Sustainable solutions to global problems

Stripe and stem rust are significant and destructive diseases in wheat, and currently pose the threat of a global epidemic. **Dr Lesley Boyd** of the John Innes Centre is leading a vital project to identify and develop new molecular markers for resistance to both diseases

Stripe and stem rust have been around for some time; what is the history of the current epidemic?

Nature has shown us that we must not become complacent with regard to crop disease. The new stem rust race Ug99 made a sudden appearance in Uganda in 1999, and wiped out 70 per cent of the developing world's wheat varieties. A new, more aggressive race of stripe rust appeared in the U.S. in 2000. This subsequent return of stripe rust epidemics across the U.S. reminds us of the words of the late Nobel Prize winner, Norman Borlaug that "rusts never sleep".

What is the focus of the work being conducted by your research group?

I have led a research programme at the John Innes Centre on wheat-rust interactions since 1995. The focus of the work has been the genetic, biological and molecular characterisation of sources of rust resistance that confer durable resistance. The control of rust in wheat has relied heavily on major, race-specific R-genes. Whilst easy to control in a traditional wheat-breeding programme, their value in a sustainable agricultural system is minimal, any newly introduced R-gene having an effective life on average of 2-4 years. Durable sources of rust resistance are known, but these often confer a partial, developmentally-regulated phenotype, being referred to as Adult Plant Resistance (APR). Our research group's programme uses DNA markers to genetically define APR for wheat rust, microscopy to determine the biology of different APR genes, and functional genomics to determine the mechanism by which individual APR genes confer resistance.

Can you tell us more specifically about the 'Sustainable Agriculture Research for International Development' SARID project?

This is a collaborative project with Professor Zakkie Pretorius, University of the Free State, South Africa, Dr Reneé Prins, CenGen Pty Ltd, and Susanne Dreisigacker of the International Wheat and Maize Development Center, Mexico. I have collaborated with Pretorius and Prins since 1996, when stripe rust first appeared as a field disease of wheat in South Africa. At that point in time no characterisation of stripe rust resistance in South African wheat varieties had ever been undertaken. The threat of the new stem rust Ug99 races originating in Uganda (and prevalent in Kenya and Ethiopia) spreading to the rest of Africa (including South Africa) necessitated the detection of new sources of effective and potentially durable resistance to stripe and stem rust.

What are the project's aims?

The aim of the SARID project has been to identify and develop molecular markers for new sources of APR for both stripe and stem rust that are effective in Africa (and Europe in the case of stripe rust). To do this we have worked to identify non-R-gene type APR genes, and APR genes that confer resistance through different and complementary mechanisms. By combining APR genes conferring complementary mechanisms of resistance we hope to produce new wheat varieties with improved resistance that has the potential to remain effective for longer.

International collaboration and capacity building are obviously important SARID objectives, for instance the training of African students in wheat-rust pathology and cereal marker technologies. Why do you think this is so integral?

Capacity building is a major focus of this project. We need DNA tools to identify and biologically define new sources of durable APR against the diseases devastating wheat so that we can accumulate them into new wheat varieties for use by small and large scale farmers alike. In doing this it is imperative that a new generation of researchers are trained who understand these aims. If a knowledge-technology transfer pipeline from the developed world into Africa is to be sustainable, then a new generation of individuals, with the required knowledge and skills, needs to be trained. The SARID programme is training African nationals in wheat-rust pathology and cereal marker technologies, which in the case of Gloudi Agenbag will result in the award of a PhD. The student is receiving training in field trial management, rust infection procedures and resistance assessment, statistical and genetic (genetic mapping and QTL analysis) analysis, and molecular marker technologies. These well trained individuals will be a major asset to the future development of modern agriculture in Africa.

STRIPE RUST INFECTION ON PLANTS IN THE FIELD

Finding answers across continents

A project led by **Dr Lesley Boyd** hopes to address the global crisis in wheat, caused by the hypervirulent strain of the stem rust race known as Ug99. Resistance to wheat rust is integral to ensuring the future of food production not only in regions in Africa, but worldwide

FARMERS HAVE BATTLED against crop diseases for as long as they have farmed, but we have seen in recent decades waves of disease epidemics that spread quickly and widely, bringing with them huge levels of destruction. In wheat production, stem and stripe rust in particular have become globally significant problems. In 1999 a new, hypervirulent race of the stem rust pathogen *Puccinia graminis* f. sp. *tritici (Pgt)* appeared in Uganda. Commonly known as Ug99, this race rapidly spread to Kenya and Ethiopia. Boyd describes the astonishing virulence of this strain and the way in which it has overcome genetic specificities: "Ug99 overcame the race-specific R-gene *Sr31* present in 80 per cent of the world's wheat varieties. Additional virulences have subsequently appeared in Ug99, overcoming the race-specific R-genes *Sr24* and *Sr36* (Ug99 lineage) and rendering further wheat varieties ineffective," she says. The ferocity of its spread is deeply concerning. The Ug99 lineage reached Yemen in 2005, Iran in 2008 and South Africa in 2009, and it is anticipated that it will eventually reach all wheat growing regions of the world, including Europe.

A NEW STRIPE RUST THREAT

As well as the hypervirulent Ug99 spreading from eastern Africa, another wheat rust has started to pose a global threat. In 2000 a new, more aggressive race of stripe rust that is able to grow at higher temperatures and is caused by the fungus *P. striiformis* f. sp. *tritici*, was detected in the U.S. This race was found in Europe in 2001 and western Australia in 2002, where previously the warmer climate was not conducive to stripe rust infection. Alarmingly, the rate at which this pathogen has spread represents the fastest ever reported.

WHEAT STEMS WITH RESISTANCE TO STEM RUST **(LEFT)** THROUGH TO INCREASING SUSCEPTIBLE STEM RUST **(RIGHT)**

Boyd and her team are employing genetic mapping techniques to identify DNA markers linked to the new sources of rust resistance

THE BIRTH OF SARID

In response to this global crisis the international wheat community established the Borlaug Global Rust Initiative (BGRI), named after the late American agronomist, humanitarian, and Nobel laureate, Dr Norman E Borlaug – regarded by some as the father of the 'Green Revolution'. Boyd is an active member of the initiative, along with Professor Zakkie Pretorius from the University of the Free State, South Africa. It is partly out of this association that Boyd, Pretorius and Dr Reneé Prins of CenGen Pty Ltd carved out the opportunity for a renewed collaboration under the auspices of the Sustainable Agriculture Research for International Development (SARID) initiative.

GLOBAL INITIATIVE WITH A LOCAL VIEW

The vision of SARID is certainly global in approach and breadth, but understands also the specificities of the localities with which it is engaged, as Boyd explains: "Breeding for sustainable rust resistance is both economically and environmentally the way forward. While chemical control strategies are available for the rusts, the yield returns for wheat in Africa are small, making fungicides economically unviable for large-scale farmers and completely out of reach for small scale farmers". In Kenya, 70 per cent of small-scale farmers grow wheat for sale, providing them not only with food but a livelihood. Rust is obviously a huge risk in such situations, and Boyd sees rust-resistant wheat varieties as the only way that small-scale farmers in Africa can achieve a return on a wheat crop when such diseases are endemic.

FRESH APPROACHES FOR LONG-TERM SOLUTIONS

In order to identify and develop possible rust-resistant wheat varieties, the SARID team are taking new approaches that they hope will bring long term solutions to this current global threat, as Boyd explains: "To stay one step ahead of the rust pathogen we must find – and genetically and biologically characterise – sources of rust resistance which will remain effective over long-term and large-scale usage, unlike the race-specific R-genes so commonly used to date." Boyd and her colleagues are employing genetic mapping techniques to identify DNA markers linked to the new sources of rust resistance, and QTL analyses to determine the impact of each resistance gene over environments and throughout the wheat plant's development. Fluorescent microscopy studies enable the identification of resistance genes with different modes of function, providing additive and potentially durable resistance when combined.

DR RENEÉ PRINS, DR LESLEY BOYD AND PROFESSOR ZAKKIE PRETORLUS

SUCCESSFUL DEVELOPMENTS

Coming now towards the end of the Biotechnology and Biological Sciences Research Council (BBSRC) funding for the SARID project, Boyd is incredibly pleased with how things have progressed: "The work has gone well and we have achieved more than originally proposed," she reflects. Amongst these achievements, new gene-based SNP markers have been developed for 2 stripe rust APR genes in the cv. Kariega. This represents the introduction of a new marker technology in wheat into South Africa, and provides a valuable resource that wheat breeding in South Africa can use to identify these stripe rust APR genes within their current wheat breeding programmes. Boyd's collaborators have also completed a genetic mapping and gene identification analysis of stripe rust resistance in the old French cv. Cappelle-Desprez, which has led to the identification of a number of APR genes effective against stripe rust in South Africa. After the screening of over 300 wheat genotypes, two lines carrying good stem rust resistance have been crossed to a stem rust-susceptible wheat line to develop populations that segregate for rust resistance. These populations will be used to genetically map and characterise the stem rust resistance in the said lines.

WORK TO BE DONE

Whilst the SARID project might be coming to an end, Boyd's work certainly is not. The team has certainly achieved a lot – not only technically, but also in the wider capacity-building aims within the project's African context. Considerable advances have been made in mapping plant-pathogen interactions in wheat rust, but work still remains to be done in translating these findings into applied knowledge and practices in farming, both in Africa and worldwide.

INTELLIGENCE

SARID

SUSTAINABLE AGRICULTURE RESEARCH FOR INTERNATIONAL DEVELOPMENT

OBJECTIVES

- To fine map and develop Single Nucleotide Polymorphic (SNP) markers for stripe rust APR genes previously identified in the South African cultivar Kariega
- To genetically define and characterise stripe rust resistance in the old French cultivar Cappelle-Desprez which still confers some resistance in the UK, and has proven to confer effective stripe rust resistance in South Africa
- To identify stem and stripe rust APR in a collection of over 300 wheat genotypes held in the Gene Bank at JIC

KEY COLLABORATORS

Dr Lesley Boyd, John Innes Centre, Norwich Research Park, Norwich, UK

Dr Reneé Prins; Professor Zakkie Pretorius, University of the Free State, Bloemfontein, South Africa

Susanne Dreisigacker, International Wheat and Maize Development Center, Mexico

FUNDING

Biotechnology and Biological Sciences Research Council (BBRSC)

CONTACT

Dr Lesley Boyd
Principal Investigator

John Innes Centre
Norwich Research Park
Colney
Norwich,
NR4 7UH
UK

T +44 01603 450614
F +44 01603 450000
E lesley.boyd@jic.ac.uk

LESLEY BOYD was awarded an MSc in Plant Breeding and Genetics from the University of Wales, Aberystwyth and a PhD in Molecular Biology from the University of Saskatchewan, Canada. She has been at the JIC from 1990, and was awarded the Jeanie Borlaug Laube Women in Triticum Mentor Award in 2011 in recognition of the support she has given to young female researchers in cereal sciences.

John Innes Centre