

O01

Historic overview of stem rust research

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Many of the discoveries and early developments in cereal rusts – heteroecism, *formae speciales*, physiologic races, early attempts at resistance breeding, NILs, - all took place with stem rust, a long feared disease. By 1950 significant resistant varieties like Ceres, Hope and Double Cross had been produced and resistance break-down experienced. Flor's work put host:parasite genetics on a scientific basis. The race 15B epidemic in North America and losses of resistance in Eureka (*Sr6*) and Gabo (*Sr11*) in Australia showed that resistance was neither permanent nor complete. A consequence of the 15B epidemic was the International Rust Nursery and its philosophy that all materials were freely donated for the benefit of all – no restrictions, no MTAs, etc. The availability of aneuploid lines permitted the location and cataloguing of resistance genes in conjunction with the establishment of NILs and other research materials. The Australian group with an interest in global movement of rust pathogens undertook an international gene virulence survey, the results of which were not published until 1983. From the 1960s the global incidence of stem rust declined, as did 'new' research. It is important to ask why this decline occurred – early maturity, resistance in key hotspot locations, contributions of the CIMMYT program, and the global use of *Sr31* probably all contributed. My view of the successful use of resistance is not only crop protection but also inoculum reduction. Largely, *Sr31* achieved this. However, now with UG99 and derivatives the situation is reversed – we have virulence and a huge area of *Sr31*-containing varieties that offer a selective advantage to those pathotypes along with the concerning additional virulences they possess. With the continuing spread of UG99, resistance sources are a priority for all. We need an appropriately balanced approach to seek resistance in common wheat, and its near and distant relatives utilizing our knowledge of homology and homoeology. Slow rusting opportunities should be sought, but may not be as readily available as with the other rusts and powdery mildew. It is probably too early to expect imminent success through transformation technologies.

O02

Ug99 Surveillance: Current status, evolution and migration of the Ug99 lineage

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Race TTKSK (syn. Ug99) of *Puccinia graminis* f. sp. *tritici*, recognized for possessing virulence to the stem rust resistance gene *Sr31*, was first identified in Uganda in 1998. Since then, TTKSK has been identified in Kenya in 2005 and Yemen in 2006. In addition to virulence to *Sr31*, race TTKSK was found to be virulent to many resistant genes that are commonly used in breeding, and is considered as a major threat to wheat production in areas where stem rust occurs and a large number of current cultivars are susceptible. Two new races, TTKST with virulence to *Sr24* and TTTSK with virulence to *Sr36*, were identified in Kenya in 2006 and 2007, respectively. The virulence profile of TTKST and TTTSK is similar to that of race TTKSK on most of the known stem rust resistance genes. Simple sequence repeat (SSR) markers were used to examine the genetic relationship between isolates of these races. All isolates of the "TTKS" group shared an identical SSR genotype. Virulence profile and SSR genotype suggest that the TTKS group is a distinct lineage and that races TTKST and TTTSK might be recent in origin. Because of their broad virulence to stem

rust resistance genes in the adapted germplasm, these races present a major challenge for developing resistance in breeding.

O03

Current resistance sources and breeding strategies to mitigate Ug99 threat

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Continued spread of race Ug99 (TTKSK) of *Puccinia graminis* from Eastern Africa to Yemen and Iran, and its evolution to overcome resistance genes *Sr24* and *Sr36* has further increased the genetic vulnerability of wheat crop in Africa, Middle East and Asia where about 90% of the area is sown to moderately susceptible or susceptible varieties. Seedling and field screening has identified wheat materials with both race-specific (R) and adult plant resistance (APR). Although several R-genes, mostly alien in origin, continue to confer adequate to moderate field resistance to Ug99 and its variants, the most promising R-genes for immediate use and present in improved spring wheat materials include: *Sr25*, *Sr26*, *SrTmp* and 3-4 possibly novel R-genes. Other effective R-genes either need to be transferred to high yielding wheats from unadapted genetic backgrounds or their alien chromosome segments need shortening. These R-genes must be deployed in combinations to enhance longevity. Identification of improved spring wheats such as 'Pavon 76', 'Kiritati' and 'Kingbird' and advanced breeding lines with adequate levels of APR based on the durable "Sr2-Complex" has increased the possibility of developing and deploying spring wheat materials with durable APR in areas where Ug99 poses the greatest threat. This deployment strategy is likely to ease selection pressure in Ug99 to evolve further; which may help enhancing the effectiveness of R-genes in other lesser risk areas. Shuttle breeding between Mexico and Kenya was initiated in 2007 to enhance the frequency of plants with APR in segregating populations. High yielding spring wheats with APR and R-genes are being tested in multi-site yield trials in various countries. The 1st year results indicated the possibility of identifying replacement varieties with superior performance.

O04

Molecular markers for wheat stem rust resistance: current research and future plans

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The “Durable Rust Resistance Project” was recently funded by the Bill and Melinda Gates Foundation to further the goals of the Borlaug Global Rust Initiative. The goal of this project is to systematically reduce the world's vulnerability to rust diseases of wheat through an international collaboration of unprecedented scale and scope. The primary goal of the Marker Development and Optimization component of the project is to identify robust markers for previously characterized and novel sources of stem rust resistance. A progress report will be presented on our four sub-objectives: 1) Optimization of markers for previously characterized stem rust resistance genes including genes contributing complex adult plant resistance, 2) haplotyping uncharacterized rust resistant genotypes to infer novelty and to plan new mapping experiments, 3) pyramiding novel sources of rust resistance, and 4) mapping novel sources of rust resistance. Our collaborating labs will work synergistically on these sub-objectives to develop the resources for deploying Ug99 stem rust resistance in superior varieties. The activities associated with this component will be coordinated and integrated with the rest of the project to prioritize the sources of resistance, the varieties to be improved, the breeding strategies, and deployment of improved varieties. This project will have direct linkages to objective 5 - Conventional and molecular breeding to produce rust resistant replacement wheat varieties and objective 7 - Reducing linkage drag associated with rust resistance genes.

O05

Detection of wheat stem rust race “Ug99” (TTKSK) in Iran

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In 2007, significant levels of stem rust were observed in experimental plots and occasionally in farmers' fields in the Lorestan and Hamadan Provinces of Iran. Race analysis of four stem rust samples collected from Borujerd, Hamedan, Poldokhtar and Kelardasht in 2007 and a race collected from Borujerd in 1997 was conducted using differentials carrying the stem rust (SR) resistance genes *Sr5*, *6*, *7b*, *8a*, *9a*, *9b*, *9d*, *9e*, *9g*, *10*, *11*, *17*, *21*, *24*, *30*, *31*, *36*, *38*, *Tmp*, and *McN*, plus several additional wheat genotypes. Two isolates from samples collected from Borujerd and Hamedan in 2007 produced high infection types (ITs 33⁺ - 4) on differential lines carrying SR genes *Sr5*, *6*, *7b*, *8a*, *9a*, *9b*, *9d*, *9e*, *9g*, *10*, *11*, *17*, *21*, *30*, *31*, *38*, and *McN*, and low ITs of ;C1⁻ to 2⁻, ;C to ;N1⁻, and 2⁺ on lines carrying *Sr24*, *Sr36* and *SrTmp*. Based on the high/low ITs on the 20 differentials in the modified North American SR differential set, the two isolates from Borujerd and Hamedan in 2007 were identified as race TTKSK (“Ug99”). The two isolates from samples collected from Poldokhtar and Kelardasht in 2007 and the isolate collected from Borujerd in 1997 were identified as races TRFSC, TTJQC, and RRHSC, respectively. Race TTKSK produced high ITs of 3⁺4 on several wheat genotypes carrying the 1BL.1RS translocation, further confirming the virulence of this race for *Sr31*. Results to date implicate the progressive migration of “Ug99” from Africa to Iran. Field evaluations of the responses of Iranian wheat germplasm to “Ug99” in Kenya in 2006 and 2007 showed that 98% of the entries were fully susceptible. Seedling evaluation of Iranian wheat cultivars and advanced lines to isolates of TTKSK from Iran confirmed full susceptibility. These results reinforce the serious threat of race TTKSK to wheat production in Iran.

O06

Chromosome engineering to enhance utility of alien-derived stem rust resistance

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In the past 50 years, a number of stem rust (*Sr*) resistance genes identified from wild relatives of wheat have been incorporated into wheat genomes through chromosome engineering. Some of these genes, including *Sr25*, *Sr26*, *Sr32*, *Sr37*, *Sr39*, *Sr40*, *Sr43*, *Sr44*, *SrR*, and three unnamed novel *Sr* genes from *Ae. speltoides* and *Haynaldia villosa*, are highly effective against Ug99. However, the alien chromosomal segments possess deleterious genes in addition to the *Sr* genes in most of the introgression lines. To enhance the utility of these *Sr* genes in wheat breeding, we have been eliminating the deleterious linkage drag associated with these *Sr* genes through homoeologous recombination. The *ph1b* mutant was used to induce recombination between the alien chromosomal segments and their homoeologs in wheat. Recombinants with reduced alien chromatin were identified and characterized through stem rust testing, molecular marker analysis, and fluorescent genomic *in situ* hybridization. To date, several resistant lines with modified or shortened alien chromosomal segments have been developed. Lines containing modified alien chromosome segments with genes *SrR*, *Sr26*, *Sr32* and *Sr39* are undergoing backcrossing and field evaluation for yield and quality characteristics in wheat breeding programs.

O07

Status of Ug99 resistance in current Australian wheat cultivars and breeding materials

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Annual pathogenicity surveys of *Puccinia graminis* f. sp. *tritici* (*Pgt*) conducted at the University of Sydney since 1919 have provided a sound basis for Australian stem rust resistance breeding efforts. Initially, single stem rust resistance (*Sr*) genes (*Sr6*, *Sr11*, *Sr17*, *Sr9b*, *Sr36*) were used, but from 1965 multiple *Sr* genes were used and yield losses were reduced significantly. The surveys revealed 3 incursions of 4 exotic *Pgt* isolates all of which had significant impacts on wheat production, highlighting the importance of current exotic threats such as *Pgt* race "Ug99" and its variants. Following the disastrous stem rust epidemic of 1973/74, a stronger national focus was placed on stem rust resistance by rust testing of germplasm, research on genetics of resistance including reducing linkage drag associated with alien *Sr* genes, and the development and application of markers linked to important *Sr* genes.

Sunday 24 August
Ug99 Workshop Abstracts

This strategy, coordinated by (currently) the Australian Cereal Rust Control Program and largely funded by (currently) the Grains Research and Development Corporation, has led to a robust understanding of deployed *Sr* genes and a resulting ability to predict response of Australian germplasm to “Ug99”. These predictions have been refined by field testing germplasm in Kenya with the assistance of the Kenyan Agricultural Research Institute from 2005-07. Because *Sr31* has not been used widely in Australia, the greatest impact of “Ug99” on germplasm to date has been due to virulence for *Sr30*, combined virulence for *Sr38* with other genes, and more recently, virulence for *Sr24* and *Sr36*. While virulences for *Sr30*, *Sr36* and *Sr38* have been detected in Australia, virulence for *Sr24* has not. The genes *Sr2*, *Sr12*, *Sr13*, *Sr22* and *Sr26*, effective against “Ug99” and derivatives, are important contributors to the resistance present in current germplasm.

O08

Operation and development of screening facilities in East Africa

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Development and Operation of Screening Facilities in East Africa Since 2005, the Ethiopian Institute of Agriculture Research (EIAR) and the Kenya Agriculture Research Institute (KARI) enabled field research that 1) established the full extent of the world’s vulnerability to wheat stem rust races emerging from East Africa (i.e, ‘Ug99’); 2) identified sources of resistance including minor gene adult plant resistance; and 3) catalyzed a multi-faceted global response leading to expanded awareness, accelerated research, and resource mobilization.

This presentation reviews the role of critical facilities in both Ethiopia and Kenya in the ongoing global response to the emergence of Ug99. Current information on the operations of these facilities can be found at www.globalrust.org.

O09

The Borlaug Global Rust Initiative and International Collaboration

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The global threat of stem rust Ug99 to wheat production calls for a coordinated global response. The Borlaug Global Rust Initiative (BGRI), chaired by Dr N.E. Borlaug, advocates for sustainable international resources and coordinated action to reduce the world’s vulnerability to stem, yellow, and leaf rusts of wheat. The BGRI Executive Committee includes permanent representation from the Food and Agriculture Organization of the United Nations (FAO), the International Center for Agricultural Research in the Dry Areas (ICARDA), and the International Maize and Wheat Improvement Center (known by the Spanish acronym, CIMMYT), Cornell University, and rotating representation from national agricultural research systems of both industrialized and developing countries. General membership is open to all interested parties (<http://www.globalrust.org>).

Cornell University recently announced a \$26.8 million grant from the Bill & Melinda Gates Foundation for a Durable Rust Resistance in Wheat (DRRW) project (<http://www.wheatrust.cornell.edu>), which includes many of the activities advocated by the BGRI. The Cornell project will provide Secretariat services for the BGRI and support

Sunday 24 August
Ug99 Workshop Abstracts

increased advocacy to mobilize additional global resources and cooperation to a level commensurate with the rust threat. The DRRW project will provide 3 years of support to 16 institutions, with a focus on developing improved wheat varieties that protect resource-poor farmers, primarily in Africa and Asia. Development of a broader-based second phase proposal due for submission in mid-2009 is a significant project milestone. Improved international collaboration will be key to obtaining future funding and effectively managing the threat of emerging rust diseases.