Durable disease resistance in cereals

MORTEN LILLEMO AND ÅSMUND BJØRNSTAD

Morten Lillemo and **Åsmund Bjørnstad** explain their projects investigating disease resistance in cereal crops, work which is based in Norway but has implications which could stretch across the globe

Firstly, what motivated you to specialise in durable disease resistance in cereals?

I have seen too many promising wheat cultivars becoming susceptible to important diseases within a short time after their release. Lack of adequate resistance to powdery mildew was identified as the main challenge to wheat production in Norway at the start of the modern plant breeding era more than a century ago. Resistance breeding has been given top priority, but still, we have many examples of recent cultivars that are as susceptible as those grown by farmers 100 years ago. These cultivars had race-specific resistance genes that were overcome by genetic changes in the pathogen within one to three years of cultivation. At the same time we have several examples of older cultivars with partial and race non-specific resistance that have not eroded over time. Furthermore, a more recent disease, *Fusarium*, has begun to appear in the past two decades due to changes in cultivation environment comprising a reduction in the amount of tilling administered, as well as seasons that are both warmer and wetter. No race-specific resistance is available. The resistance identified, however, is applicable to different species of the fungus.

What are the main objectives of your current research project?

Our main focus is to determine the genetic basis of partial and potentially durable resistance to the top three diseases in Norway: powdery mildew, *Fusarium* head blight and *Stagonospora nodorum* leaf blotch. In collaboration with the Graminor breeding company we have been able to develop molecular marker assays that can be used to speed up the breeding of new cultivars with improved resistance to these important diseases, such that essential crops worldwide will continue to have good yields. We are also pursuing largely collaborative projects in wheat and barley. Working alongside international research programmes in this field, our joint approach gives us additional breadth and strength in our investigations. In oats, however, international research is much more limited since it is a cool season crop accounting for only 1 per cent of total production of cereal worldwide, but with the Nordic region as the world's third largest producer. Oats have too long been neglected in biotechnological tool development, but marker methods are now becoming avaiable through international collaboration. One major goal is to identify resistance factors to *Fusarium* in oats, and we are now mapping such factors.

How do you ensure field testing remains in isolation and does not disperse into the wider environment?

This is not an issue as we only use naturally occurring pathogen strains in our experiments. Powdery mildew is so abundant in south-eastern Norway that our disease nurseries get reliably infected by spores from surrounding wheat fields every year. We have a similar situation for leaf blotch, but here we apply mist irrigation in order to create more favourable conditions for the disease and keep the plants free of powdery mildew. The *Fusarium* nurseries are inoculated in order to achieve uniform disease pressure, but the inoculum is produced from locally collected pathogen isolates. Of course, we are very concerned about biosafety, but in all of these cases our experiments are perfectly safe.

In what way do you contribute to the Consultative Group on International Agricultural Research (CGIAR)-funded International Maize and Wheat Improvement Centre (CIMMYT)?

Norway contributes money to the CGIAR group, but not directly to CIMMYT itself, which is based in Mexico. We do have a postdoctoral position funded from Norway working in CIMMYT, contributing to ongoing research worldwide. We are able to collaborate closely with CIMMYT; this is a mutually beneficial arrangement in which we exchange information about germplasm, disease resistance data and molecular marker assays. In this way, our research not only helps wheat breeding in Norway, but has a much wider impact. The main beneficiaries of the high-yielding wheat breeding material with durable resistance developed by CIMMYT are resource-poor farmers in developing countries who can neither access nor afford fungicides to protect their crops.

What do you consider to be the greatest success of CIMMYT to date?

The greatest success of CIMMYT has been their widely adapted semi-dwarf wheat germplasm with continuous yield improvements. Since the first adoption of CIMMYT wheat cultivars in countries like India and Pakistan in the early 1960s, wheat yields in the third world have tripled. Furthermore, an equivalent of 1.2 billion hectares of land have been saved from deforestation, should the same amount of wheat have been produced without those improvements in cultivars and cultivation methods instigated by CIMMYT.

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Future-proofing food

With global demand for food increasing, an interdisciplinary team at the **Norwegian University of Life Sciences** has been investigating cereal durability, with the ultimate aim of maintaining international supply

THE TASK FOR plants to remain healthy is a challenging one, with millions of bacteria and fungal spores landing on their surface every day. Whilst the majority are benign, some cause severe diseases and epidemics, destroying both the quality and quantity of food. In order to avoid expensive fungicides, naturally resistant cultivars of cereals are desirable. Whilst most plants are resistant to most diseases, where this resistance is based on a single gene rather than a broader resistance a simple mutation can cause problems of recurrence.

A research team at the Norwegian University of Life Sciences led by Dr Morten Lillemo has been studying multiple gene resistance, identifying durable protection through genetic mapping and developing molecular markers, simplifying the selection process. Powdery mildew in wheat is an example of the type of disease the researchers are tackling. With Norwegian crops particularly susceptible because of farming techniques and climate issues, the group is working to identify race non-specific resistance. This will break the cycle of resistance and mutation which has dogged the production of wheat during recent years. The aim is not to eliminate powdery mildew, but to slow its spread in a robust manner, helping to give food production the tools it requires to counteract serious diseases. In collaboration with international partners, the scientists have identified several genes for race non-specific resistance that not only retards the growth of powdery mildew but also protects in a similar manner against the more damaging rust diseases of wheat.

STEM RUST

The danger of relying on single resistance genes for disease control is well illustrated by the case of stem rust. Once known as the most devastating wheat disease of the world, it was kept under control without any disease outbreaks in the major wheat growing areas since the 1960s. However, a new race appeared in Uganda in 1998, and this strain has since been travelling. Because the resistance of most wheat cultivars worldwide was based on a single, race specific gene, Sr31, the majority of wheat cultivars could potentially be affected by this new stem rust. Already in Iran, this race is now moving towards Pakistan and India, both nations with extremely large wheat outputs. In the future, different resistances must be combined, as opposed to simply harnessing a race-specific gene. Work conducted at the International Maize and Wheat Improvement Centre (CIMMYT) has shown this approach to be viable; not only would it result in better resistance to stem rust and other diseases, it would also provide a strategy with durable disease control. International efforts are now underway to produce new cultivars before the modified stem rust causes significant international disruption to wheat production, with the aim of providing them to areas at greatest threat from the modification of this disease.

PREVENTING POISONINGS

The research group has also been investigating the *Fusarium* head blight disease, which affects oats, barley and wheat. This disease is caused by fungal pathogens that lives on dead plant material in the soil surface. However, in moist conditions *Fusarium* is able to infect the plant, and its impact on yield and plant reproduction is minor in comparison to the danger it poses to humans and animals through the mycotoxins they produce. *Fusarium* infections increase worldwide due to a reduction in ploughing, which leaves dead plant material on the soil surface that provides a culture for the infection, which

INTELLIGENCE

DURABLE DISEASE RESISTANCE IN CEREALS

OBJECTIVES

To develop more effective disease resistance breeding in cereals by use of molecular markers.

PARTNERS

Graminor, Norway • **Bioforsk**, Norway • **The International Maize and Wheat improvement Center** (CIMMYT), Mexico • **Chinese Academy of Agricultural Sciences**, Beijing, China • **Jiangsu Academy of Agricultural Sciences**, Nanjing, China • **Mekelle University**, Ethiopia

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MORTEN LILLEMO received his PhD from the Norwegian University of Life Sciences in 2001. His work as a researcher focuses on projects on powdery mildew, *Fusarium* head blight and leaf blotch resistance in wheat and development of marker assays for breeding in collaboration with Graminor.

ÅSMUND BJØRNSTAD is a Professor in plant breeding. His main research areas are disease resistance in cereals; genetic diversity and germplasm enhancement of oats; genetic diversity and breeding of Ethiopian barleys.

then spreads to the new growth. Furthermore, shifts in the climate are causing new strains of *Fusarium* to move into the north of Europe, making this a central challenge for Norwegian cereal production. While most international breeding efforts in wheat are based on a single source of resistance, derived from the Chinese cultivar Sumai 3, the team in Norway focuses on broadening the genetic base of resistance and providing robust protection against *Fusarium* based on multiple resistance mechanisms. With mycotoxins in oats reaching EU limits in the last few years, the problem is reaching a tipping point. Oats receive far less international attention, so the researchers are studying the infection in depth before mapping resistance. Similarly to their work on powdery mildew, the ultimate aim is to develop molecular markers which will assist in the selection process.

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NATURAL RESISTANCE

The challenge faced worldwide has elicited different responses, with some groups calling for an increase in environmental solutions to disease including natural pest control and set aside borders. Åsmund Bjørnstad, who works alongside Lillemo, is pressing for the broadest possible approach: "There is no one path to sustainability, and specifically in our work we have found that partial resistance is better than race-specific specialisation". The problems which arise from breeding to a point of specialisation have been flagged to researchers since the 1960s, and the case of stem rust encapsulates the issues that high global genetic uniformity can cause.

The working group has a long-term collaboration with Mekelle University in Ethiopia, which has highlighted the strength and necessity of local approaches. Dr Fetien Abay found that farmers in Tigray were not adopting the recommended varieties of barley because they were unfit for their environments. She concluded that varieties had to be developed in the environment where they were to be grown and for the end uses needed by farmers. This implied involvement of farmers in the testing process at a much earlier stage. One new variety was released in 2011 and two in 2012, with good adaptation and also quality for the local bread matching the indigenous staple. Local seed businesses have been established by farmers and supported through the project. Two PhD theses are investigating the key traits behind this success. The next stage is due to involve the molecular mapping of important traits in barleys relevant for specific landscapes and ecologies.

ADVANCED APPROACHES

The progress made in the breeding of wheat, particularly in the partner organisation CIMMYT, has revolved around the use of better techniques and technologies to advance the genome. Shuttle breeding – which is able to improve the generational output as well as robustness of the cultivars – is one such major innovation. Based on the production of two generations per year, the programme also utilises two highly contrasted environments to test the potential of the cultivars as thoroughly as possible.

The breeding population is grown on the central Mexican highlands during the summer. They experience high rainfall and elevation, and large pressure from diseases including stripe rust, *Septoria* and *Fusarium* head blight, as well as abiotic stresses like lodging and waterlogging. The lines which are considered most successful are maintained for the next generation, and then planted in the desert environment at sea level in northwest Mexico. They are artificially irrigated, and selected for yield potential and resistance to stem rust as well as leaf rust. Consequently, the resulting cultivars are able to survive in a range of conditions, and have good resistance to most common diseases. Now, this breeding approach is enhanced further by introduction of genomic selection based on molecular markers. Such techniques are helping to transform cereal production, protecting it against threats to sustainable yield.

FURTHER DEVELOPMENT

Public debate about the resistance of crops has been focused on genetically modified organisms (GM). Bjørnstad is aware of this, and sees the advantages that this approach offers: "GM is a very valuable way of increasing available diversity, but it is currently constricted by counterproductive IPRs and overstated public concerns". One of the major advantages that GM has been able to demonstrate is a close protection of the strains developed. *Bacillus thuringiensis* (Bt) Maize and cotton are surrounded by mandatory refuge areas, where susceptible strains are grown. If such a scheme had been adopted with ordinary cereals, there would be a far smaller international problem than the one which is currently being faced. However, until the pressure on GM subsides, marker-assisted breeding is the best option available to produce widely useable resistant cultivars. It is the Norway group's hope that they will be at the forefront of this programme of innovation, providing the food of tomorrow.