Version 1.0

Action Plan to Minimize Impact of Ug99 Stem Rust in the United States

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Executive summary

An integrated research, communication and outreach approach is needed to combat the threat of the new virulent Ug99 stem rust mutant for U.S. wheat and barley production. This integrated approach will guide the evaluation of wheat and barley germplasm for vulnerability, develop diagnostic technologies and disease management systems, and accelerate the development of new varieties with genetic protection. This approach will also outline an effective monitoring, reporting and communication network. Strategic deployment and use of these resources and technologies will help to minimize the impact of new and emerging races of stem rust caused by *Puccinia graminis f. sp. tritici Pgt-Ug99* or its derivatives. The structure of this Action Plan provides both a program and a scientific focus to ensure that the wheat and barley research, extension and outreach communities attains planned results in an effective and timely manner to minimize the impacts of these new virulent races of stem rust. The strategic goals of this Action Plan span the programmatic range of establishing a national communications network, demonstrating effective disease management systems, understanding host-pathogen interactions, developing enhanced germplasm, improving

knowledge of pathogen biology, and developing decisions models to guide the implementation of control measures.

An ad hoc USDA workgroup, representing the broad interests of industry and the wheat research community, was charged with developing and writing this Action Plan which further defines actions to be taken for immediate implementation to solve the problem, describes what will be produced, assigns accountability for the work to be accomplished, and provides a mechanism for assessment of research progress.

Introduction

Stem rust of wheat caused by *Puccinia graminis f. sp. tritici* is historically one of the most important diseases of crops worldwide. In the early 1900s, stem rust epidemics in spring wheat were frequent in the northern Great Plains of the United States and Prairie Provinces of Canada. Major epidemics resulted in dramatic losses in the United States occurred in the mid 1930s and again in the 1950s. Stem rust also caused significant yield losses in the hard red winter wheat in the southern and central plains as well as in soft red and soft white wheat in the Midwest and southern United States. The disease has been brought under effective control through the use of host resistance in combination with the elimination of the alternate host, common barberry, from the wheat producing areas of the U.S. A number of stem rust resistance genes, designated as Sr genes in wheat and its close relatives, were described and cataloged, and monogenic lines carrying the individual Sr genes are available in several wheat backgrounds. Most of the Sr genes have been characterized for their reactions to specific races of *P. graminis f. sp. tritici* including reactions at the seedling stage. The gene Sr24, originally transferred to bread wheat has been a valuable source of resistance against a broad spectrum of stem rust races worldwide. The gene Sr31 has been widely deployed in Europe, China, and the United States. Wheat cultivars carrying the Sr31 gene typically also have broad agronomic adaptability, as well as carry resistance to stem rust, leaf rust, stripe rust and powdery mildew. The gene Sr38 was originally found in the wheat relative *Triticum ventricosum,* and was bred into cultivated wheat through a germplasm line developed in France. The decrease in incidence of stem rust to almost non-significant levels by the mid 1990s throughout most of the world was coincident with a decline in research and breeding emphasis to such a level that in many countries breeding was done in the absence of the disease.

In 1999 however, high severities of stem rust were observed in Kenya on previously stem rust resistant wheat lines. This new race, labeled “Pgt-Ug99”, was subsequently shown to attack the stem rust resistance genes Sr31 and Sr38, which were previously effective resistance genes. Since then, similar virulences have been confirmed in Kenya, Ethiopia, Yemen, and Iran, indicating that this new race, or its derivatives, has spread within North Africa and into the Middle East. Should the spatial and temporal spread of these new races follow the same pathway as races of stripe rust caused by *Puccinia striiformis,* that had arisen in eastern Africa in the 1980s and eventually moved to North America, then the new Pgt races are expected move to the Middle East, West Africa, and South Asia within a period of approximately 10

years if not sooner. There also exists the possibility that these races may be introduced into new areas, including North America via intentional or unintentional human-mediated activities.

Background

Soon after these Pgt races were observed in Africa, the International Maize and Wheat Improvement Center (CIMMYT) shared concerns with the U.S. Wheat Crop Germplasm Committee and asked for assistance from U.S. scientists. The Agricultural Research Service (ARS) of the United States Department of Agriculture (USDA) provided scientific expertise in characterizing the new stem rust mutant and in assessing seedling vulnerability of widely grown wheat cultivars worldwide. Initial seedling assessment at the ARS Cereal Disease Laboratory indicated that widely grown CIMMYT wheat varieties were vulnerable to the new stem rust mutant. As the global threat of Ug99 became realized, CIMMYT and the International Center for Agricultural Research in the Dry Areas (ICARDA), along with Nobel-Prize winner Norman Borlaug joined with international scientists to launch the Global Rust Initiative to combat Ug99. ARS mobilized pathology and genetics expertise. Research was redirected to improve pathogen detection and genetic characterization to better monitor genetic changes in Ug99 and to understand its genetic lineage to U.S. races of stem rust. ARS developed a specific cooperative agreement with CIMMYT for field germplasm screening at the Kenyan Agriculture Research Institute, Njoro, Kenya. Scientists at the Cereal Disease Laboratory (CDL), the National Small Grains Germplasm Repository, Aberdeen, Idaho, Plant Science Unit, Raleigh, North Carolina, and other ARS research units at Lincoln, NE, Manhattan, KS, and Pullman, WA, collected and submitted wheat and barley germplasm for resistance screening. These included the USDA regional variety nurseries of wheat and barley lines that are candidates for release, collections of current widely used and historical U.S. cultivars, germplasm lines and differential lines with known genes for stem rust resistance, as well as other germplasm that may have resistance to Ug99. The germplasm screening was conducted in partnership with U.S. public and private sector breeders and coordinated with the National Wheat Improvement Committee and the National Barley Improvement Committees. The ARS also supported efforts to monitor the spread of Ug99. As part of the Global Rust Initiative, collaborators have made collections of wheat stem rust at key locations in Africa, the Middle East, and south Asia which were analyzed at the CDL. These tests confirmed the presence of Ug99 in Kenya, Ethiopia, and Yemen. The presence of Ug99 in Iran was confirmed by February 2008.

U.S. wheat and barley scientists have contributed to international and national wheat meetings focused on the Ug99 threat. These have included the First International Workshop of the Global Rust Initiative, Alexandria, Egypt, Oct. 2006, an FAO Expert Workshop on Breeding and Disease Management Strategies for the Prevention and Control of the New Virulent Race of the Wheat Balck Stem Rust, Rome, Italy, Dec. 2006; Ug99 workshop of the International Wheat Meeting in Argentina sponsored by ARS; Ug99 Rust Workshop at the International Wheat Genetic Symposium, Bisbane, Australia, Aug. 2008; as well as the U.S. National Wheat and Barley Improvement Committee Meetings, Wheat and Barley Crop Germplasm Committee

Meetings, WERA-97 and NCERA-184 annual meetings; and a special symposium session at the 2007 annual meeting of the American Phytopathological Society in San Diego, CA.

The United States Department of Agriculture (USDA) recognizes that research strategies for protection from this destructive pathogen are a top priority for U.S. wheat and barley growers represented by the National Wheat and Barley Improvement Committees, U.S. Wheat Associates, the North American Grain Export Association and the American Malting Barley Association. In response to the recent movement of Ug99 into the Middle East and the threat of eventual introduction into North America, three USDA agencies organized a National Workshop on New Virulences in Wheat and Barley Stem Rust, facilitated by the American Phytopathological Society (APS) in March 2008 at Baltimore Maryland. The cooperating USDA agencies include the Cooperative State Research, Education and Extension Service (CSREES), the Animal and Plant Health Inspection Service (APHIS), and the Agricultural Research Service (ARS). The purpose and goals of the workshop were to obtain input from organizations concerned with preparations for the possible introduction of new races of wheat stem rust into North America. Over 45 scientists and stakeholders with knowledge of critical fields of wheat germplasm resources, wheat genetics, wheat and barley genomics, fungal pathogen biology, disease management, and predictive modeling participated in the workshop, reviewed the current status of protective measures for stem rust in the United States, and reached agreement to develop this strategic action plan for stem rust research and response.

The outcome of the workshop is this National Action Plan for the Coordination and Integration of Wheat Stem Rust Response, which outlines research goals and objectives, outreach and communication, guidance for safe movement of germplasm, surveillance/monitoring and detection, forecasting and disease management, and genetic resources protection strategies. This Action Plan also describes roles and responsibilities of Federal, state, university, and industry cooperators from a national and international perspective and outlines significant milestones to measure progress toward mitigation of this potentially devastating disease.

USDA Action Plan Workgroup

Kay Simmons and Rick Bennett, USDA-ARS National Programs, Matt Royer, USDA-APHIS; Marty Draper, USDA-CSREES, Kent Smith, USDA-ARS-AO, Office of Pest Management Policy.

Action Plan for Ug99 Stem Rust

Component 1: Cereal Stem Rust Assessment and Pathology

Objective 1: Assess vulnerability of cereal varieties and germplasm to current and newly identified races of stem rust in the U.S. and world wide.

Approach: Evaluate wheat and barley seedlings for resistance and susceptibility to African stem rust races under authorized, contained conditions at the ARS Cereal Disease Laboratory (CDL).

Cooperators: Research is being done by Yue Jin (ARS-St. Paul) and Brian Steffenson (U. Minnesota), under the regulatory authorization of USDA-APHIS, Plant Protection and Quarantine.

Approach: Conduct field screening of U.S. wheat and barley advanced breeding lines, currently grown varieties and U.S. Small Grains Repository accessions for resistance to Ug99 and other stem rust races in Eastern Africa. ARS will support a specific collaborative agreement with CIMMYT and the Kenyan Agricultural Research Institute (KARI) for germplasm screening (2008-2010). Funding is provided by the National Plant Disease Recovery System. ARS partners with the National Wheat and Barley Improvement Committees to invite U.S. cereal breeders, both public and private, to submit advanced breeding lines and varieties for screening. David Marshall, ARS, Raleigh, will serve as the overall coordinator for the field screening (2008-20100 and his responsibilities will include prioritizing lines for screening and data compiling. ARS scientists (B. Goates, H. Bockelman, M. Bonman) at the Small Grains Genetic Resources Management Unit, Aberdeen, Idaho, will conduct seed acquisition and oversee shipment of currently grown U.S. cultivars, advanced breeding lines, and USDA repository accessions for the African germplasm screening project. ARS scientists (Y. Jin, St. Paul; D. Marshall, Raleigh, and M. Bonman, S. Jackson, and B. Goates along with international rust experts will or have evaluated stem rust resistance of the U.S. lines at KARI, Kenya. Other cooperators include the coordinators of the ARS regional wheat and barley variety trials and U.S. wheat and barley breeders.

Accomplishment: Over 5000 U.S. lines have been evaluated in Kenya. Results of the 2005-2007 screening show that Ug99 has overcome still more major resistance genes in U.S. wheat germplasm. However, breeding lines with resistance to Ug99 have now been identified for every market class of wheat and barley. Another 3000 advanced breeding lines from over 25 U.S. wheat and barley breeding programs were sent to Kenya in April for the 2008 germplasm screening trial under natural Ug99 infection conditions. Results of all germplasm evaluations are posted on the ARS Cereal Disease Laboratory and GrainGenes wheat genome database web sites to ensure that all cereal breeders have access to the data.

Objective 2: Identify sources of genetic resistance to stem rust, and characterize race specificity of resistance.

Approach: Cereal Disease Laboratory (CDL) and collaborators will evaluate wheat and barley germplasm from breeding programs throughout the United States for resistance to stem rust using prevalent races, and races that have high virulence to rust resistance genes common in released cultivars and breeding lines. They will postulate the presence of rust resistance genes in seedling tests using specific races of stem rust. Lines will be evaluated for adult plant resistance in field plots using a mixture of races.

Objective 3: Identify and characterize avirulence effector genes in the pathogen.

Approach: Genetic mapping and mining genomic sequence data of selected isolates will be used to identify candidate effector genes. Transient expression assays using wheat differential lines will be used to confirm function.

Accomplishment: Release of the draft genome sequence and annotation of the *P. graminis* genome: The recent release of the genetic sequence of the wheat stem rust fungus at: http://www.broad.mit.edu/annotation/genome/puccinia graminis/Home.html, will provide a critical resource for identifying and characterization of avirulence genes. The Pgt genome sequencing project is a collaborative endeavor between the CDL with the Broad Institute, MIT, and Harvard, North Carolina State University, and Genome Sciences Center. NSF funds the Pgt genome project through the NSF/USDA Microbial Genome Sequencing Program. A whole shotgun sequence of approximately 12X coverage was generated by paired-end sequencing of the two plasmid libraries and a fosmid library. The current draft sequence assembly has an estimated genome size of 89Mb and coverage of 7X.

Accomplishment: The Cereal Disease Laboratory has genetically mapped eight avirulence genes using molecular markers. This map will be used for map based cloning of these genes.

Component 2: Detection and Identification

Objective 1: Develop molecular markers for genotyping the pathogen.

Approach: Develop molecular markers for the stem rust pathogen. The Cereal Disease Laboratory will develop DNA markers for characterizing populations of the wheat stem rust fungus.

Accomplishment: Molecular and genomic tools are currently being applied at the Cereal Disease Laboratory to understand the evolution of *P. graminis f.sp.tritici (Pgt)*. Changes in race structure of Pgt are commonly observed as this rust adapts by overcoming resistance genes.

Simple sequence repeat (SSR) marker analysis indicated that Ug99 (race TTKS with virulence to Sr31, TTKSK) represents a distinct genetic lineage from race structures found in North America, Central Europe, Middle East, and North Africa. Preliminary analysis of two new races found in Kenya (TTKST in 2006 with virulence to Sr24 and Sr31, and TTTSK in 2007 with virulence to Sr36 and Sr31) indicated that these new races represent adaptations within Ug99 lineage rather than an occurance of a new genetic lineage.

Objective 2: Develop diagnostic assay for use in NPDN labs and Land Grant Universities.

Approach: The CDL will develop real time PCR based assays for the rapid identification of Ug99 and other exotic races of the wheat stem rust pathogen. Genomic and EST data from Ug99 lineage and a select set of isolates (North American and international) will be mined for potential targets. PCR primers and probes will be tested with a broad range of isolates representing a diverse range of races and genotypes. The CDL will train diagnosticians from the NPDN on the real time PCR assay when it is available.

Accomplishment: The current SSR method can be used with either spores or infected leaf tissue for genotyping the wheat stem rust pathogen, but the technology cannot be easily deployed to the NPDN labs at land grant universities for diagnostic purposes. Instead, the CDL is working to develop a RT-PCR assay that will better meet the diagnostic needs of the NPDN. CDL and collaborators have generated a preliminary data set of genomic and EST sequence data from Ug99 which is being compared with the sequenced isolate.

Objective 3: Develop methods for predicting and detecting long distance spread of stem rust spores in the atmosphere.

Approach: The CDL and collaborators will develop a network of rain collectors for detection of stem rust spore deposition.

Accomplishment: The CDL is cooperating with the National Atmospheric Deposition Program (NADP) to detect aerial transport of urediniospores from southern states and the Caribbean basin through 100 rain collection sites. The project examines rain samples for the presence of spores as a reliable method to detect the presence of inoculum. Preliminary results suggest that this knowledge is useful, when coupled with disease models, to predict the time of initial occurrence of stem rust in the Central U.S. Wheat stem rust spores can be detected in rain samples three weeks before the disease appears in a given area. Current assay is specific for stem rust and needs to be improved to detect specific genetic lineages and/or races.

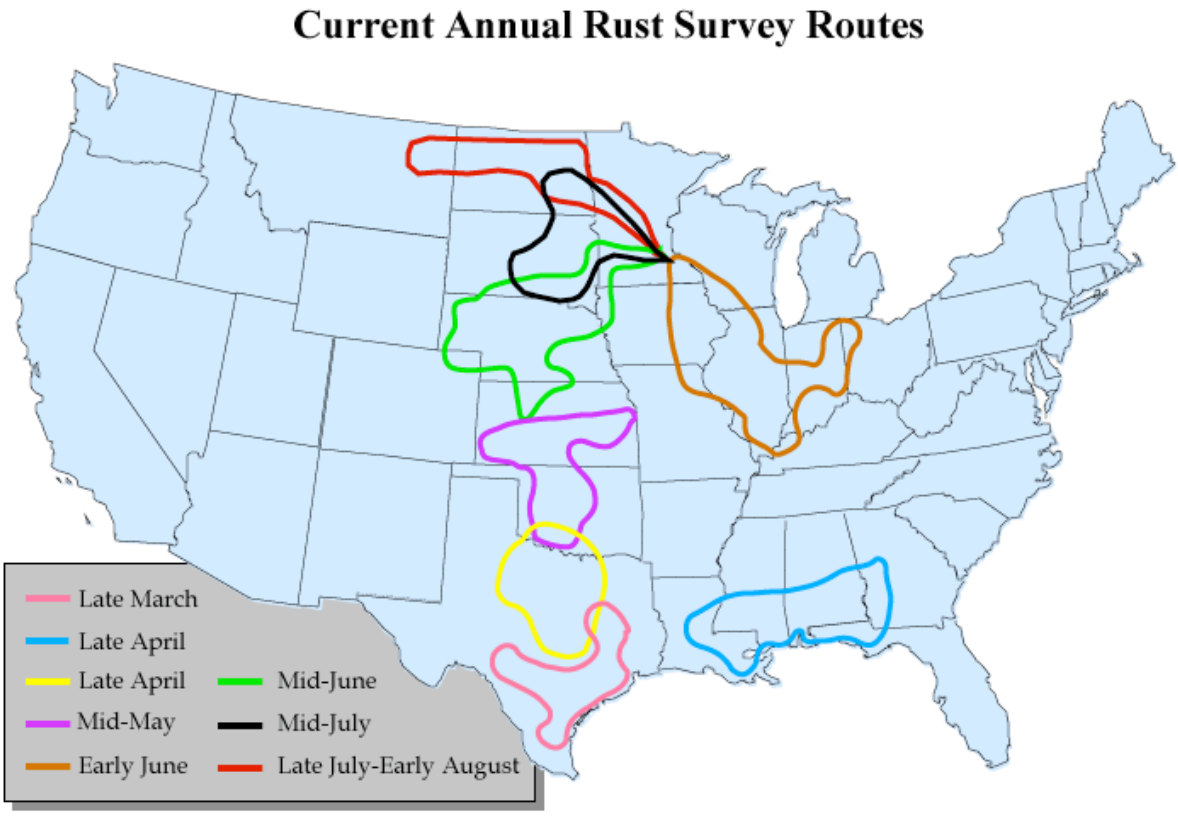
Accomplishment: The CDL and collaborators at Penn State University have been comparing spore deposition data (Asian Soybean Rust pathogen) with the IAMS model of spore deposition based on meteorological and known source data. This system is being adapted for the wheat stem rust system.

Component 3: Monitoring and Reporting

Objective 1: Monitor development, evolution, and spread of wheat stem rust races.

Approach: Establish and monitor "trap" and nursery plots with wheat varieties that have differential resistance and vulnerability to African stem rust races, particularly Ug99. Monitor for possible appearance of Ug99 in the U.S. through observation of the specific combination of infection responses on the differential wheat varieties that indicates Ug99 infection.
Plots will be monitored by Cereal Disease Laboratory (CDL) scientists through seven or more rust survey trips throughout the U.S. and with observation from regional cereal breeders and disease experts. Differential plots are established along known wheat rust pathways throughout the Great Plains, the Mississippi river valley, the mid-Atlantic and in known overwintering areas. During past epidemics, the rust pathway of the Great Plains normally occurred in several movements depending on weather and environmental conditions. Rusts will typically overwinter in Texas but can survive as far north as Kansas if conditions are favorable. Spores are often moved northward on storm fronts and deposited by rain.

CDL rust surveys trips begin in Texas during late March-April. Fields are surveyed for rust pustules at approximately every 20 mile intervals along the survey routes. Field notes are recorded for incidence and severity of disease, location, variety planted if known, and overall condition and growth stage of the crop. A few collections are made for race identification at the CDL. Occasionally, rusts from barley, oats, and wild grasses are included in the survey. Survey routes are determined based on past experiences and for counties with large grain acreages. Survey routes remain flexible to maximize chances of successfully locating targeted disease and to ensure that critical regions are covered. Historically, the optimal time to survey for rust is during mid to late stages of grain filling (berry to soft dough). Most CDL surveys occur between late March and early August.



Known barberry bushes in MN and WI are being monitored closely every year by CDL staff. Aecial infections are collected and formae speciales (f.sp.) of stem rusts present on the barberries are identified. In the past 5 years, all collections from barberry were identified to be f.sp. secalis and none of the collections belongs to *P. graminis f. sp. tritici* (wheat stem rust) or *P. graminis f. sp. avenae* (oat stem rust). A lack of wheat stem rust is likely due to a lack of telial inoculum because of the absence of a wheat crop nearby and/or the high level of resistance in current cultivars to U.S. races. These barberry bushes will continue to be closely monitored.

Comment: Since aecial infections by wheat stem rust have not been detected on barberry, this alternate host has not been routinely surveyed, but recombination in barberry of a Ug99 race could be important.

Accomplishment: A Ug99 Stem Rust Disease Surveillance Workshop was held on July 30-31, 2008, following the American Phytopathological Society Centennial Meeting. Session topics included: "Developing Plans for Enhanced Monitoring", "Addressing Potential Gaps in Disease Management". The Workshop was sponsored by CSREES, and was held at the Cereal Disease Laboratory, St. Paul, MN. A summary of the workshop can be found at: http://www.ars.usda.gov/Main/docs.htm?docid=14649. Participants of the workshop identified needs, strengths and weaknesses of the current surveillance system. They commended USDA-ARS for ongoing commitment to the survey, and recognized the large network of Land-grant university cooperators who have added considerable strength to the effort.

Accomplishment: USDA, Land-grant, extension and other rust experts coordinated U.S. plot locations and monitoring plans for the 2008 wheat season at a meeting in Fargo, ND, March 2008.

Approach: Rust races are identified through collection and characterization. Each year, more than a thousand collections of rusted leaves and stems of wheat, oat, barley and rye are processed at the CDL. Since rusts are obligate pathogens, isolates of rust for testing must be maintained as infections in living plants. For long-term storage, spores collected from infected plants are sealed in glass vials and placed in liquid nitrogen. For race identification, spores from single infections are collected and used to inoculate sets of differential lines with different specific genes for resistance. Race identity is determined by avirulence/virulence on these specific genes. By testing samples collected in survey trips and of samples sent to the CDL from all over the United States, CDL scientists are able to determine the frequency and distribution of rust races in the United States each year. A preliminary determination of a race identity will take about two weeks to complete the testing cycle for a sample containing a pure race. Mixed races often occur from field samples and it will take more time (one or two additional cycles) to develop into pure isolates so that individual races in the mixture can be determined. Collections that are suspected to be Ug99 or similar races will be initially evaluated with molecular markers to determine if it is in the Ug99 or other exotic lineage. If the isolate belongs to a North American genetic lineage, then it will be subjected to our normal race identification protocol. If the isolate is of the Ug99 or other exotic genetic lineage, then race identification will be done in containment, either in the BL-2+ facility at the CDL or in the adjacent BL-3 facility at the University of Minnesota.

Objective 2: Provide information on cereal rusts and Ug99 to the wheat and barley community including researchers, growers, and industry.

Approach/Accomplishment: An USDA Website can be found at: http://www.ars.usda.gov/ug99/ containing the latest information on the movement of Ug99 from Africa to the Middle East, links to related USDA programs, the CDL, university links and information on Ug99 workshops. This is a USDA website with a dedicated webmaster which

will provide regular updates and the latest information on variety reactions including information on genotypes with adult-plant resistance (APR) (Sr2).

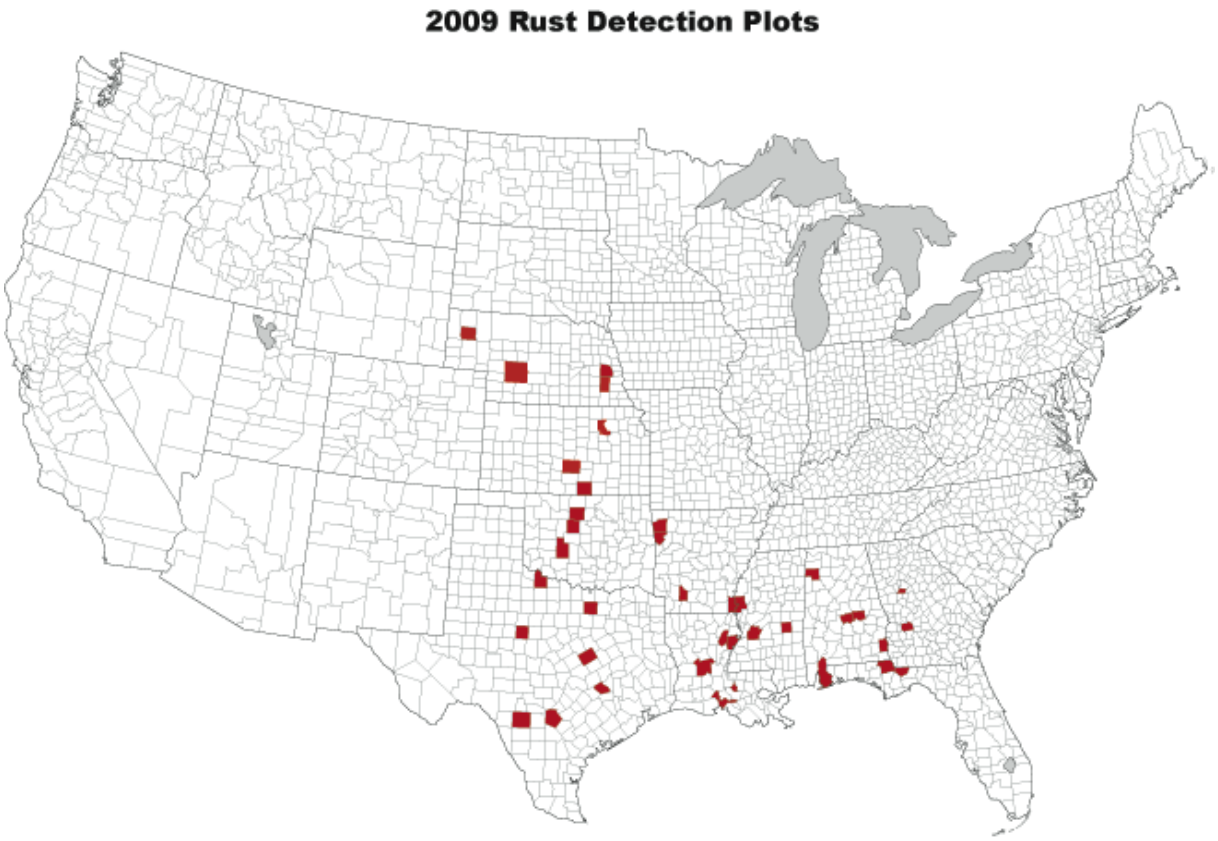
Approach: An effective communication network has been developed in the U.S. among wheat rust pathologists and wheat breeders based on personal contacts and a longstanding history of cooperation. In addition to such formal interactions, the USDA has laboratories located at Land-grant universities, with national mandates for wheat rust diseases. Among other responsibilities, these laboratories provide a national service for identification of rust races and maintain substantial knowledge regarding rust resistance genes. At present, wheat stem rust is handled by the USDA Cereal Disease Laboratory on the University of Minnesota campus. Several vehicles (described below) currently exist to facilitate communications among wheat rust workers in the U.S. Much of the information is related to the annual surveys by CDL through representative areas (need a map showing these areas) of the Great Plains and Midwestern states from Missouri to Ohio to monitor rust development in the small grain crops and to collect rust samples.

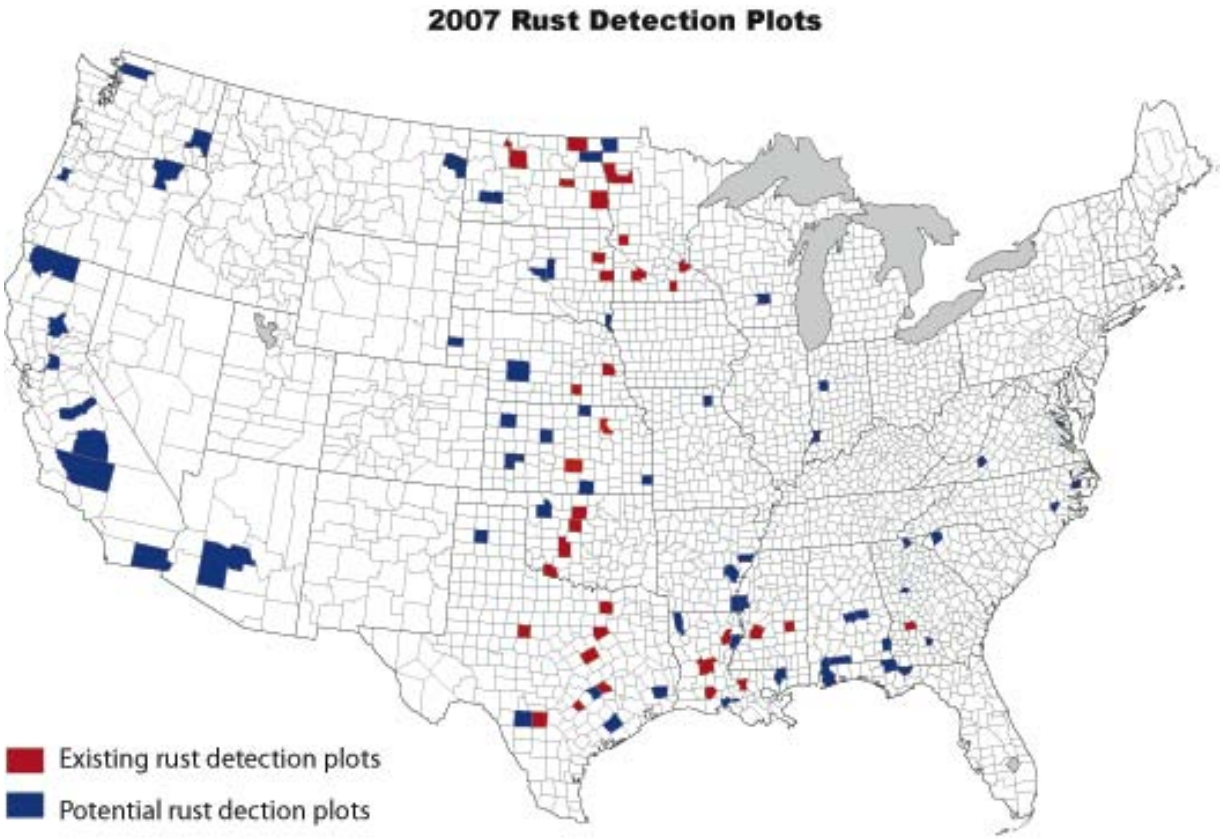
Approach/Accomplishment: Results of the surveys and race identification are distributed in the Cereal Rust Bulletins (bi-weekly) and alerts posted at the CDL website: http://www.ars.usda.gov/Main/docs.htm?docid=9757. Rust observations by CDL survey staff and cooperators are distributed in a timely manner through the Cereal Rust Survey Listserv. After the recent Ug99 Surveillance Workshop, CDL, in collaboration with extension plant pathologists has developed a new Stem Rust Surveillance Listserv list. Information for current surveys is posted and updated weekly, including race identifications. A change of status is noted by a color change in a location marker (dot on the map). Each location is selectable to gain more information on the site and race identification. Historical survey data for the first date of disease occurrence for each year across the Great Plains are available for the past 70 years.

Approach and Role of Cooperators for Surveillance: The current surveillance effort processes hundreds of leaf rust, stem rust, crown rust and stripe rust samples from around the United States. Land-grant cooperators contribute about half of these rust collections. Collections from nurseries are most useful when found on varieties known to be previously resistant. **More targeted sampling of resistant material would be beneficial to develop lists of sentinel varieties for each market class for growers.** The current rust detection plots include susceptible varieties in the Great Plains and parts of the South. The best varieties for plots are those varieties that are universally susceptible to many races, and are well adapted to produce enough grain to replant.

Need: Many cooperators believe that the number of detection plots in the Southeastern states of Louisiana, Mississippi, Alabama and Florida should be enhanced because stem rust is most likely to survive south of 30 degrees latitude. The Gulf coast from Castroville, Texas to Quincy Florida is an important area and historically the first rust will appear in this area each year. Rust often migrates north up the Mississippi valley and should be monitored by

cooperators. The Gulf coast and Mississippi river valley are top priorities for plots. Late boot to early heading is generally a good growth stage to target. Stripe rust surveys generally are best at earlier growth stages. Trap plots are best if planted in highly susceptible varieties in plots 300 ft long to obtain more sampling area and increase the variety of landscape sampled. Sometimes, it is beneficial to survey for disease in the fall and revisit these locations in the spring to check for overwintering. Fields that are highly fertilized and not grazed have the greatest potential as overwintering sites.





Participants at the 2008 Ug99 Surveillance Workshop pointed out that the current surveillance is intended to detect large increases of rust disease and to identify new races of the pathogens within the United States. The timing of the surveys relative to crop growth may diminish the value of the surveillance however for local disease management. The information is of greater value within a growing season in the north where the greatest losses are known to occur. Outbreaks in the south increase the risk of the pathogen moving to the northern regions. Observations during the early stages of crop growth that may be important for in-season management of rust in the southern Great Plains will need to be obtained from Land-grant university cooperators and local scouting.

Approach: To enhance the current surveillance system, a project has been funded (*through Pennsylvania State University)* to apply aerobiological modeling concepts to examine potential routes of aerial transport and entry for the new virulent African wheat stem rust variants to be introduced to the US. The team of scientists involved in the project includes university/USDA-CSREES, USDA-ERS, and USDA-ARS collaborations and consultation with USDA-APHIS.

Approach: To enhance the current surveillance system, a project has been funded (*through Kansas State University*) to coordinating planning to optimize the observation network,

determining what the best monitoring network would look like and what field screening differentials should be deployed to optimize the detection of new virulence types of *Puccinia graminis* f.sp. *tritici*. The result will be earlier detection/recognition, allowing producers the most appropriate and rapid response possible for reaction with protectant fungicide treatments. The project will also implement the observation network in a **pilot** project to determine program successes and areas for improvement. Participants and full collaborators include leadership from land grant universities and USDA-ARS scientists at the Cereal Disease Laboratory working closely together to extend the network of collaborators across the country in the most inclusive way possible into all wheat producing states. Current disease management methods will be considered and detailed plans for optimal management in various production situations will be considered. Near real-time access to information is important such as an ipmPIPE model or something similar. Communication of that information to practitioners is also important. Various methods could be used and will be considered.

Approach: Land grant university cooperators will develop a fact sheet with photos and information on variety reactions to help others with identification. A tri-fold laminated card focused on identification of the three major rusts of wheat and barley will include diagnostic indicators on how to differentiate the three diseases. A diagnostic guide will be developed to support the fact sheets including variety reactions to Ug99. There is also a need to include a warning about the possibility of spreading the disease via uredeniospores on contaminated clothing, especially when returning from "the field" where new races of stem rust occur in foreign countries.

Approach: Results of monitoring and surveillance will be reported through extension publications.

Approach: Develop a network of cooperators to provide timely and accurate information to breeders and growers.

Objective 3: Public release of information on rust incidence.

A set of criterion is needed that can be used in the decision making process. Elements should include: a) variety infected to determine if it is potentially suspected to overcome current resistance genes; b) proper identification of the disease i.e. stem rust vs. leaf rust; c) first line of identification i.e. NPDN lab or CDL?; d) verification prior to public release of information. Information on a suspect sample will be kept on a 'need to know' basis until confirmed. There is a need for all parties involved in sample collection (NPDN, breeders, pathologists, CDL, state agriculture depts., etc.) to agree to keep information confidential until confirmed and made officially public. Even information that a suspicious sample was collected will be confined to those in the identification chain.

The disease is likely to spread very rapidly to wheat and barley -growing areas in the US by means of windborne spores. Therefore, APHIS will not attempt to prevent its spread via a

domestic quarantine regulation. State regulatory officials, growers, extension agents, and others are very interested in quick detection of Ug99 in order to effectively manage the disease. In this regard, APHIS will be allowing States to conduct their own diagnostics as they deem necessary after APHIS confirms the first detection on a host in a State. APHIS has been working closely with stakeholders to prepare for the arrival of Ug99 A number of diagnosticians with the National Plant Diagnostic Network and State departments of agriculture have been trained to morphologically identify *P. graminis and* they have trained first responders. States should decide whether identifications, after the initial PPQ-confirmed state/host records, are based on morphology, or morphology and PCR.

Objective: Develop a model framework for communicating the presence of the pathogen to leaders in regulatory, government and stakeholder groups.

Approach: A panel will be convened to develop a standard operating protocol for confirmation and notification of critical personnel across agencies at the state and federal level.

Component 4: Germplasm Development

Objective 1: Identify and develop stem rust resistant cereal germplasm using primary, secondary, and tertiary gene pools.

Approach: Sources of resistance to stem rust, race Ug99, will be sought in adapted cultivars, experimental lines, and breeding lines (all primary gene pool sources); in related species within wheat (*Triticum*) or barley (*Hordeum*) genera (secondary sources); and in distantly related relatives of wheat and other grasses (tertiary sources).

Project	***Principal Investigator(s)***	***Affiliation***
Identification of resistance in primary gene pools of winter wheat	D. Marshall and Y. Jin	USDA/ARS
Identification of resistance in primary gene pools of adapted spring wheat	Y. Jin	USDA/ARS
Identification of resistance in land races of wheat	M. Bonman, E. Jackson, and Y. Jin	USDA/ARS
Introgression of sources of resistance from primary gene pools of winter wheat to adapted background	D. Marshall, G. Brown-Guedira, M. Pumphrey, and Y. Jin	USDA/ARS
Identify and develop adult plant resistance to stem rust in winter wheat	D. Marshall, G. Brown-Guedira, and B. Bowden	USDA/ARS

Identify and introgress resistance from primary and secondary sources into barley	Y. Jin and B. Steffenson	USDA/ARS and Univ. Minnesota
Identify and introgress resistance from *Triticum timopheevii* and *Aegilops speltoides* into wheat	M. Pumphrey and Y. Jin	USDA/ARS
Identify and introgress resistance from *Aegilops sharonensis* into wheat	E. Millet and B. Steffenson	Univ. Minnesota
Screen wild relatives of wheat and barley seedlings with race Ug99	Y. Jin and B. Steffenson	USDA/ARS and Univ. Minnesota
Reduce linkage drag associated with rust resistance genes	S. Xu and M. Pumphrey	USDA/ARS
Identify and introgress resistance from underused wheat relatives into wheat	D. Marshall, G. Brown-Guedira, and S. Xu	USDA/ARS
Identify resistance from rye	P. Gustafson	USDA/ARS
Investigate the basis of stem rust resistance in rice	Y. Jin and B. Steffenson	USDA/ARS and Univ. Minnesota

Objective 2: Identify and develop molecular tools to facilitate the rapid incorporation of stem rust resistance into adapted cereals.

Approach: Molecular techniques and methods will be adapted and verified for effectiveness in quickly incorporating stem rust resistance into adapted germplasm.

Project	***Principal Investigator(s)***	***Affiliation***
Develop and optimize markers for previously characterized resistance genes	J. Anderson and M. Rouse	Univ. Minnesota
Haplotype uncharacterized rust resistance genes	M. Sorrells	Cornell Univ.
Map novel sources of stem rust resistance	J. Dubcovsky, R. Singh, S. Chao, and M. Rouse	Univ. California and CIMMYT, USDA/ARS, and Univ. of Minnesota

Component 5: Pre-Breeding, Nursery Evaluation, and Cultivar Development

Objective 1: Use molecular markers to genotype and combine resistant germplasm.

Approach: Genotyping strategies will be used to deploy resistance genes into regional wheat and barley breeding programs.

Project	***Principal Investigator***	***Affiliation***
Eastern Regional Genotyping and Pre-Breeding	G. Brown-Guedira	USDA/ARS
Southern Plains Regional Genotyping and Pre-Breeding	G. Bai	USDA/ARS
Northern Plains Regional Genotyping and Pre-Breeding	S. Chao	USDA/ARS
Western Regional Genotyping and Pre-Breeding	D. See	USDA/ARS
Data coordination and distribution	O. Anderson and D. Matthews	USDA/ARS

Objective 2: Use Regional Nurseries to identify newly-developed, disease resistant, adapted cultivars.

Region	***Coordinator***	***Cooperators***
Eastern Winter Wheat	D. Marshall and H. Bockleman, USDA/ARS	Land Grant Universities and Private Companies in FL, GA, SC, NC, VA, MD, NY, OH, KY, LA, AR, MO, IN, IL, and MI.
Plains Winter Wheat	R. Graybosch, USDA/ARS	Land Grant Universities and Private Companies in TX, OK, KS, NE, CO, and SD.
Plains Spring Wheat	D. Garvin, USDA/ARS	Land Grant Universities and Private Companies in SD, ND, MN, and MT.
Western Wheat	K. Campbell, USDA/ARS	Land Grant Universities and Private Companies in WA, OR, ID, UT, and CA.
Winter Barley	D. Marshall and M. Bonman, USDA/ARS	Land Grant Universities and Private Companies in SC, NC, VA, TX, NE, ID, OR, WA, CA, and MT.
Spring Barley	Y. Jin, USDA/ARS and B. Steffenson, Univ. of Minnesota	Land Grant Universities and Private Companies in MN, ND, and SD.

Spring and Winter Oat	H. Rines and D. Marshall, USDA/ARS	Land Grant Universities and Private Companies in FL, GA, SC, NC, MD, LA, IL, IN, WI, ND, and MN.

Objective 3: Release, increase, and deploy new stem rust resistant cultivars.

Federal, State, and private company breeders will release new, stem rust resistant cultivars to their respective foundation seed association, crop improvement association or purity and multiplication division for seed increase. Following one or two growing seasons, sufficient quantities of seed of new cultivars will be available to growers for production.

Component 6: International Wheat and Barley Germplasm Exchange, Coordination, Evaluation and Pathogen Monitoring

Objective 1: Coordinate and support U.S.-based international nurseries and germplasm evaluation and exchanges.

Approach: Spring wheat: APHIS, Plant Protection and Quarantine, ARS, and two major University programs currently cooperate on importation, quarantine increase, and U.S. distribution of CIMMYT international nurseries that include germplasm with resistance to Ug99. Winter wheat nurseries originating from Turkey are grown out by J. Peterson, Oregon State University under USDA-ARS supervision by ARS pathologist Blair Goates, USDA-ARS, Small Grains and Potato Germplasm Unit, Aberdeen, Idaho. In February, 2008, due to the urgency of the Ug99 threat, APHIS, PPQ, facilitated the risk assessment and new permitting requirements for import and field growout of seed from Turkey. As a result, over 150 new germplasm accessions were introduced, increased under quarantine, and seed was distributed to over 25 breeding programs throughout the US. For 2009, plans are to introduce, increase, and distribute up to 400 new candidate lines from the CIMMYT winter nursery program under USDA supervision. Spring wheat nurseries originating from Mexico are grown under greenhouse quarantine by A. Klatt, Oklahoma State University. Over 500 new spring germplasm lines were introduced, and made available to US breeders in 2008. USDA-ARS provides partial support and assists with seed increase and distribution. Continued access to these international nurseries is critical to provide U.S. breeders with new sources of resistance to Ug99 and other major wheat diseases.

Approach: Participate in germplasm exchange and evaluation with the international crop research centers, CIMMYT and ICARDA, and other international projects by collaborating with the Borlaug Global Rust Initiative and the Durable Rust Resistance in Wheat Project, DDRW (Cornell University) www.globalrust.org.

Objective 2: Monitor development, evolution, and spread of new stem rust races in cooperation with international collaborative efforts.

Approach and Cooperators: The DRRW (Cornell University), which will implement and operate a Global Cereal Rust Monitoring System. Yue Jin, ARS-St. Paul, and T. Fetch, Agriculture and Agri-Foods Canada, will participate.

Accomplishment: In March 2008, USAID sponsored an international workshop at ICARDA, Syria, to plan and coordinate international tracking and monitoring of Ug99 for 2008.

Objective 3: Introduce, evaluate, and distribute elite germplasm from International Agricultural Research Centers with enhanced rust resistance.

Approach: Conduct cooperative research through participation in the Durable Rust Resistance in Wheat Project (Cornell University) and contribute to the Borlaug Global Rust Initiative. ARS, U. Minnesota and U. California, Davis, are participating in the Cornell University-led DRRW Project.

Component 7: Disease Management

The front line defense in management of wheat stem rust has been and continues to be genetic resistance. If genetic resistance breaks down, there is often a need for other management tactics while new genetic resistance is developed. There are presently several fungicides that provide acceptable control of rust diseases, but long term use of fungicides as a stand-alone control tactic opens the possibility for fungicide resistance to develop.

The North Central Education/Extension and Research Activity Committee on Management of Small Grain Diseases (NCERA-184) has developed information on fungicide efficacy for control of a number of foliar diseases of wheat for use by the grain production industry in the United States.

Objective 1: Assure efficacious and judicious use of properly applied fungicidal controls as a stopgap to introgressing effective resistance in agronomically acceptable and adapted germplasm.

Approach and cooperators**:** A project has been funded (through South Dakota State University) to prepare for greater frequency of wheat stem rust in the US due to the introduction of new virulences such as Ug99. Three objectives are included in this project. Model systems for stem rust risk will be assessed to determine risk for producers. Fungicide efficacy will be tested on proxy virulent (model) system to determine the utility of currently available fungicides and to optimize their performance with the adoption of improved application technologies. A First Detector module will be developed to improve recognition of wheat stem rust and improve response time when an epidemic occurs.

Approach: Determine effective residual periods and application timing for various fungicide chemistries. Work with industry to determine realistic periods of protection.

Approach: Determine effective application technologies to optimize fungicide performance. A project will be funded through the CSREES Critical and Emerging Pests and Disease program that will assess optimized covered and disease control efficacy with modern application technologies.

Objective 2: Assure availability of appropriate fungicides, label language with common recommendations across state lines, and interpretation of treatment implications in grazing areas as opposed to non-grazing areas.

Approach: Work with existing structure in NCERA-184 Diseases of Cereals and WERA-097 Diseases of Wheat multistate committees to coordinate recommendations and uniform tests. This process is already underway. Although only a few studies have specifically addresses this topic, the available data will be summarized in an efficacy table for stem rust in a format similar to other diseases of small grains. This information will be distributed to small grain pathologists to help facilitate consistency of recommendations.

Approach: Work through ARS-OPMP to develop a chemical control working group to meet by conference call on a regular basis for information exchange in chemical control of wheat stem rust.

Approach: Train area pathologists in rating stem rust to assure uniformity in disease and damage assessment.

Approach: Assess the potential impact of planting dates and days to maturity in assessing and distributing risk of disease losses.

Approach: Ensure coordination of outreach and information exchange with the communications plan.

Approach: Through the university Extension Service, train producers and farm mangers to recognize wheat stem rust on their crops and how to respond. Participants in the Stem rust monitoring and management workshop outlined content for extension publications. One of the publications will focus on identification and differentiation from other cereal rust diseases. The second publication will focus on the determining risk of yield loss and in-season management.

Fungicides Registered in the U.S. for Management of Wheat and Barley Rust
Status as of September 15, 2008

Items in blue are not currently being marketed

Active ingredient	Product name (company)	Federally registered on*		Chemical class**			Limitations
		Wheat	Barley	Protec	Strobi	Triazol	
azoxystrobin	Quadris (Syngenta)	x	x		x		2 app/season; REI=4 hr; PHI=45 d for grain and straw, 14 d for hay **Feeding:** Do not harvest treated barley or wheat for forage
azoxystrobin + cyproconazole	Quadris Xtra (Syngenta)	x			x	x	Tolerance for cyproconazole on wheat was established on 5/14/08 (40 CFR 27756). Quadris Xtra is federally registered on wheat but has no state registrations on wheat at this time.
azoxystrobin + propiconazole	Quilt (Syngenta)	x	x		x	x	2 app/season, REI=12 hr, PHI=45 d for grain and straw **Feeding:** Do not harvest wheat for forage. Do not graze or feed livestock treated forage or cut green chop for hay or forage.
cyproconazole	Alto (Syngenta)	x				x	Tolerance for cyproconazole on wheat was established on 5/14/08 (40 CFR 27756). Alto is federally registered on wheat but has no state registrations on wheat at this time.

Active ingredient	Product name (company)	Federally registered on*		Chemical class**			Limitations
		Wheat	Barley	Protec	Strobi	Triazol	
fenbuconazole	Enable (Dow Agro)	x				x	2 app/year, REI=12 hr, PHI=no later than flowering or within 35 d **Feeding**: Do not apply within 14 days of harvest for forage and hay
mancozeb	Dithane M-45 (Dow Agro), Manzate (DuPont)	x	x	x			3 app/season, REI=24 hr, PHI=no later than heading or less than 26 d **Feeding:** Do not graze livestock in treated areas prior to harvest.
metconazole	Caramba (BASF)	x	x			x	2 app/season, REI=12 hr, PHI=30 d **Feeding:** no restrictions
metconazole + pyraclostrobin	Multiva (BASF)	x	x		x	x	2 app/season, REI=12 hr, PHI=no later than beginning of flowering **Feeding**: Do not harvest barley hay within 14 days of last application
propiconazole	Bumper (Makhteshim-Agan), Propimax (Dow Agro), Tilt (Syngenta)	x	x			x	1 or 2 app/season; REI=12-24 hr; PHI=30 d for forage, 40 d for grain and straw, 45 d for hay **Feeding:** Do not apply more than 1 application if forage or hay will be harvested.

Active ingredient	Product name (company)	Federally registered on*		Chemical class**			Limitations
		Wheat	Barley	Protec	Strobi	Triazol	
propiconazole + trifloxystrobin	Stratego (Bayer)	x	x		x	x	2 app/season, REI=24 hr, PHI=35 d (wheat) and 40 d (barley) **Feeding:** If 2 applications are applied, do not allow livestock to graze within the treated area and do not harvest the treated crop for forage or hay. If 1 application is applied, do not allow livestock to graze within 30 days or harvest forage within 30 days (hay within 45 days).
prothioconazole	ProLine (Bayer)	x				x	2 app/year, REI=48 hr, PHI=30 d Hand harvesting is prohibited **Feeding**: no restrictions
prothioconazole + tebuconazole	Prosaro (Bayer)	x	x			x	2 app/year, REI=48 hr, PHI=30 d Prosaro is federally registered by will not be available until 2009. **Feeding**: no restrictions
pyraclostrobin	Headline (BASF)	x	x		x		2 app/season, REI=12 hr, PHI= no later than beginning of flowering **Feeding:** Do not harvest hay or feed green chop within 14 days of last application.

Active ingredient	Product name (company)	Federally registered on*		Chemical class**			Limitations
		Wheat	Barley	Protec	Strobi	Triazol	
tebuconazole	Folicur (Bayer) Orius (Makhteshim-Agan)	x	x			x	1 app/crop season, REI=12 hr, PHI=30 d **Feeding:** Straw cut after harvest may be fed or used for bedding. Do not allow livestock to graze or feed green forage for 6 days after treatment with tebuconazole.

* State registrations may vary – consult state or local authorities.
** Chemical class: Protect = protectants, Strobi = strobilurins, and Triazol = triazoles or DMI fungicides

Please direct questions and recommendations concerning this table to Marty Draper, USDA-CSREES, at 202-301-1990 or mdraper@csrees.usda.gov, or Kent Smith, USDA-ARS, at 202-720-3186 or kent.smith@ars.usda.gov.

Disclaimer: Read the pesticide label prior to use. This information is not a substitute for a pesticide label. Trade names used herein are for convenience only; no endorsement of products is intended, nor is criticism of unnamed products implied.

Component 8: Communication and Outreach

Objective 1: Communicate and coordinate information on current and emerging rust threats throughout cereal industry.

Approach: Communicate results of U.S. cereal rust surveys and monitoring. Results of the surveys and race identifications are distributed in the Cereal Rust Bulletin, Annual Wheat, Barley, and Oat Newsletters, and published in scientific journals. The Cereal Rust Bulletin is produced at 2-week intervals from April to August and is distributed to over 400 postal and e-mail addresses as well as being made available to thousands of American and Canadian readers of various internet services. Subscribers include universities, state departments of agriculture, and more than 40 private corporations. The Cereal Disease Lab also compiles annual estimates of yield losses to rust diseases in wheat, barley, oat, and rye for all cereal-producing states in the United States. The yield loss estimates are distributed to scientists and university libraries throughout the U.S. Presumably, the recipient list for the Cereal Rust Bulletin could be used to contact wheat workers with a turnaround time of less than a week in the event of an emergency that required immediate reaction.

Approach: The NCERA-184 and WERA-097 committees on small grain diseases also have dedicated listserv capacity that can be used to communicate among small grain disease specialists in case of emergency. The July monitoring workshop also recommended that an additional listserv also be established for specific communication about stem rust monitoring in the US. This list has been approved and should be operational by January of 2009.

Objective 2: Communicate cereal genome information including rust molecular marker and genetic mapping data.

Objective 3: Communicate information to extension specialists concerning those fungicides that are nationally available.

Approach: If genetic resistance breaks down, there is a need for other management tactics until new genetic resistance is developed. There are presently several fungicides that provide acceptable control of rust, but long-term use of the fungicides as a stand-alone control tactic opens the door for fungicide resistance to develop. A list of fungicides that are registered and available for use along with key information that will help extension specialists in making their selections will be developed. A list of key extension specialists and other experts will be assembled and kept informed on a regular basis by email and teleconferences of any changes or concerns concerning the availability of fungicides. One important concern is feeding restrictions on the use of various fungicides. This could limit the availability of fungicides is areas where wheat is grown as a forage crop as is done in many southern states. The information relayed to extension specialists will give detailed information on the feeding limitations of specific fungicides. The NCERA-184 and WERA-097 currently maintain this information about fungicides options is efficacy tables. Preliminary information is now in place for stem rust and information distributed to small grain pathologists throughout the US.

Roles and Responsibilities of USDA Agencies

Agricultural Research Service

- Assessing vulnerability of U.S. wheat and barley varieties to Ug99
- Characterizing wheat and barley stem rust races
- Developing detection and identification methods
- Monitoring pathogen populations and identifying emerging rust races
- Leading wheat and barley germplasm screening for stem rust resistance including a specific cooperative agreement with CIMMYT for screening in East Africa
- Regional nursery coordination and variety trials
- Identification of new sources of genetic resistance wheat and barley, as well as wild and weedy relatives
- Breeding for genetic resistance

Much of this research is conducted in partnership with university, public and private sector projects. ARS is also a participant in the Borlaug Global Rust Initiative.

Cereal Disease Laboratory, St. Paul, MN

- Determine relative vulnerability of present cultivars of wheat and barley, and experimental germplasm to Pgt-Ug99;evaluate segregating breeding populations.
- Evaluate the effectiveness of wheat and barley stem rust resistance genes against race Pgt-Ug99
- Develop DNA-based diagnostic assays and protocol for Pgt-Ug99
- Characterize *P. graminis f. sp. tritici* isolates from Africa and compare to U.S. races for molecular genotype and virulence phenotype. .
- Conduct a national sampling program through examination of rain samples through aerial transport of urediniospores from the southern U.S..
- Conduct annual surveys of rust through major wheat growing areas of the U.S.
- Develop SSR markers tightly linked to Sr genes to characterize race structures

U.S. Small Grains Respository, Small Grains Genetic Resources Management Unit, Aberdeen, ID

- Coordinate seed acquisition and shipment of currently grown U.S. cultivars, advanced breeding lines, and USDA repository accessions for the African germplasm screening project.

Wheat Genotyping Laboratory, Fargo, ND

Wheat Genotyping Laboratory, Manhattan, KS

Plant Sciences Research Unit, Raleigh, NC

- Integrate present Pgt-Ug99 screening data with the project's cultivar and breeding line database
- Develop specific genetic pools of vulnerability (or protection) and to better pinpoint those local and regional genetic pools that need improvement
- Accelerate marker screening for the stem rust genes of interest.
- Collaborate with cooperators at the University of Georgia, Louisiana State University, and Virginia Tech University to assist in developing stem rust-resistant breeding lines and cultivars to Pgt-Ug99.

Wheat, Sorghum, and Forage Research Unit, Lincoln, NE

- Develop stem rust-resistant breeding lines and cultivars to PGT-Ug99 races in the southern wheat growing regions of the U.S.

Animal and Plant and Health Inspection Service (APHIS)

- Provide phytosanitary and regulatory expertise within the United States, and internationally.
  http://www.aphis.usda.gov/plant_health/index.shtml
- Provide leadership in emergency response and crop biosecurity with respect to new and invasive plant pests and diseases.
  http://www.aphis.usda.gov/plant_health/plant_pest_info/biosecurity/index.shtml;
- Facilitate safe importation of germplasm through a process of reviewing applications for Federal import permits.
  http://www.aphis.usda.gov/plant_health/permits/plantproducts.shtml
- Communicate a harmonized strategy for the regulatory agencies of Canada, Mexico and the United States via the North American Plant Protection Organization (NAPPO):
  http://www.nappo.org/Standards/Other-Docs/UG99StrategicPlan15-07-08-e.pdf
- Communicate Federal regulations regarding barberry
  http://www.aphis.usda.gov/plant_health/plant_pest_info/barberry/index.shtml
- Provide a general protocol for communicating pest identification procedures and diagnostic results for most new plant pests
  http://www.aphis.usda.gov/plant_health/plant_pest_info/pest_detection/downloads/state-diagnostic-notification.pdf.
  However, in the case of new races of wheat and barley rust, ARS (not APHIS) identifies the race or variant of a rust sample.
- APHIS notifies states and foreign countries only for the first occurrence of new races in the US.
- APHIS posts the first finding of a new race in the United States to the NAPPO Phytosanitary Alert System, after it receives notification from ARS as to the identify of the new race: http://www.pestalert.org/index.cfm?NAPPOLanguagePref='English'.
  APHIS notifies foreign countries as required.

Cooperative State Research Education and Extension Service (CSREES)

Engages the land grant university system and assures their involvement in research, education, and extension of the information to the general public and coordination with USDA programs.

Supports competitive research on Ug99, including, but not limited to:

- Aerobiological modeling project to assess potential pathways of introduction of Pgt-Ug99.
- Coordinated disease survey and communication.
- Other issues of critical and immediate concern for wheat stem rust management.

USDA Office of Pest Management Policy (OPMP)

Development of recovery plans through the national Plant Disease Recovery System (NPDRS).
Interface with the Environmental Protection Agency (EPA) on fungicide registration
Assess chemical control needs.