Plant breeding vital for sustainable agriculture – ADAS study

By delivering improvements in crop yields, resource use efficiency and reduced environmental impact, plant breeding has been a major contributor to meeting the goals of sustainability in agriculture, according to the interim findings of an independent review by ADAS.

Leading figures from across the food, farming and research sectors gathered at the Royal Society in October to hear a preview of the wide-ranging study, which involved a systematic review of published scientific literature and other available information sources.

With a focus on UK and EU plant breeding in key food and forage crops over the past 10 years, ADAS assessed the extent to which modern breeding programmes and associated research support the objectives of sustainable intensification in agriculture – as defined in the Foresight Report and other influential publications.

The study found that plant breeding provides an important foundation to address multiple sustainability goals, and is a major contributor to raising yields, increasing resource use efficiency and reducing the negative environmental impacts of food production.

Continued overleaf

ADAS REPORT HIGHLIGHTS

Raising yields
Plant breeders have helped improve and protect crop output by selecting for physical yield and resistance to pests and diseases, and by improving crop quality to maximise marketable yield.

Disease resistance in particular has been successfully targeted by breeders, with commercial varieties offering a degree of resistance to economically damaging diseases, and further research work is under way to broaden the scope of resistance in crops such as oilseed rape and sugar beet.

Pest resistance has also been a focus for breeders, particularly in wheat (orange wheat blossom midge) and sugar beet (beet cyst nematode), with further work in the breeding pipeline to select for aphid resistance in wheat.

Crop quality has also been a key objective of modern plant breeding, with improvements in wheat varieties for breadmaking, enhanced quality and processing efficiency of malting barley, and oilseed rape bred for specific markets, e.g. high erucic acid rape (HEAR) and varieties with a high oleic, low linolenic fatty acid profile (HOLL).

Increasing resource use efficiency
Resource use efficiency in the context of plant breeding focuses on improving the efficiency with which the plant uses resources, principally water and nutrients. Efficiency of resource use is linked to improving yield, with higher yields associated with more efficient use of nutrients and reduced emissions per tonne of output. Traits to target further improvements in nutrient use efficiency are in the research pipeline, with N optima traits identified in a range of crops and genes linked to nitrogen use efficiency found.

There has also been a breeding focus on improving phosphorous use efficiency in herbage crops, while research targeting further improvements in water use efficiency is under way, with a specific focus on improved rooting in wheat and herbage crops.

Reducing the negative environmental impacts of food production
Protecting yield by targeting increased resistance/tolerance to diseases and pests and improving nutrient and water use efficiency via enhanced rooting has helped to reduce the negative environmental impacts of food production leading to improved soil and water quality. The contribution of plant breeders in this area is supported by other measures such as legislation, farm practices and voluntary initiatives.
Impact of plant breeding on sustainability traits in major crops
Using illustrative examples, the following table provides a snapshot summary of the ADAS study, with breeding objectives classified by crop species and according to whether commercial varieties have already delivered impact in the market place (blue) or whether further research work is in progress, or required (green).

<table>
<thead>
<tr>
<th>Trait</th>
<th>Wheat</th>
<th>Barley</th>
<th>Oats</th>
<th>Oilseed</th>
<th>Field Beans</th>
<th>Field Peas</th>
<th>Forage Maize</th>
<th>Herbage</th>
<th>Sugar Beet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase harvestable yield</td>
<td>Increase by 0.7t/ha decade since 1980</td>
<td>Plant breeding accountable for 92% improve in W.B &amp; 87% in S.B since 1982</td>
<td>Improve harvest index and no. grain per sq. metre</td>
<td>0.5t/ha increase per decade since 1980</td>
<td>Little increase seen</td>
<td>Average increase of yields of 0.05 t/ha/year</td>
<td>Focus on DM and starch yield</td>
<td>Focus on DM yield</td>
<td>Yield increased faster than any UK arable crop since 1980</td>
</tr>
<tr>
<td>End use quality</td>
<td>Bread making quality</td>
<td>Low β-glucan levels, low β-amylase</td>
<td>Naked oats, oil content</td>
<td>Decrease glucosinolate &amp; fibre</td>
<td>Reduce tannins, amino acid content</td>
<td>Digestibility energy content</td>
<td>Sugar content</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resistance to disease</td>
<td>Eyespot Sept., rust</td>
<td>Mildew rust, Rhyncho. Ramularia, Net blotch</td>
<td>Rust, mildew</td>
<td>LLS stem canker</td>
<td>Leaf and pod spot</td>
<td>Pea wilt, Downy mildew</td>
<td>Eyespot Mildew, Rhyncho. rust</td>
<td>AYPR Fusarium</td>
<td>BMYV, BYV</td>
</tr>
<tr>
<td>Resistance to pests</td>
<td>OWBM</td>
<td>Little work</td>
<td>Little work</td>
<td>TuYV</td>
<td>Little work carried out</td>
<td>Corn borer resistance</td>
<td>Little work BCN tolerance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adaption to env. extremes</td>
<td>Drought tol. QTLs</td>
<td>Little work</td>
<td>Little work</td>
<td>Little work</td>
<td>Traits found</td>
<td>Traits found</td>
<td>QTLs found</td>
<td>Drought tolerant</td>
<td>Traits identified</td>
</tr>
</tbody>
</table>

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“Welcome the ADAS study, Defra Minister Lord de Mauley said:
“The study is particularly relevant because of the global need for more productive, climate resilient and sustainable agriculture. It is right in line with our priorities in the Agri-Tech Strategy, Defra’s Sustainable Intensification Research Platform, the BBSRC’s Sustainable Intensification Research Club and Defra’s Genetic Improvement Networks.
“My work on Agri-Tech has shown me how much my colleagues across the Government recognise the importance of a productive, competitive and sustainable agricultural industry, with a thriving commercial plant breeding sector, working with the public sector.”

BSPB chairman Dr Richard Summers said:
“The concept of ‘sustainable intensification’ in agriculture – producing more output per unit of resource and environmental impact – is widely established as the necessary response to Sir John Beddington’s ‘perfect storm’ of population growth, climate change and declining natural resources. Less clear is precisely what this means in practice for different product sectors and farming systems.
“Unpacking the components of sustainability is the starting point for developing new metrics in agriculture, paving the way for common, agreed definitions of what sustainable intensification means in practical terms – so that we can benchmark current performance, measure improvements over time, understand the best technologies, farming systems and practices to deliver it, and use all that information to frame the R&D agenda going forward.
“This latest report from ADAS makes a valuable contribution to that process, and clearly demonstrates the role of plant breeding innovation as a major contributor to more sustainable farming systems.”

A significant conclusion from the report is that plant breeders’ focus on selection for marketable yield delivers benefits to resource efficiency and the environment.
Breeding for disease resistance

Faced with constantly changing disease pressures, reduced efficacy of chemical controls and the potential loss of key fungicides, the availability of crop varieties with in-built resistance to economically damaging diseases is a critical component of sustainable, productive agriculture.

Disease control is critical for successful crop production, and the importance of varietal resistance is increasing as pathogens develop resistance to existing chemical controls and regulatory constraints limit the range and availability of active ingredients.

For example, *Septoria tritici* is developing resistance to the major azole fungicides – the primary control method for this important disease of UK wheat. Light leaf spot in oilseed rape, which used to be confined to the North, now affects more than 85% of UK crops, yet available fungicides offer limited control and current genetic resistance is starting to break down in high pressure locations.

The host-pathogen arms race

The genetic basis for much disease resistance is a gene-for-gene relationship between major resistance or *R* genes in plants, and virulence or *Avr* genes in pathogens. Provided the *R* gene can recognise the pathogen, plant resistance works. Eventually, however, and accelerated by widespread use of the same *R* gene in different varieties, selection pressure causes new mutant *Avr* genes to evolve. The host resistance conferred by the *R* gene is no longer effective and the variety becomes susceptible until the breeder can find a new source of resistance. This breakdown of resistance can be dramatic and devastating, as in the case of the highly aggressive Warrior race of yellow rust in UK winter wheat.

Breeding objectives and strategies

Plant breeders constantly search for new sources of disease resistance. The objective is not to rely on single *R* gene resistance, because of the limited lifespan and catastrophic effect of breakdown but to breed for durable resistance – more effective control over multiple years of widespread use – for example by pyramiding multiple *R* genes or using combined sources of partial resistance.

CASE STUDY

**EYESPOT RESISTANCE IN WHEAT**

The *Pch1* gene is the most potent known source of eyespot resistance in wheat, derived from goatgrass (*Aegilops ventricosa*) and crossed into wheat. *Pch1* is associated with higher protein content but also causes yield drag which has limited its commercial use to date. Breeders have been trying for 40 years to segregate the desirable eyespot resistance and protein content from the deleterious effect on yield. Research is now under way to identify markers and to clone the gene to help breeders separate out the undesirable traits.

Promising lines are grown in the field in areas with high disease pressure so that susceptible plants can be easily identified and discarded.

Screening wheat lines for eyespot resistance in the glasshouse.
Genetic markers are an essential component of breeding for disease resistance, and genomic selection is used increasingly. Genomic selection uses several thousand markers across the whole genome and predicts statistically from the distribution of markers which genes are likely to be in early crosses, allowing breeders to identify high potential material more quickly.

Selection and evaluation
Promising early stage material is grown on in breeders’ selection trials, all untreated and grown in settings conducive to disease. Susceptible lines are discarded at this stage.

As material moves through the breeding funnel and into National and Recommended List trials, selection for disease resistance becomes even more rigorous and includes use of disease nurseries in which plants are deliberately inoculated to guarantee infection and test resistance.

RL disease ratings are calculated from the inoculated nursery data, information from untreated trials and disease observation plots situated in areas where the disease is most prevalent. Data from all of these are combined and analysed to produce the familiar 1-9 ratings where 9 is fully resistant and 1 highly susceptible.

The RL system sets minimum disease resistance standards for recommendation and provides robust, independent data on which farmers can base variety choice, balancing yield against disease resistance, quality and agronomic characters to suit their individual circumstances.

Intractable disease problems
Alongside the increasing use of genomics and marker-assisted selection, new breeding technologies may offer potential solutions to intractable disease problems.

UK plant scientists at NIAB and the John Innes Centre, for example, are using GM techniques to introduce novel sources of take-all resistance in wheat. Take-all is a particular problem for wheat growers, with no truly effective means of chemical control and no sources of genetic resistance within the wheat gene pool. Sources of take-all resistance have been identified in oats, but the only possible means of transferring that resistance into wheat is by using GM techniques. This early stage research shows promise as a means of boosting wheat yields and saving growers hundreds of millions of pounds a year.

Researchers in China have used advanced gene editing techniques – known as TALEN and CRISPR – to produce disease resistant wheat plants by inducing highly targeted mutations leading to heritable broad spectrum resistance to powdery mildew. The research is an early indication of the potential power of these new breeding techniques in inducing more targeted genetic changes than the mutation breeding approaches previously available to breeders.

Disease resistance is a major objective for UK plant breeders. It is a complex and ongoing challenge, working on a 10 year horizon to ensure varietal resistance keeps pace with constantly evolving disease pressures, and to combine durable resistance with other desired characters.

Genomics and marker-assisted selection are widely used by breeders to improve the selection process. Advanced breeding techniques such as GM and gene editing also offer exciting opportunities to tackle intractable disease problems such as take-all in wheat and BYDV in barley, although the regulatory position of these technologies remains uncertain within the EU.
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That’s why BSPB is encouraging more farmers to go paperless on FSS – by opting to receive declaration forms and other communications electronically. This will help streamline the FSS process while saving printing, stationery and postage costs.

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COVER CROPS – A REMINDER

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Although these cover crops are not taken to harvest, the farm-saved seed payment is still due at the time of sowing.

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As the new European Commission prepares plans for an overhaul of EU seed legislation, Europe’s plant breeders are supporting the regulatory pillars of variety registration and seed certification as the basis for an innovative and market-focused plant breeding and seeds sector.

Earlier this year, the European Parliament voted to reject the Commission’s draft proposals for a new regulatory framework on Plant Reproductive Material (PRM). It is widely expected that a revised text from the Commission will be presented early next year for consideration by EU ministers and the new European Parliament.

The shape and direction of the revised PRM Regulation is critical to the continued success of the UK’s research-intensive, science-based approach to plant breeding, and must support IP protection, encourage private sector R&D investment and guarantee seed quality, health, identity, traceability and performance.

A legislative framework which supports continued investment in a progressive EU plant breeding and seeds sector is needed to maintain productive, competitive and sustainable farming systems in Europe.

In particular, BSPB is calling for the key principles of existing seed legislation to be retained:

**Transparent consumer protection**

The basic components of variety registration – Distinctness, Uniformity and Stability (DUS) and, where it applies, Value for Cultivation and Use (VCU) – provide a guarantee of transparency and traceability for customers and an assurance that approved varieties meet the demands of sustainable, efficient, productive agriculture.

**Seed certification**

Seed certification provides an independent assurance of the health, identity, purity and quality of seed and forms the basis for international trade. Existing, pre-defined categories of seed (pre-basic, basic, certified and standard) represent different quality levels and meet consumer demands for choice.

### BBSRC chief visits plant breeding station

Professor Jackie Hunter, chief executive of the Biotechnology and Biological Sciences Research Council (BBSRC), visited RAGT’s plant breeding station near Cambridge in August to meet BSPB representatives and tour the cereal breeding facilities.

BBSRC funds much of the early-stage scientific research on which future breeding advances depend, and the renewed R&D policy focus on delivering productive, sustainable and climate resilient agriculture has seen closer collaboration between BBSRC scientists and commercial plant breeders, for example through BBSRC’s Crop Improvement Research Club.

In particular, the visit highlighted the importance of translating our rapidly advancing knowledge base in basic plant science into commercially accessible breeding tools and germplasm, through co-ordinated pre-breeding research effort and strong partnerships between public and private sector.

**Counting off-types in DUS growing tests to ensure new varieties meet rigorous standards for distinctness, uniformity and stability**