THE WINSTON CHURCHILL MEMORIAL TRUST OF AUSTRALIA

Report by Dr Michael Francki

2011 Churchill Fellow

The Ron Badman Family Churchill Fellowship to develop new resistant wheat varieties to ensure the security of Australian wheat production upon incursion of foreign pests and diseases- Syria, Mexico, USA

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Signed: Dr Michael Francki Date: 1 June 2012

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INTRODUCTION

Exotic diseases and pests pose a significant threat to the Australian wheat industry. The likely pests and diseases that pose a threat include wheat Stem Sawfly, Hessian fly and Karnal Bunt and are considered as medium to high risk incursions. If established in Australian wheat growing regions, they have the potential to cause significant crop loss damage. Australian organisations have neither the scientific expertise nor the necessary resistance to counteract incursion and maintain wheat yields. The study tour established and fostered key linkages with global scientists and organisations, identified and accessed knowledge, resources and expertise in breeding resistant varieties that will contribute towards ensuring the security of Australian wheat production upon incursion of foreign pests and diseases.

The study tour included visits to major international wheat improvement centres in Mexico and USA. Although it was originally proposed that the visit would include the International Centre for Agricultural Research for the Dry Areas (ICARDA) in Aleppo, increasing political unrest precluded travel to Syria as part of the Fellowship. However, it is envisaged that future opportunities to interact with colleagues in Syria on exotic pests will eventuate when the political situation improves.

I sincerely thank the Winston Churchill Memorial Trust of Australia and in particular, the Ron Badman Family, for sponsoring and supporting this study tour. The Trust has made a significant contribution towards initiating activities to develop new varieties that will protect one of Australia's largest agricultural commodities and maintain future wheat production if an incursion of exotic diseases and pests eventuate. It is organisations like the Churchill Trust that allow opportunities to act on foresight, to instigate innovation and to advance science and technology that will make Australia a competitive and more productive nation.

I thank colleagues at CIMMYT, University of Nebraska- Lincoln, Kansas State University and Purdue University for the valuable discussion and offers of resources and assistance that can be used for breeding wheat varieties. Special thanks to Drs Hans Braun, Christie Williams, Bernd Friebe and Professors Steve Baenziger and Bikram Gill for hosting my visit at their respective organisations. Finally, I extend my thanks to the Department of Agriculture and Food Western Australia for providing an opportunity to travel so that I can undertake this Fellowship.

"Continuous effort - not strength or intelligence - is the key to unlocking our potential."

-Sir Winston Churchill

EXECUTIVE SUMMARY

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The value of the Australian wheat industry for export is worth an average $3.48 billion annually for the period 2002/03-2009/10[1]. Significant industry investments in research, development and extension activities address existing challenges to improve wheat grain yields under different environmental constraints. However, a threat to grain production is the incursion and establishment of foreign diseases and pests in Australian environments. Therefore, awareness of biosecurity threats and measures to counteract any incursions is important if we are to protect future wheat productivity.

Measures are in place to reduce the risk of incursion of foreign pests and diseases. However, the introduction of wheat streak mosaic virus and new virulent isolates of stripe (yellow) rust are typical examples of diseases prevailing quarantine borders in the past ten years and new rust races such as Ug99 loom as high possible threats of incursion. Although, there have been significant efforts in breeding against these diseases since their introduction or before incursion, there is a need to be proactive in breeding for foreign pests and diseases that may threaten the Australian wheat industry.

Karnal Bunt, Hessian fly and Stem Sawfly are diseases and pests rated as medium to high risk of incursion and establishment in Australian production environments. Therefore, this Fellowship focused on visiting and developing collaborations with key international organisations with R&D and breeding expertise to these foreign pests and diseases. Highlights of the travel included:

- Expertise and genetic resources available at CIMMYT for screening and developing wheat with Karnal Bunt resistance.
- Strategies to develop resistant wheat at the University of Nebraska-Lincoln and counteract emerging threat of wheat Stem Sawfly to grain production in Nebraska.
- Progress in deploying genes from wide sources for trait improvement in wheat breeding at Kansas State University and contribution towards the international wheat genome sequencing effort.
- Knowledge of population genetics and evaluation of resistance for effective breeding against Hessian fly by scientists at USDA-ARS and Purdue University.

Pre-emptive breeding against foreign diseases and pests would involve internationally coordinated effort to:

- Foster collaboration and deploy resistance to Karnal Bunt, Stem sawfly and Hessian fly into Australian wheat germplasm
- Access expertise to evaluate breeding material for suitable resistance to foreign diseases and pests

Pre-emptive breeding has commenced with Dr Michael Francki travelling to University of Nebraska-Lincoln in June 2012 to deploy resistance against wheat Stem sawfly in Australian germplasm and identify the role of lignin genes in pest and disease resistance. This opportunity was a result of the interactions initially supported by the Churchill Trust.

[1] *Australian Commodity Statistics 2010, Australian Bureau of Agricultural and Resource Economics and Sciences*

PROGRAMME

15 - 20 April 2012
International Maize and Wheat Improvement Centre- CIMMYT
El Batan, Mexico

Scientists visited: Dr Hans-Joachim Braun, Dr Pawan Singh, Dr Ravi Singh, Dr Xinyao He, Dr Monica Mezzalama, Dr Peter Wenzl, Dr Carolina Saint-Pierre, Dr Roberto Javier Peňa, Dr Susanne Dreisigacker

22April - 4 May 2012
University of Nebraska
Department of Agronomy and Horticulture
Lincoln, Nebraska, USA

Scientists visited: Professor Steve Baenziger, Dr Gautum Saratch (USDA-ARS), Dr Bob Graybosch (USDA-ARS), Dr Gary Hein, Dr Scott Saettler (USDA-ARS), Professor Tom Clemente

7 – 11 May 2012
Kansas State University
Wheat Genetic and Genomics Resource Center (WGGRC)
Manhattan, Kansas, USA

Scientists visited: Professor Bikram Gill, Dr Bernd Friebe, Dr Guihua Bai (USDA-ARS), Dr Ming Chen, Dr Nidhi Rawat, Dr Jesse Poland (USDA-ARS), Dr Sunish Sehgal, Dr Ed Akhunov, Dr Tatiana Danilova, Dr Allan Fritz, Dr Harold Trick, Dr Bill Bockus, Dr Forrest Chumley

14 - 18 May 2012
Purdue University
Department of Agronomy
West Lafayette, Indiana, USA

Scientists visited: Dr Christie Williams (USDA-ARS), Professor Herb Ohm, Professor Joe Anderson, Dr Sue Cambron (USDA-ARS), Dr Rich Shukle (USDA-ARS), Ms Melissa McDonald, Dr Brandi Schemerhorn (USDA-ARS), Ms Jill Nemacheck (USDA-ARS)

International Maize and Wheat Improvement Centre- CIMMYT (Centro Internacional De Mejoramiento De Maiz Y Trigo)

El Batan, Mexico

CIMMYT

Background

CIMMYT is a research centre affiliated with the Consultative Group on International Agricultural Research (CGIAR). The organisation focuses on research in disease resistance, abiotic stress tolerance (e.g. drought and heat tolerance) and grain quality for developing improved wheat and maize varieties. Implementing training for crop production in developing nations is also a significant activity. It is a major global centre for public good outcomes in crop improvement that aims to improve food production and nutrition for the world's poor.

CIMMYT was established in 1963 where the wheat breeding program led by Dr Norman Borlaug took technology associated with major yield improvements from Mexico to the sub-continent, beginning the "Green Revolution". Dr Borlaug was awarded the Nobel Prize in 1970 for accelerating agricultural productivity and helping the hungry in developing nations. Commemoration to his achievements in humanity (Figure 1) is a sign of his lifetime achievement. As a direct result of Dr Borlaug's pioneering efforts, wheat production from mid 1960's to 2001 rose from 12 million to 75 million tons in India and 4.5 million to 22 million tons in Pakistan. CIMMYT continues Dr Borlaug's legacy ensuring that underprivileged nations have access to the world's best varieties to improve wheat yields.

Figure 1. Dr Michael Francki with the commemoration of Nobel Laureate, Dr Norman Borlaug, for beginning the world's "Green Revolution" in the 1960's. Photo taken at CIMMYT Headquarters, El Batan, Mexico (April 19, 2012)

Visit with Key Researchers

The visit to CIMMYT, El Batan, was hosted by Dr Hans-Joachim Braun, leader of the Global Wheat Program (GWP). Dr Braun provided details of new initiatives at CIMMYT that aim to deliver new improved wheat varieties (with associated technologies) that are adaptable to grain production environments. New initiatives include:

- Seeds of Discovery Program:- funded by the Mexican government to maintain wheat and maize yields by applying gene sequencing technologies for analysis of global seed banks and associating gene variation (alleles) to traits for increasing yields (drought and heat tolerance, diseases including Karnal Bunt, grain quality and morphological traits for adaptation).

- Wheat yield consortium:- a multi-organisational approach that aims to develop a collaboration of 50 partners from the commercial and public sector to significantly increase wheat yields in the next 20 years.

The visit enabled discussions with key CIMMYT researchers on Karnal Bunt resistance in wheat including wheat breeder Dr Ravi Singh, and plant pathologists Dr Pawal Singh and Dr Monica Mezzalama. The major outcomes on current Karnal Bunt resistance include:

- The seed health laboratories at CIMMYT are proactive in monitoring the presence of Karnal Bunt in Mexico. Considerable expertise is required for pathogen detection including the identification of *Tilletia indica* spores. There are currently DNA diagnostic tests being developed and validated for spore detection at CIMMYT to enable high throughput detection survey for the pathogen. Such tests would have significant benefits for quarantine and biosecurity detection surveys in Australia.

- Field screening based on natural infection of the disease can be unreliable. The last major disease epidemic of Karnal Bunt in Mexico occurred in 2005 and the severity of the disease is cyclical. It is thought that the lack of severe disease epidemics in recent years may be due to the high level of Karnal Bunt resistance in released varieties but a change in pathogen isolate may overcome plant resistance and cause the next epidemic in Mexico. Drier climates may also be a causal factor for the lack of disease progression. Nevertheless, it is difficult to predict the next disease epidemic in Mexico or other global production environments.

- Screening for Karnal Bunt resistance is done in cd Obregon, a northern location in Mexico. Artificial inoculation is used in the field for evaluating resistance and susceptibility because of the unreliability of natural infection and disease pressure across years. The Indian line WL7-11 is highly susceptible and used as a check variety in all screening. The most resistant material is Munat1, an elite high yielding line released in India.

- The proportion of pathology screening for Karnal Bunt resistance is approximately 10% with remaining diseases (e.g Fusarium) accounting for the majority of screening. Screening for resistance to other pathogens takes precedence due to higher disease severity annually.

- A proportion (2-3%) of the wheat breeding program is dedicated to developing Karnal Bunt resistance in wheat and the remaining is focused on other disease resistance (rusts, fusarium head blight, spot blotches, nematodes, root diseases and *Septoria tritici*), abiotic stress tolerance (drought and heat) and grain quality characteristics that meet flour parameters suitable for various end-products.

- Significant resistance to Karnal Bunt resides in a large proportion of bread wheat varieties and immunity in synthetic bread wheat at CIMMYT. There are no reports of single major genes for resistance. Resistance is generally a polygenic trait. The identification of DNA markers linked to genes for resistance is done in collaboration with Indian colleagues and these will be used to track and select resistance in breeding. Accessing suitable wheat lines and DNA markers would position Australia in deploying and selecting genes for resistance to Karnal Bunt in Australia.

Outcomes

CIMMYT is one of the global leaders in public wheat breeding with a high impact program to improve wheat varieties for a range of diseases and abiotic stresses. The discussions with CIMMYT colleagues have forged relationships that will enable access to tools and develop strategies for improving Australian wheat varieties for resistance against Karnal Bunt and foliar diseases.

- In collaboration with CIMMYT scientists, Australian wheat varieties could be evaluated for resistance to Karnal Bunt using artificial inoculation in trials at cd. Obregon. The information could be used to strategically deploy resistance in Australian breeding material.

- In the event that suitable levels of resistance is not predominant in Australian wheat lines, the linkages with CIMMYT will enable access to suitably resistant germplasm that can be used for crossing with Australian elite wheat lines. DNA markers developed in conjunction with CIMMYT and Indian colleagues will provide molecular tools to track resistance genes in breeding.

- There was a significant interest from CIMMYT scientists for the global coordination of disease resistant screening nurseries (other than rust screening where such activities exist) with nodes in strategic regions of the world's wheat production areas. Australia could be a major contributor and coordinator in such a consortium.

University of Nebraska, Lincoln (UNL)
Lincoln, Nebraska, USA

Background

Wheat is one of the major crops grown in Nebraska alongside corn and soybeans and is in the top 10 wheat producing states in the US. Approximately 1.5-2.0 million acres of wheat is produced in Nebraska, mostly in the Western half of the state with a value of up to $500 million annually. The University of Nebraska has a distinguished wheat breeding program, led by Professor Steve Baenziger (Figure 2) that develops hard red winter wheat varieties adaptable to production environments in the Western region. Apart from traits required for new wheat varieties such as regional adaptation, improved disease resistance and quality traits for milling and baking performance, the breeding program is now commencing activities in breeding for Stem Sawfly resistance. Breeding efforts are supported by entomologists, pathologists, cereal chemists and molecular marker specialists at UNL.

Figure 2. Professor Steve Baenziger, wheat breeder and host for the visit at UNL, inspecting a field trial. Photo taken at Mead, NE (24 April 2012).

The wheat breeding program at UNL has recently developed a public-private partnership with Bayer CropScience (BCS) to improve wheat breeding and varieties for the US market. The agreement has allowed access of UNL germplasm to BCS in exchange for new technologies and investments in research and education programs. UNL are leading the way in fostering university-industry partnerships and the Bayer's North American breeding program located in Nebraska will guide a more profitable and competitive global wheat industry.

Visit with Key Researchers

There are increasing efforts to monitor Stem Sawfly infestation in Western Nebraska and key researchers are involved in on-going surveillance of the pest. Furthermore, breeding resistant wheat varieties has commenced as sawfly is becoming more prevalent across Nebraska. The approaches taken by UNL to combat it's effects on wheat production in Nebraska provides a model system to control the insect if it is introduced and established in Australian grain production environments.

Nebraska has significant pathogens in their production systems that have been recent outbreaks in Australia. Wheat Streak Mosaic Virus (WSMV) is prominent in the wheat production areas of Nebraska and was a major biosecurity issue in Australia from 2002. The virus was prevalent in wheat breeding nurseries at CSIRO in Canberra, leading to significant measures to control the spread of the pathogen. In addition to investigating pests that threaten the Australian wheat industry, the visit to UNL provided an opportunity to gain knowledge on the sources of resistance to WSMV that will be beneficial for developing resistance in Australian varieties.

The visit to Nebraska was hosted by Professor Steve Baenziger, wheat breeder at UNL and discussions with a number of colleagues on sawfly incidence in Nebraska and breeding for resistance through the interaction of lignin genes for solid stems in wheat.

Stem Sawfly

- The entry of Stem Sawfly into the US is largely unknown but thought to have originated from Europe and introduced through straw importation. Since its introduction, sawfly has been naturally selected and adapted in wheat and now has been difficult to eradicate. Infestation is suited to drier climates and sandy soils in Western Nebraska, similar to wheat production environments of Western Australia, and the insect is moving east adapting to different environments across Nebraska.

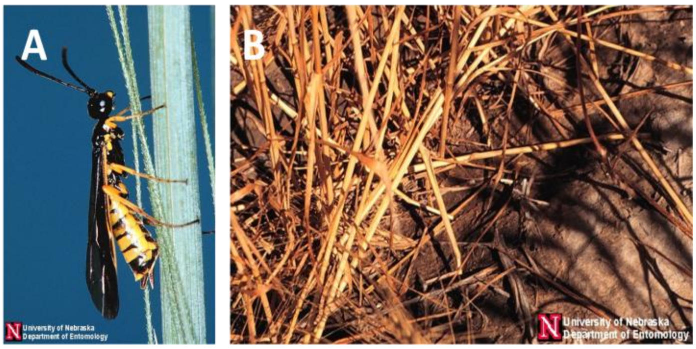

Figure 3. Wheat Stem Sawfly and infested wheat crop. An adult female insect on wheat stem (A) and a lodged wheat crop after infestation (B). Photos by Dr Gary Hein, Department of Entomology, University of Nebraska-Lincoln .

- Infestation of sawfly was first detected in 1995, however, the low incidence was not regarded as a major threat to wheat yields in Western Nebraska. Drier climates and drought affected environments in subsequent years coupled with continuing no-till farming practices resulted in increased infestation of the pest.

- Sawfly is prominent in spring wheat varieties (Figure 3A) but population adaptation is coinciding with winter wheat growth. The insect generally infest the outer boundaries of wheat crops and rarely progresses into the central portions of fields. Sawfly infests and lay eggs in late May to early June in Nebraska when wheat commences flowering, damaging stems and causing the crop to lodge (Figure 3B). Predictive modelling to pre-empt emergence and infestation patterns of Sawfly across Nebraska are being considered which could be useful tools to advise growers the risk of Sawfly damage to crops.

- Insecticides are an option to control Sawfly, but require multiple applications between May and June for effective on-farm management. Farmers are unlikely to use this option because of higher costs and uncertainty that the insect can be effectively managed by chemical applications. Minimising tillage could also reduce the incidence of infestation but benefits of no-till farming practices significantly outweigh the problem of controlling the insect pest. An alternative is to breed Sawfly resistance in new wheat varieties.

- Effective resistance to Sawfly requires varieties with thicker stems, preventing the insect burrowing and laying eggs eventually causing lodging and grain loss. However, solid stem thickness in earlier cultivars has been associated with significant yield penalty but, more recently, this negative correlation has not been observed in recent cultivars with solid stems. It is clear that further investigation is warranted to study the relationship between solid stems and grain yield.

- Stem thickness is controlled by cell wall lignificition. Researchers at USDA-ARS located at UNL have significant expertise in lignin accumulation and characterising enzymes and genes for the biochemical pathway. Much of studies in lignification from other crop and plant species can be translated to wheat. The role of the lignin biosynthetic pathway is a research area of interest to control solid stems and collaborations with researchers at UNL would provide an opportunity to develop innovative solutions for Stem Sawfly resistance for wheat breeding relevant for Nebraska and Australia.

Wheat Streak Mosaic Virus

WSMV is a recent example of a pathogen that breached quarantine borders and established as a viral disease in Australian grain production areas. WSMV is a seed borne virus transmitted by mites causing severe yellowing and reduced grain yields. In Nebraska, WSMV was first detected in the 1920's and significant advances have been made in breeding for resistance.

- The hard red winter wheat variety 'Mace" (PI 651043) has suitable levels of resistance to WSMV derived from the wild relative, *Thinoyprum intermedium* (wheatgrass), where the *Wsm-1* gene is translocated onto wheat chromosome 4D. The level of resistance in 'Mace" and breeding lines is determined by the extent of yellowing compared to the susceptible variety 'Tomahawk' shown in Figure 4A. DNA markers for the wheatgrass derived *Wsm-1* gene has been developed and used for selection in wheat breeding. .

- Alternative source of resistance to WSMV has been identified in Triticale (Figure 4B). The source of resistance is derived from rye. The genes in 'Mace' and Triticale could be used for developing resistance to WSMV in Australian wheat cultivars.

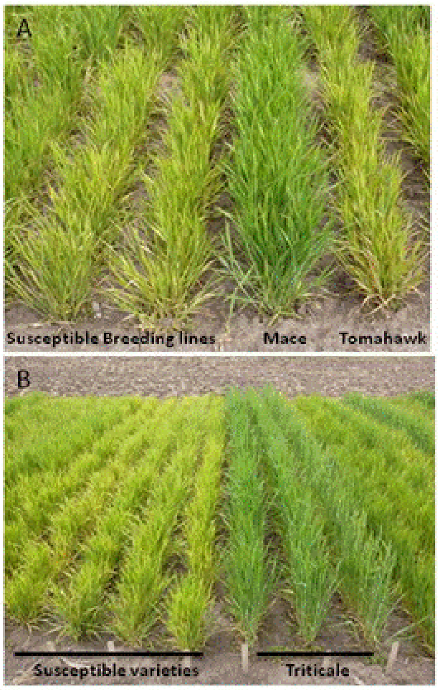

Figure 4. Evaluation of WSMV in wheat breeding program at UNL. The variation in yellowing for resistant and susceptible varieties 'Mace' and 'Tomahawk', respectively are shown amongst breeding lines (A). A different source of resistance to WSMV from rye is expressed in Triticale

Outcomes

UNL has a distinguished and internationally renowned wheat breeding program with a focus on delivering hard red winter to wheat growers in Nebraska and other states. The availability of supporting disciplines has significantly progressed breeding new improved varieties

- Wheat stem Sawfly is becoming an increasing problem across wheat growing regions in Nebraska. Entomologists at UNL are surveying production areas to document prevalence and abundance of the insect. It is recommended that interactions are maintained with colleagues at UNL to access information on migratory patterns that may be relevant if Sawfly is introduced and established in Australia.

- Wheat Stem Sawfly resistance is becoming increasingly important in breeding and UNL have commenced new cultivar development with solid stems in germplasm relevant to Nebraska. It is, therefore, recommended that Australian researchers collaborate with UNL and adopt a pre-emptive breeding approach for Sawfly resistance. UNL are using parental lines in crossing program to introduce solid stem and Sawfly resistance in Australian wheat germplasm. Progeny of these crosses will be made available to Australian researchers but further studies are recommended to determine the effect of solid stems on grain yield in Australian environments

- The role of lignin provides the basis to further investigate the biochemical control of solid stems and Sawfly resistance in wheat. Dr Michael Francki will be returning to UNL for a short sabbatical in June 2012 to commence further studies on the role of lignin genes for solid stems, Sawfly resistance and yield effects in wheat. The Churchill Fellowship was instrumental in developing the necessary linkages to commence these studies and sabbatical leave is supported by funding from the Organisation of Economic and Cooperative Development (OECD).

- WSMV is becoming an increasingly problem since its first detection in Australia in 2003. UNL are in advanced stages of breeding and continually identifying new sources of WSMV resistance. It is, therefore, recommended that linkages with UNL are maintained for exchange of germplasm and knowledge of WSMV to breed wheat varieties with improved resistance.

Wheat Genetics and Genomics Resource Center (WGGRC)
Kansas State University (KSU)
Manhattan, Kansas, USA

K-STATE
Kansas State University

Background

Kansas produces more wheat than any other state, representing approximately 20% of the US crop with a production value of around $1 billion dollars annually. Hard red winter wheat is the most prevalent class whereby two thirds of the crop is exported and the remaining used in domestic flour milling for bread making. Wheat research in Kansas began in the 1860's at Kansas State University where breeding commenced at the turn of the 20th century and the release of the first variety "Kanred" in 1917. New modern varieties are still being bred at KSU, specifically adapted to the state's production environments with consistent high quality grain and resistance to pests and diseases. The release of new commercial varieties involves a large interdisciplinary team of wheat scientists across different agencies, including USDA and Kansas Crop Improvement Association.

KSU has a globally recognised wheat research program, the Wheat Genetics and Genomics Resource Center (WGGRC). The Center has a long history in collecting, conserving and utilizing germplasm for wheat improvement, creating, exchanging and promoting technologies for wheat genetics and biotechnology and providing academic training for students and researchers in wheat improvement. The collection of wheat germplasm (cultivated and wild accessions) and the transfer of genes to improve, biotic and abiotic stress tolerance, grain quality and yield improvements using modern biotechnologies and strategies has enabled WGGRC to be a major contributor in developing improved wheat varieties for the US and globally.

Visit with Key Researchers

The WGGRC at KSU has a vast program of scientists and graduate students with interdisciplinary expertise including germplasm curation, wheat genomics, molecular cytogenetics, molecular marker technologies, plant pathology and biotechnology that support wheat improvement. The Center is led by Professor Bikram Gill and the visit was co-hosted by Dr Bernd Friebe. The visit enabled interactions with a number of key researchers across disciplines and included tours of laboratory and greenhouse facilities and field trials.

- The WGGRC at KSU has an extensive seed bank collection with 3,000 accessions of wheat, wild relatives and cytogenetic stocks that serve an important purpose for identifying new genetic variation for trait improvement that can be introgressed into cultivated wheat. The genebank collection (Figure 5) is maintained and curated by Dr John Raupp and has distributed accessions to countries involved in wheat genetics research. The genebank collection is an important source for genetic variation and plays a significant role in supporting global genomics research and wheat improvement.

- WGGRC is leading a major global consortium in sequencing the wheat genome (in excess of 16 gigabases or 5 times the size of the human genome) and is making significant progress in fingerprinting, assembling and aligning 500,000 bacterial artificial chromosome (BAC) clones for chromosomes 1D, 3A, 4D and 6D in preparation for sequencing. The information on BAC contig assemblies and the sequenced chromosomes will be made publicly available to the global wheat community when completed. The genome sequencing project will make a valuable contribution to understanding and using genes and their variants that control traits for wheat improvement.

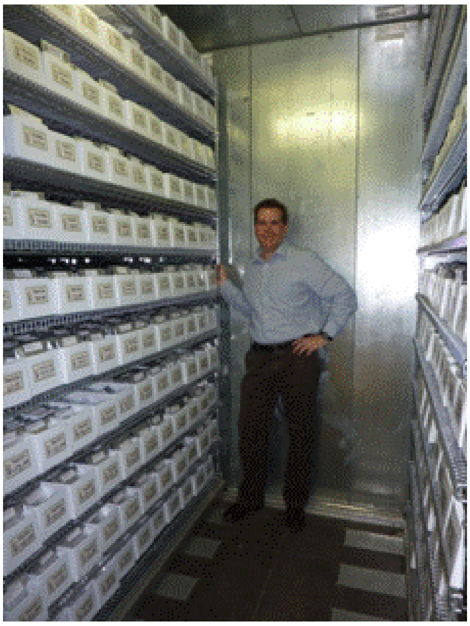

Figure 5. Dr Michael Francki in the genebank collection for 3,000 accessions of wheat, wild relatives and cytogenetic stocks. Photo taken in the WGGRC at KSU (9 May 2012)

- Researchers at the WGGRC at KSU have taken a leading role and made significant advances in developing new molecular marker technologies based on single nucleotide polymorphism (SNP) of DNA. Work is currently focused on developing high resolution genetic maps to identify the chromosomal position of 7000 SNP markers in the wheat genome which allows a detailed analysis of loci and identification of markers linked to genes controlling traits important for wheat improvement.

  The SNP based map will also be instrumental in aligning BAC clones to genetic maps for the wheat genome sequencing project and identifying genes controlling trait expression.

- Entomologists at KSU have expertise in Hessian fly, including evaluation of breeding germplasm and global seed collections for resistance. Warm temperatures with high moisture are ideal conditions for Hessian fly development and the pest is significant in wheat growing regions of Texas, Washington and Kansas. Biotypes of Hessian fly are characterised according to their reaction against 33 resistance genes (H1-H33) and new resistance is continually sought amongst global germplasm collections for breeding. Profiling of susceptible and resistant lines has identified in excess of 2000 metabolites indicating a cascade of complex biological pathways involved in plant-pest interactions providing information with possibilities to develop alternative genetic solutions for new resistance.

- KSU has a strong reputation in introgressing, manipulating and characterising novel genes from wild relatives into cultivated wheat through conventional crossing. Examples include genes for Hessian fly resistance (H21 and H25) from rye which are effective against several biotypes of the insect. These genes are being deployed for breeding new wheat varieties against the insect pest. The molecular cytogenetics group at the WGGRC has also identified genes from wheatgrass for resistance to WSMV currently being deployed in global wheat breeding.

Figure 6. Mr Duane Wilson from WGGRC at KSU inspecting trial plots of wheat and wild relative accessions from the WGGRC genebank collection. Photo taken at Manhattan, KS , (10 May 2012).

- Dr Michael Francki presented a seminar to scientists at the WGGRC titled "Delivering pre-breeding outcomes in the innovation pipeline: flour b* colour as an example". The seminar provided an opportunity to share with US colleagues some Australian experiences in developing pre-breeding outcomes in the public domain and fostering partnerships with the commercial sector to transfer technologies for wheat improvement in breeding companies. Discussions on models for commercialisation of research products in public-private partnership arrangements continued with Dr Forrest Chumley, CEO of Heartland Plant Innovation Center, Inc (HPI). HPI is a start-up company partnering with KSU, WGGRC and private sector organisations to commercialise research products for wheat improvement in Kansas and the US.

- The visit to KSU provided an opportunity to view laboratory facilities for wheat genetic and genomics. Field trials of accessions from the WGGRC genebank collection demonstrated unique characteristics and novel traits that could be used for improvement in commercial wheat varieties (Figure 6)

Outcomes

WGGRC at KSU has significant strengths and a strong history in genetics and genomics for wheat improvement. The research outcomes for public benefit will contribute to future global wheat production through:

- New trait variation from wild relatives that can be exploited for developing new wheat varieties. The germplasm resources will make a significant contribution to improving adaptability of wheat varieties to challenging environments under climate change and improve future global wheat production.

- Access and utilization of wheat genome sequence data for identifying individual genes and their function in controlling trait expression. The information will be valuable in tracking genes and the desired variants necessary for wheat improvement. The eventual release of the wheat genome sequence will provide the tools to revolutionize selection strategies for more efficient breeding of new improved wheat varieties.

Purdue University

West Lafayette, Indiana, USA

Background

Purdue University has a strong history of wheat improvement with the testing of new varieties beginning in 1880 and commenced breeding wheat varieties at the turn of the 20th century. The Purdue breeding program has continued to develop new soft red winter wheat (SRWW) with a focus on winter hardiness, disease resistance, tolerance to abiotic stresses and baking quality. SRWW varieties developed at Purdue University dominated the eastern US from the 1950's to 1980's and the program continues to release commercial varieties for the same production regions. Flour from SRWW varieties is used for the manufacture of biscuits, cookies and cakes.

The Purdue University breeding program has a history of releasing new wheat varieties with resistance to a number of fungal pathogens. The program has long and successful history in breeding resistance to Hessian fly. Much of the research and development of new varieties with Hessian fly resistance has been done in collaboration with colleagues from the United States Department of Agriculture- Agricultural Research Service (USDA-ARS).

Visit with Key Researchers

The visit to Purdue University was originally organised by the Head of Wheat Breeding, Distinguished Professor Herb Ohm. Unfortunately, Prof. Ohm had a major health issue prior to my arrival and was unable to host the visit. However, Dr Christie Williams (Research Scientist, USDA-ARS) organised an itinerary to meet with key researchers and discuss progress and strategies to deploy Hessian fly resistance in wheat breeding. The visit included interactions with Purdue University graduate students in the wheat breeding program and USDA-ARS researchers including Dr Brandi Schemerhorn (insect population genetics), Drs Sue Cambro and Rich Shukle (phenotypic evaluation of resistance and insect biotypes), Ms Jill Nemacheck and Dr Christie Williams (gene discovery and biological factors controlling insect-host interactions).

- Hessian fly is a global pest wherever wheat is grown, except for Australia and Japan. The insect pest is present in New Zealand and poses a significant threat of incursion into Australia. Since Hessian fly travels a limited distance in prevailing winds, so the most likely mechanism of incursion is through human mediated transport. Hessian fly can have alternative hosts including tall fescues and perennial ryegrasses which can influence the spread of virulence if Hessian fly is introduced and established in Australia.

- Larvae infest plants at the seedling stage causing stunting and eventual plant death. Larvae can also affect mature crops at the nodes and weaken developing stems.

- Hessian fly populations are genetically divergent with no indications of inbreeding. If less than 1% of individuals within a population are virulent, then populations can overcome host resistance. If 50% of individuals within a population have virulence, it is

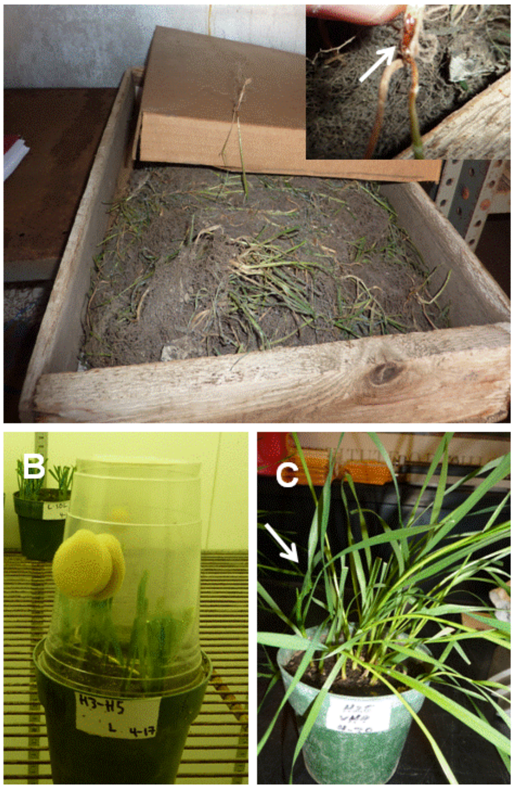

Figure 7. Hessian Fly screening at Purdue University and USDA-ARS. (A) Rearing flies with infected wheat in flats. Arrow in inset shows pupae infecting wheat. (B) Screening chambers in controlled environments. (C) Resistant and susceptible lines segregating in breeding material. Stunted plant with leaf curling highlighted by white arrow shows a susceptible plant. Photos taken at Purdue University, Department of Entomology (15 May 2012).

anticipated that host resistance would breakdown within 12 months. Therefore, surveying virulence and genetic population structure within and between populations is necessary to assess the durability of host resistance suitable for wheat breeding.

- Management practices and application of pesticides to control Hessian fly populations can have sporadic effects in limiting crop damage caused by Hessian fly. Therefore, genetic resistance in the host is the most cost-effective means of protecting crops. However, deployment of single genes for resistance in commercial cultivars has shown limited success, with resistance being effective for up to 5 years before becoming ineffective. This is largely due to the high genetic diversity of the pest and its ability to developed virulence that can overcome resistance in a short period of time. Therefore, stacking multiple resistance genes into single lines would provide longevity of genetic resistance in new commercial varieties.

- USDA-ARS scientists at Purdue University have expertise in rearing flies on artificial diets (Figure 7A) and phenotypic evaluation of new breeding lines evaluated at the seedling stage in controlled environment conditions (Figure 7B). Analysis of healthy or stunted and shrivelled plants following insect infestation of seedlings provides ratings of lines resistant and susceptible to Hessian fly, respectively (Figure 7C).

- There are 33 resistant genes for Hessian fly and the most effective against current biotypes include H24, H25 and H26. There is a possibility that these genes combined in single wheat cultivars could provide broad range resistance and, therefore, would be obvious choices for deployment in Australian breeding germplasm.

- There is on-going R&D in identifying molecular DNA markers linked to genes for resistance to Hessian fly. In the case of stacking genes, it is important that molecular markers are used in selecting resistant and susceptible breeding material as Hessian fly screening alone would not necessarily identify the presence of more than one gene. Molecular markers for tracking Hessian fly resistance genes is available in the public domain and accessible for selecting segregating breeding material prior to pest evaluation.

- USDA-ARS scientists are actively involved in identifying the molecular process involved in resistance and susceptibility at the site of Hessian fly feeding. Microarray analysis of infected or uninfected resistant and susceptible lines shows that genes controlling several biochemical pathways are differentially expressed. The most notable genes are those encoding lectin proteins that are upregulated in resistant lines and thought to bind to sugar moieties causing disruption of the insect midgut. The knowledge of lectin genes involved in host-pest interaction could provide alternative strategies to manipulate genes for effective resistance to Hessian fly.

- The visit to Purdue University was accompanied by a field trip to Agronomy farm in West Lafayette to inspect SRWW wheat trials. A Disease screening nursery for evaluating resistance to Fusarium Head Blight (a fungal pathogen predominant in most wheat growing regions of the world except Australia) were inspected along with trials for evaluation of tilling inhibition genes and performance of advanced breeding lines suitable for release as commercial varieties to growers (Figure 8).

Figure 8. (A) Purdue University graduate students in plant breeding and genetics at the Department of Agronomy, Ms Melissa McDonald and Ms Shaylyn Wiarda, with Dr Michael Francki inspecting a Fusarium Head Blight disease screening nursery. (B) Yield trials of advanced breeding lines of SRWW from the Purdue wheat breeding program. Photo taken at Agronomy farm, West Lafayette, USA (16 May 2012).

Outcomes

The SRWW breeding program at Purdue University and USDA-ARS scientists interact in basic research and translate outcomes to develop Hessian fly resistance in wheat. Progressing collaborations with colleagues at Purdue University and USDA-ARS will enable Australian scientists to:

- Assist in surveys and analysis of population genetic structure if there is an incursion and establishment of Hessian fly in Australia. This would predict the spread of virulence in production environments and develop the most effective strategies for breeding resistance in Australia.

- Access germplasm with H24, H25 and H26 resistance genes for deploying into Australian wheat germplasm.

- Access relevant molecular markers for tracking Hessian fly resistance in wheat breeding. This would be most effective strategy for deploying resistance genes in new breeding material as currently there are no means for evaluating Hessian fly infestation in Australia.

- Assess newly developed Australian breeding material against wide spectrum of Hessian fly biotypes using collaborative screening strategies with Purdue University and USDA-ARS as partner organisations.

CONCLUSIONS AND RECOMMENDATIONS

The Australian wheat industry is vulnerable to incursion of exotic pests and diseases and pre-emptive measures are need to limit the effects if and when they establish in Australian production environments.

The Ron Badman Churchill Fellowship has been valuable in identifying relevant global expertise for three major biosecurity threats to the Australian wheat industry: Karnal Bunt, Stem sawfly and Hessian fly. The Churchill Fellowship has formed the basis to build and further develop global relationships with key scientists and organisations that will enable Australian wheat scientists to access:

- Capabilities and resources for surveillance of Karnal Bunt, Stem sawfly and Hessian fly to monitor threats, predict virulence patterns and potential damaging effects to the wheat industry if exotic diseases and pests breach Australian quarantine barriers.

- Germplasm, molecular marker and genomic technologies to deploy effective resistance to Karnal Bunt, Stem sawfly and Hessian fly in Australian wheat breeding lines. These resources are critical if Australian scientists are to make gains in pre-emptive breeding for resistance to these exotic pests and diseases.

- Capabilities and resources to evaluate effective resistance in Australian breeding material. The relationships developed between international organisations will be paramount in accessing expertise and capabilities to develop and effectively evaluate resistance in Australian wheat germplasm.

Developing relationships with key scientists and organisations is the first step that will place Australian scientists in a strong position to transfer knowledge and resources to improve wheat against exotic diseases and pests. To realise the practical benefits of such interactions, the following recommendations will assist in developing pre-emptive breeding for exotic diseases and pests:

- Develop global disease screening nurseries in collaborative partnerships with CIMMYT (and associated organisations in CIMMYT's mandate) to evaluate wheat germplasm for suitable resistance to a wide range of pests and diseases. A coordinated global strategy will ensure that Australia and CIMMYT's mandated countries exchange germplasm and information to improve resistance against local and foreign pests and diseases.

- Develop collaborative partnerships with UNL to transfer genes for stem sawfly resistance into Australian wheat germplasm. Research activities have commenced with UNL receiving Australian wheat varieties for crossing with US germplasm. Dr Michael Francki will be travelling to UNL in June 2012 to commence work with key researchers to evaluate progeny for solid stems and identify suitable sawfly resistance in Australian derived germplasm. Moreover, he will work with UNL scientists to identify the relationship between lignin genes and solid stem to develop candidate gene markers for stem sawfly resistance. The work is supported by a three month fellowship from the Organisation for Economic Co-operation and Development (OECD).

- Foster relationships with Purdue University and USDA-ARS to access germplasm and screening capabilities for Hessian Fly resistance and seek funding opportunities to commence strategies to deploy new genes in Australian germplasm. Key international researchers have offered to share germplasm, marker technologies and screening capabilities for Australian organisations to develop new Australian germplasm with suitable resistance.

- Engage industry and other stakeholders to invest in pre-emptive breeding strategies for wheat. Coordinated global disease and pest screening nurseries would encourage stakeholders to invest in a strategy that would simultaneously benefit improvements for resistance of existing, emerging and foreign diseases in wheat.