Linda Maile, who retired from the role in summer 2022. Linda had worked at NIAB, in the OSTS, for a recordbreaking 53 years. Helen moves to the Chief Officer position having managed NIAB's LabTest service in Cambridge since 2016. She originally joined the OSTS in 1988 as a Trainee Seed Analyst.

Professor Xiangming Xu has become NIAB's Director of Research. Formerly Head of Science at NIAB's horticultural centre at East Malling in Kent, Professor Xu is now responsible for developing and delivering the strategy for research activities across the whole of NIAB. This is in addition to his role in co-ordinating research activities at East Malling.

Peter Craven has joined NIAB in the new role of Research Development Manager in Potatoes. The appointment comes at a critical time, as the UK potato industry seeks to remain at the technological forefront following the demise of AHDB Potatoes. Peter joins NIAB's established team of research scientists, crop specialists and field/laboratory technicians, widely known for providing potato R&D, services and advice across the UK and beyond.

Dr Charles Lang and Kathy Fidgeon have retired as NIAB Board members and were awarded NIAB Fellowships by outgoing NIAB Board Chair Jim Godfrey and CEO Professor Mario Caccamo at their final meeting in November 2022. Mr Godfrey is now a member of the National Institute of Agricultural Botany Trust, with John Elliot taking over the Trust Chair position from Jeremy Lewis. Thank you to all our retiring Trust and Board members for their work and support.

ARTIS NIAB

Technical training courses

Classroom Courses 2023

11 January	**Essentials of good soil management** • Trained by Nathan Morris • NIAB Park Farm
17 January	**Best practice agronomy for cereals and oilseed rape** • Trained by Bryce Rham • NIAB HQ
2 February	**Optimising nutrient management for combinable crops** • Trained by Andrew Watson • NIAB HQ
15 February	**Using an integrated approach to weed management in arable crops** • Trained by John Cussans • NIAB HQ
23 February	**Advanced nutrient management for combinable crops** • Trained by Stuart Knight • NIAB HQ
28 February	**Gross margin, budgeting and management** • Trained by Chris Winney • NIAB HQ
1 March	**Understanding Potato Growth Stages (am)** • Trained by Sarah Roberts • NIAB HQ
	Improving potato yields and profitability by measuring and monitoring performance (pm) Trained by Sarah Roberts • NIAB HQ
2 March	**Scheduling Irrigation to optimise yield and quality in potatoes (am)** • Trained by Katharina Huntenberg • NIAB HQ
	Understanding and optimising potato nutrition (pm) • Trained by Elizabeth Stockdale & Joseph Martlew • NIAB HQ
9 March	**Better control and avoidance of disease in wheat** • Trained by Aoife O'Driscoll • NIAB Park Farm

Virtual Courses 2023

18 January	**Profitable growing of vegetable brassicas** • Trained by Andy Richardson
25 January	**Optimising crop management of bulb onions** • Trained by Andy Richardson
26 January	**Exploring regenerative agriculture** • Trained by Elizabeth Stockdale and Richard Harding
1 February	**Advanced crop management of bulb onions** • Trained by Andy Richardson
8 February	**Best practice onion storage** • Trained by Andy Richardson
14 & 15 February	**Benefits of cover crops in arable systems** • Trained by Nathan Morris
15 February	**Integrated approach to weed management in arable crops** • Trained by John Cussans
21 February	**Improving soil organic matter and farm carbon management** • Trained by Elizabeth Stockdale and Becky Willson

Register your interest

We are still in the process of organising some of our courses. Please visit www.artistraining.com to register your interest for a course or join our mailing list for regular updates.

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