Recovery Plan
for
Stem Rust of Wheat

caused by

Puccinia graminis f. sp. *tritici* Ug99 (race TTKSK) and its derivatives

Completed 31 March 2010

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This recovery plan is one of several disease-specific documents produced as part of the National Plant Disease Recovery System (NPDRS) called for in Homeland Security Presidential Directive Number 9 (HSPD-9). The purpose of the NPDRS is to insure that the tools, infrastructure, communication networks, and capacity required to mitigate the impact of high consequence plant disease outbreaks are such that a reasonable level of crop production is maintained.

Each disease-specific plan is intended to provide a brief primer on the disease, assess the status of critical recovery components, and identify disease management research, education and extension needs. These documents are not intended to be stand-alone documents that address all of the many and varied aspects of plant disease outbreaks, all of the decisions that must be made, and the actions to be taken to achieve effective response and recovery. They are, however, documents that will help the USDA guide further efforts directed toward plant disease recovery.

Executive Summary

Stem rust of wheat caused by *Puccinia graminis* f. sp. *tritici* historically has been one of the most important plant diseases worldwide. Stem rust has been effectively controlled in the United States (US) for the past 50 years by eliminating common barberry (*Berberis vulgaris*), the alternate host of the stem rust fungus, from wheat-producing areas of the US and growing wheat cultivars with genetic resistance in combination with earlier maturity. In 1999, a new strain of the stem rust pathogen, commonly referred to as Ug99 (formally known as race TTKSK), able to cause disease on previously resistant wheat cultivars carrying stem rust resistance gene *Sr31* was reported in Uganda. Since then, Ug99 and related races have spread within eastern Africa, across the Red Sea into Yemen and into Iran. From there they are likely to move southward in Africa, into the Middle-Eastern countries, central and southern Asia, and China. There is great concern that Ug99, or races derived from it, will be introduced into the US through natural or human-mediated pathways and threaten wheat and barley production. This document describes the current state of knowledge regarding stem rust and the options for responding to an introduction of these new virulent races into the US.

The first line of defense for controlling stem rust has been genetic resistance in wheat and barley cultivars. Durable rust resistance, i.e., resistance that remains effective after commercial use over a large area for a long period of time and across areas where epidemics of the disease are common, has been difficult to achieve due to genetic changes in the stem rust pathogen. These changes result in new pathogen races that are able to overcome the genetic resistance present in wheat and barley cultivars. Thus, continued development of new wheat and barley cultivars with effective genetic resistance is imperative.

Other disease control options are needed to the extent that resistant cultivars are not able to effectively control stem rust. Although several fungicides that control stem rust are registered for use on wheat and barley, they have economic and environmental costs, may not be effective in severe epidemics, and supplies may be inadequate if there is a large epidemic-driven demand. Furthermore, there is concern that long-term use of fungicides will result in development of fungicide-resistant populations of the stem rust pathogen and thus render fungicides ineffective.

Common barberry, a shrub introduced to the US by early immigrants, is the alternate host of stem rust. When barberry is present near wheat fields, disease often begins earlier in the season and is more severe on local crops. Barberry is also important because the stem rust fungus undergoes sexual reproduction on it, which can result in formation of new races with the potential to render genetic resistance ineffective. A federal Barberry Eradication Program, in effect from 1918 to 1981, was implemented to eliminate barberry from wheat- and barley-producing areas of the US, and was an important part of the ultimate reduction in stem rust epidemics in North America.

Important gaps exist in our knowledge of stem rust because much of our current understanding is based on 50+ year-old data, some of which must be re-examined. Updated research is

needed to improve our understanding of stem rust in the context of contemporary cropping practices, wheat cultivars, and pathogen populations. Consequently, there are four high priority themes for research on stem rust:

1. Breeding for genetic resistance in wheat and barley by incorporating existing and new resistance genes, characterize adult plant resistance, and screen breeding lines for genetic resistance to new and emerging races of stem rust.
2. Develop methods to rapidly and effectively identify new variants in the stem rust pathogen population and augment the existing stem rust surveillance network with additional locations and samples to detect new variants.
3. Conduct epidemiological studies to develop and verify disease prediction models, pathogen movement models, and role of barberry in pathogen survival.
4. Identify fungicides, application timing and methods for most effective control of stem rust along with decision support tools for their use.

Ug99 and other newly emerging races of the stem rust fungus ultimately will be controlled by producers and agriculture professionals on farms across the country. Education of stakeholders is needed to minimize the potential impact of stem rust since many producers and professionals have not dealt with it. Priorities for extension and education include:

1. Develop ‘Good Farming Practices’ tools to help with risk management.
2. Produce education and training materials for farmers and agriculture professionals to help them diagnose and control stem rust.
3. Further engage the National Plant Diagnostic Network (NPDN) by developing a Standard Operations Protocol (SOP) for diagnostics.

Recovery Plan for Stem Rust of Wheat

(caused by *Puccinia graminis* f. sp. *tritici* Ug99 (race TTKSK)
and other newly emerging races derived from it)

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I. Introduction

Stripe rust (yellow rust), leaf rust (brown rust), and stem rust (black rust) diseases of wheat occur worldwide wherever wheat is grown, including the US. Historically, stem rust of wheat and barley, caused by *Puccinia graminis* f. sp. *tritici*, has been one of the most important plant diseases worldwide. Wheat leaf rust, caused by *Puccinia triticina*, is the most common and widespread rust disease of wheat. In the US, leaf rust is found annually in the eastern wheat growing regions, the Great Plains, and the southwestern states. Stripe rust of wheat, caused by *Puccinia striiformis* f. sp. *tritici*, is most prevalent in cooler wheat producing regions. In the US, stripe rust has been most destructive in the Pacific Northwest states (Idaho, Oregon, and Washington) and California, but severe epidemics have occurred in the south central states and Great Plains since 2000. This recovery plan will address stem rust, with specific reference to the new races emerging in east Africa.

In North America, stem rust epidemics in spring wheat were frequent in the early 1900s in the northern Great Plains of the US and the Prairie Provinces of Canada. Major epidemics in this region occurred again in the 1930s and 1950s. Total losses due to stem rust in Minnesota, North Dakota and South Dakota were estimated at over 100 million bushels in 1935 and over 150 million bushels, combined over 1953 and 1954, which represents nearly $3.7 billion (adjusted to 2009 dollars) in lost production in those three seasons alone. Spread of stem rust is fastest in the Great Plains states where there is nearly continuous wheat production from Texas to the Prairie Provinces of Canada. However, smaller losses due to stem rust have been recorded in the southern and central Plains, Midwest, southeast and Pacific Northwest United States.

Stem rust was ultimately brought under control by growing cultivars with effective host resistance and earlier maturity, combined with near-eradication of common barberry, the alternate host of stem rust, from the major wheat- and barley-producing areas of the US. In the 1970s, a chromosome translocation from rye labeled '1BL.1RS' was incorporated into many wheat cultivars worldwide because it provided a significant improvement in yield and disease resistance. Consequently, stem rust resistance gene (=*Sr* gene) *Sr31* is present in many cultivars worldwide because it is located on the 1BL.1RS translocation. Many US winter wheat cultivars contain *Sr31* alone or in combination with *Sr24* and other *Sr* genes because they have provided effective resistance to stem rust in wheat. The characterization of a new race of the stem rust fungus capable of causing disease on cultivars containing *Sr31* in 1999 led to the realization that most wheat cultivars across the world, including those in the US, were now vulnerable to stem rust (Jin and Singh, 2007; Singh et al., 2008). This new race, officially designated TTKSK but commonly referred to as Ug99, has since been reported in Ethiopia, Kenya, Sudan, Yemen, and Iran. Ug99 was first detected in Uganda in 1998 and characterized in 1999, and thus the acronym Ug99 was coined. In 2006 and 2007, new variants of Ug99 capable of infecting wheat plants carrying *Sr31* and *Sr24* (race TTKST) and *Sr31* and *Sr36* (race TTTSK) were identified in Kenya (Jin et al., 2008, 2009). These new races render many Ug99-resistant wheat cultivars in the US vulnerable to infection because *Sr24* and *Sr36* are two of the major resistance genes used in breeding programs for control of stem rust.

Near-eradication of barberry from rust-prone wheat-producing areas of the US greatly limited sexual reproduction of the stem rust fungus, which both reduced the number of new stem rust races that appeared and potential overwintering sites for the fungus in the northern Great Plains. It also eliminated local sources of the pathogen, which resulted in delayed stem rust epidemics. The USDA Barberry Eradication Program began in 1918 and encompassed 13 northern-tier states (CO, IL, IN, IA, MI, MN, MT, NE, ND, OH, SD, WI, and WY) with five other states (MO, PA, VA, WA, and WV) joining by 1944. By the time the program officially ended in 1981, over 560 million barberry plants had been eradicated from the US. However, eradication of barberry was not complete and the remaining bushes have contributed to persistence and variability of the pathogen in some parts of the US. For example, the large number of stem rust races present in eastern Washington and northern Idaho relative to other wheat-producing regions of the US, some of which contain uncommon virulence genes, is attributed to presence of barberry. The risk of new races of stem rust emerging in the US is therefore real, especially if barberry populations re-emerge in the wheat-growing areas of the northern US.

Conventions: Throughout this document, ***stem rust*** will be used to refer to stem rust disease and ***Pgt*** will be used for *Puccinia graminis* f. sp. *tritici*, the fungus that causes stem rust, when discussing issues that are common wherever stem rust occurs. The original isolate of *Pgt* found in Uganda with virulence to wheat stem rust resistance gene *Sr31* has been referred to as race *Ug99* in some publications; however, Ug99 is not a race per se, but rather an individual within race TTKSK, which contains many different individuals all of which possess the ability to infect the same wheat cultivars. Nevertheless, because of its widespread use, ***Ug99*** will be used to describe issues that are specific to the new east African races of *Pgt*.

II. Signs and Symptoms

On barberry, the alternate host of *Pgt*, symptoms include raised yellow-orange lesions on leaves, petioles, blossoms and fruit (Fig. 1A). Signs (physical parts of the pathogen) include clusters of salmon-pink or orange, tubular cup-shaped structures (aecia) on leaves, petioles, and fruits. On wheat, signs include conspicuous brownish-red blister-like pustules (uredinia) that appear on stems, leaves, leaf sheaths, peduncles (portion of stem immediately below the head), glumes (chaff), and awns (Fig. 1B, C, D). Pustules are elliptical to elongate, are larger than those of leaf rust and stripe rust, and vary from less than 1/16” to over 3/8” (1-10 mm) in diameter. Pustule size is controlled by the degree of host resistance, tissue age, virulence and aggressiveness of the pathogen, and environmental conditions. Stem rust pustules typically occur on both upper and lower leaf surfaces and tend to be larger on the lower surface. The margins of stem rust pustules are often tattered where the erupting spore mass breaks through the epidermis (Fig. 1B, C, D). Abundant powdery rust-colored spores (urediniospores) are released from young pustules. Later in the growing season, the uredinia convert to telia by producing dark-colored overwintering (long-term survival) teliospores (Fig. 1E, F). Severe stem rust infection of a crop can weaken stems, leading to lodging (falling over) and prematurely ripened grain that is shriveled.

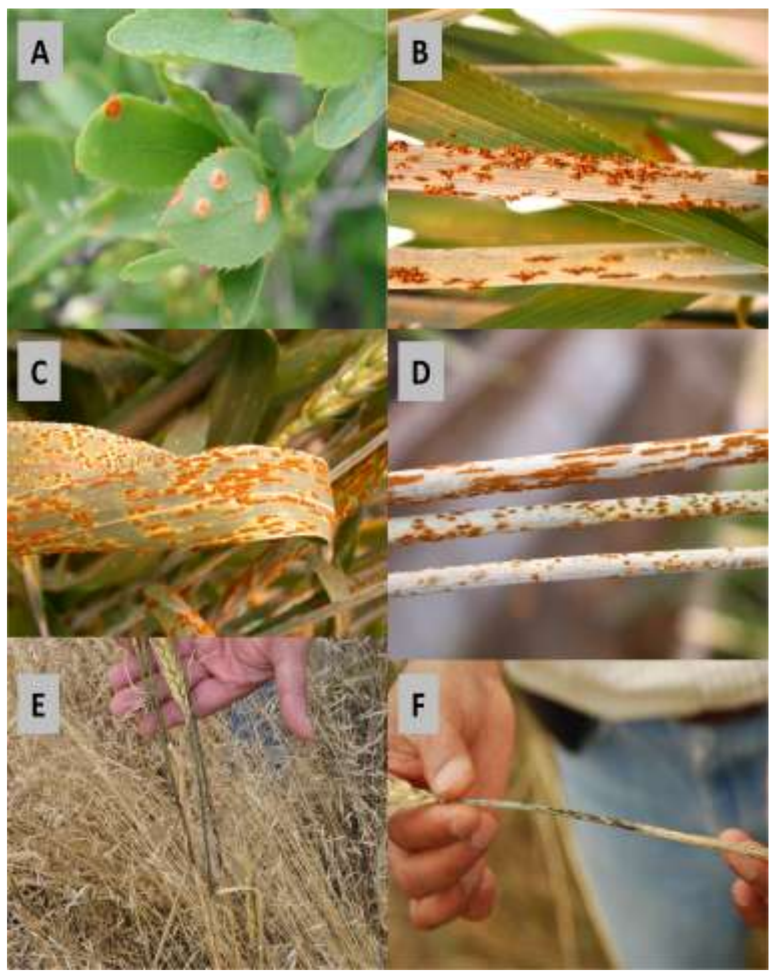


Figure 1. Signs and symptoms of stem rust. Aecia on common barberry (A), uredinia on wheat stems (B), leaves (C) and peduncles (D). Telia of stem rust on wheat stems (E, F).

III. Biology and Spread

Pgt has a complex life cycle with five different types of spores that are produced on two different types of plants, a grass (bread wheat, durum wheat, barley, or other grasses) and barberry (*Berberis, Mahoberberis,* and *Mahonia* species); the entire life cycle cannot be completed without both host plants (Fig. 2). Urediniospores are the most economically important of the five spores because they account for the most important infections on wheat and barley and can spread long distances by wind.

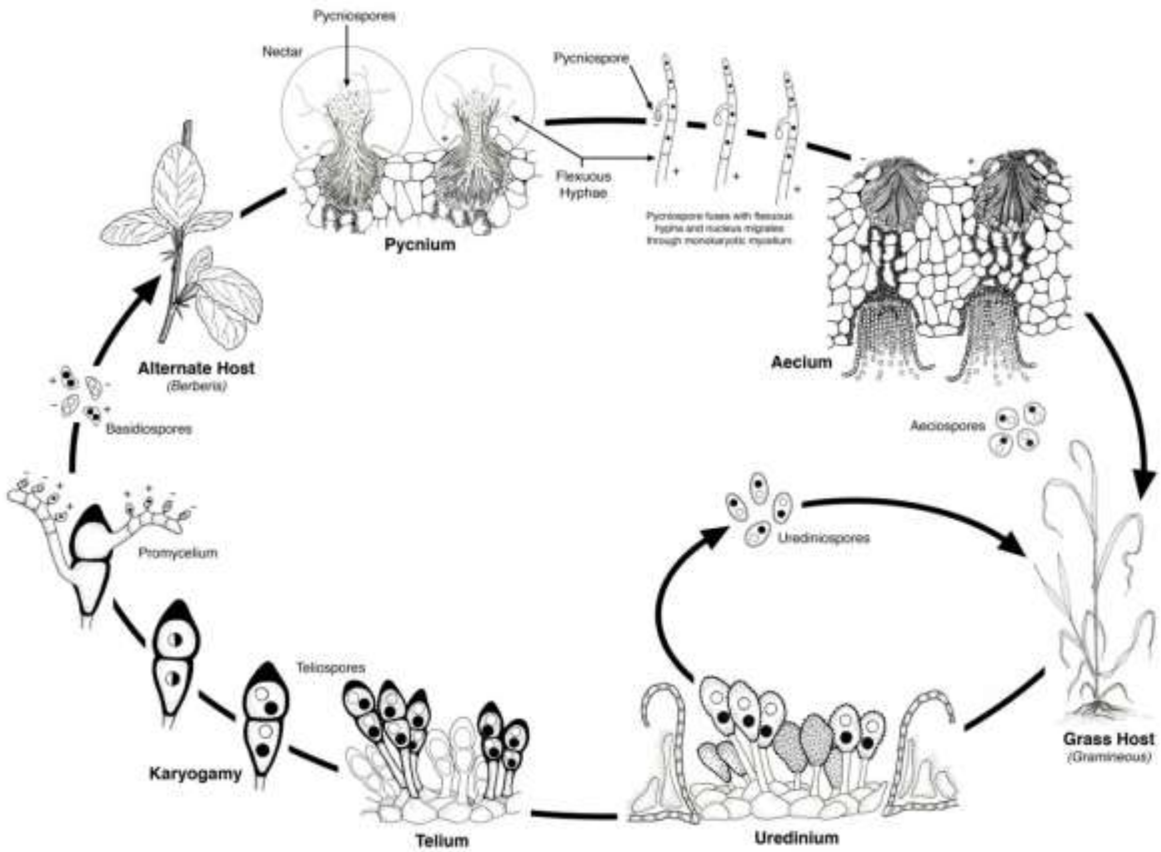


Figure 2. Life cycle of *Puccinia graminis*. The asexual stage, urediniospores, is repeated on the grass host with a new generation of spores every 7-14 days under favorable conditions. Teliospores, which begin the sexual stage of the life cycle, typically form as the grass host matures in late summer or autumn. In spring, teliospores germinate to produce basidiospores that can infect barberry, the alternate host, on which the fungus produces pycnia. Fertilization occurs between pycnia of different mating types and results in formation of the aecium, which produces aeciospores. Aeciospores infect the grass host to produce uredinia, completing the life cycle. In regions with mild winters and adequate summer moisture, *Pgt* may persist as uredinia (asexual) on autumn-sown cereals in the winter and on volunteer cereal plants or susceptible wild grasses. (From Leonard and Szabo, 2005, line drawing by J. Morison)

Pgt overwinters as urediniospores (asexual stage) only in the southern US (southern Texas and the Gulf Coast) and Mexico on fall-planted wheat, barley, and wild grasses. In the absence of barberry, these stem rust infections along the Gulf Coast and in the southern Great Plains likely are the only source of inoculum in the US. As temperature and moisture increase during the spring, winds blowing from the south spread urediniospores northward and rain deposits them onto wheat plants. This pathway of stem rust spread runs from the southern US to Canada and is referred to as the "Puccinia pathway." A similar situation exists with stem rust infecting wheat in the fall in the Gulf Coast States and subsequently spreading northward along the Atlantic coast.

Pathogen Races and Host Resistance: *Pgt* now reproduces asexually east of the Rocky Mountains and consequently, its population has been stable over the last several decades. Annual stem rust surveys have shown that two to three races of *Pgt* are typically detected in this region, and only one or two predominate in a given year. Changes in virulence over the past 50 years have been gradual and often predictable, usually occurring as simple mutations within existing races. For example, race QFCS of *Pgt* predominated in 2007 and 2008. Race RFCS was first detected in the southern Plains and Midwest in 2008 and 2009 and is likely a simple mutation from race QFCS.

The relative stability of *Pgt* populations east of the Rocky mountains is due to near-eradication of the barberry in the Midwest and northern Great Plains, which has resulted in a very small asexually (clonally) reproducing population that greatly reduces the potential for genetic change. However, the common barberry was not completely eliminated in the central US. Remnant barberry populations still exist in wooded areas of Minnesota and Wisconsin away from major wheat producing regions and are gradually re-colonizing some areas. Common barberry is also present in some wheat producing areas of the Pacific Northwest (eastern Washington and northern Idaho) and could be a source of new races of *Pgt* in the Central Plains if they successfully cross the Rocky Mountains. For example, in 2007 over 20 races of stem rust were identified in a sample of barley collected from a single field in eastern Washington and one of these races was virulent to *Sr24*, which was only the second time this virulence was found in North America. Over 10 races, most of which were novel, were identified from wheat samples collected in 2008 and 2009 from the same region. In 1989, *Pgt* race QCCJ was found in Minnesota and became established in the southern Plains on susceptible wheat cultivars; this race is postulated to have originated in the Pacific Northwest (Roelfs et al. 1993). This diversity of races is typical of a sexually reproducing population and the suspected spread of race QCCJ out of the Pacific Northwest demonstrates the potential for new races to develop on barberry and become important to wheat and barley production.

Resistance in wheat cultivars to existing North American races is often based on a combination of several resistance genes and consequently, only a small percentage of cultivars are susceptible to new races when they appear. Stem rust is now so rare in some areas of the US that cultivars susceptible to the most common races of the pathogen are being grown. This practice increases the potential for development of a stem rust epidemic, especially if the acreage of susceptible cultivars increases, which could result in serious yield loss and production of spores for long distance spread to other wheat-producing areas and selection of new races.

Favorable environmental conditions: Stem rust development is favored by heavy dews, high humidity, and warm temperatures. The optimal temperature for infection of wheat by *Pgt* ranges from 59 to 75°F (15-24°C). Light and 6 hours of leaf wetness, resulting from rain or dew, are required for infection to occur. The optimal temperature for disease development is from 75 to 86°F (24-30°C). Under these conditions, urediniospores are produced 7-14 days after infection. As a result of these temperature requirements, stem rust usually appears in June and July in the central and northern Great Plains, respectively. Late maturing cultivars usually are affected more severely than early maturing cultivars.

Disease spread: The urediniospores of *Pgt* can spread both by rain splash and wind-dispersal. The distance spores can travel by splash-dispersal is short and often results in spores only reaching neighboring plants, i.e. < 3 ft (0.9 m). In contrast, urediniospores blown by wind can travel hundreds or thousands of miles, although most are deposited within about 300 feet from the source. In both cases, location of the infections on the plant, wind velocity and turbulence, and moisture conditions influence spread (Eversmeyer and Kramer, 2000). Sunlight is another important factor influencing spread of stem rust because urediniospores of the pathogen are killed by ultraviolet light. The likelihood that viable spores will spread farther and be deposited on a susceptible plant increases with the number of spores present at the source. Consequently, urediniospores produced by a single pustule on a leaf might only result in the infection of neighboring plants, whereas a severely diseased field can produce trillions of spores that have the potential to infect plants hundreds or thousands of miles away.

In the US, stem rust annually spreads northward from Mexico and the Gulf Coast to the Great Plains and Canada. This spread follows the "green wave" of crop development that occurs as cereal crops mature progressively later from south to north. How rapidly the disease spreads depends on rainfall, wind speed and direction, and crop maturity. Consequently, the epidemic may accelerate or decelerate during the wheat growing season (Aylor, 2003). Under highly conducive conditions, the speed of movement (e.g., miles/day) of a stem rust epidemic is likely to accelerate rapidly and produce more spores, resulting in an epidemic that spreads further north (Fig. 3; Mundt et al., 2009). Thus, in severe epidemics, there may be little advanced notice of the arrival of stem rust and little time to take preventative actions.

Pgt is well adapted to long-distance dispersal and has been shown to move hundreds of miles in a single event (Nagarajan and Singh, 1990; Stakman and Harrar, 1957). Three implications of long-distance dispersal are particularly relevant to this Recovery Plan: the probability of stem rust reaching the US from the Eastern Hemisphere, its long-distance movement if established in the Western Hemisphere, and potential impacts of continental spread on US wheat and barley production. These points are discussed in detail below.

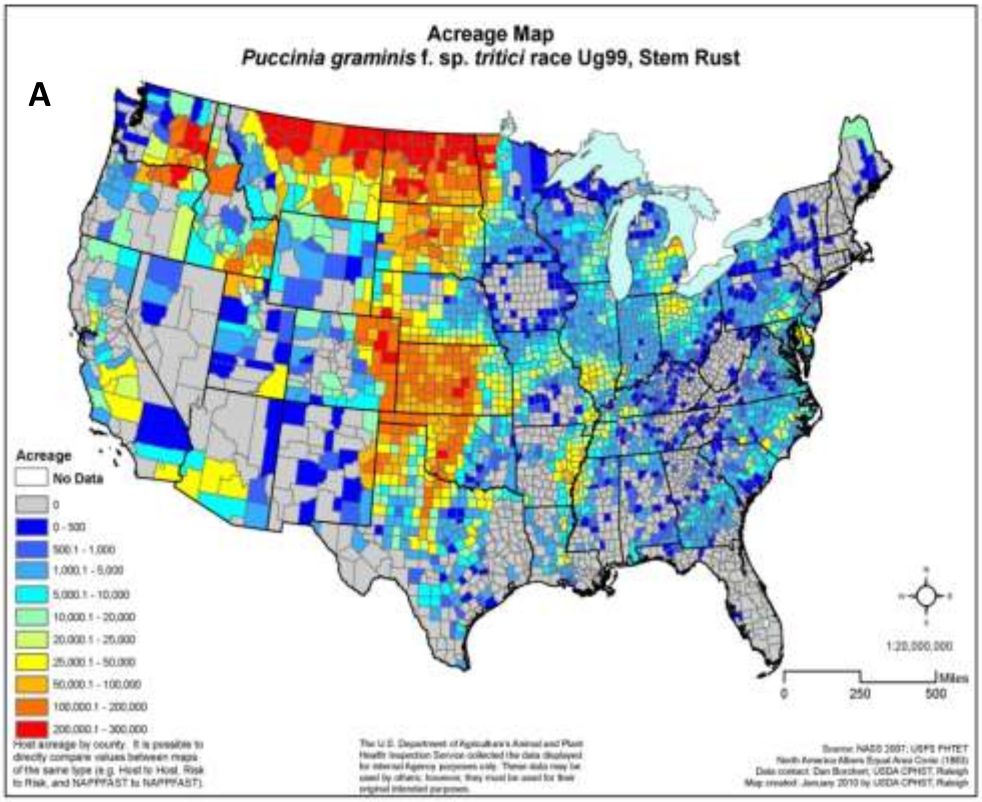
Potential for movement from the Eastern to Western Hemisphere: The aerial movement of *Pgt* spores from Eastern Hemisphere wheat and barley producing areas to the Western Hemisphere was simulated using the Integrated Aerobiology Modeling System (IAMS) developed to forecast soybean rust movement (Isard et al. 2005, 2007). The major wheat-producing areas of China, Australia, northwestern Africa/Europe, and southern Africa were the potential source regions used in the analysis. Production of wheat or barley in western Africa south of the Sahara desert is minimal and therefore, this area was not considered. Assuming that intense stem rust epidemics were present in the potential source regions, the spread of spores for all days during appropriate seasons when stem rust would be present from 1998 to 2007 was simulated. Based on approximately 5,000 daily simulations, the risk of aerial spread by natural means of Ug99 to the Western Hemisphere is very low. The implication of this finding, however, is that the most likely route by which Ug99 will enter the Western Hemisphere, if it does, is by human-mediated transport. One likely scenario involves contamination of clothing of a person visiting a field in the Eastern Hemisphere where Ug99 is present and that person then traveling to the Western Hemisphere and depositing the spores in a wheat field. This scenario is how wheat stripe rust was introduced to Australia from Western Europe (Wellings and McIntosh, 1987), and is surmised to be how barley stripe rust entered the Americas from the Eastern Hemisphere (Dubin and Stubbs, 1986).

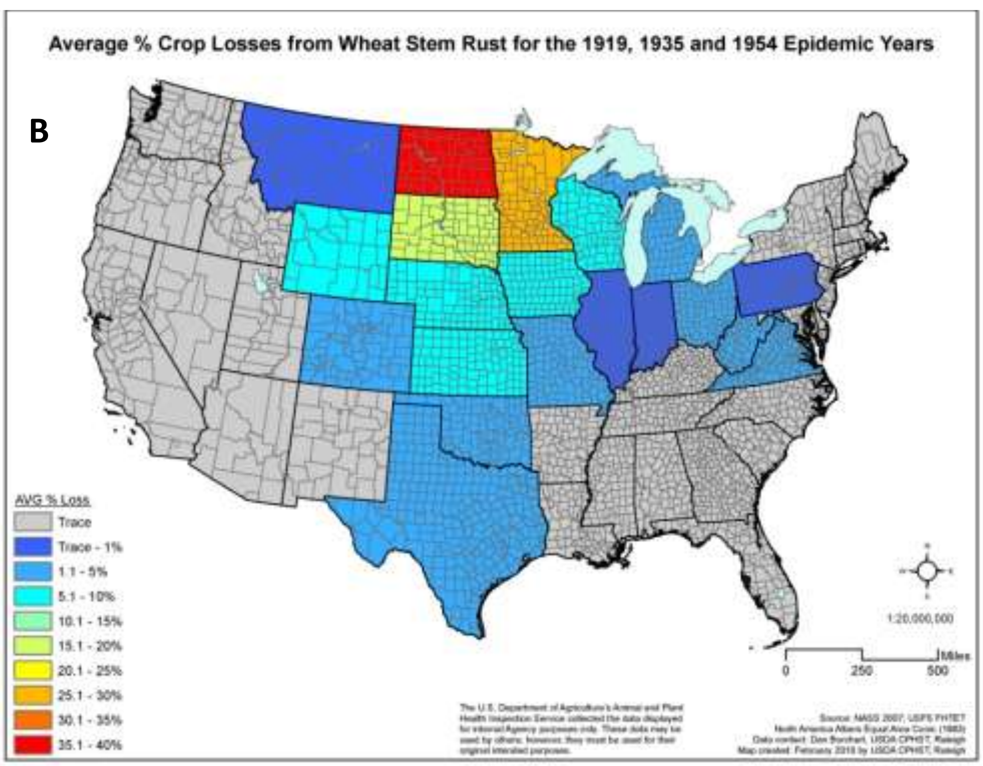
Figure 3. Continental-scale spread of wheat stem rust in North America, 1923. Solid blue indicates area of stem rust overwintering. Blue curves represent time of first appearance of wheat stem rust in different regions. Note that time between observations decreased as the season progressed, indicating the exponential rate of spread. Adapted from Mundt et al. (2009), © 2009 The University of Chicago Press. Map originally adapted from Stakman and Harrar (1957) and used by permission of John Wiley and Sons, Inc.

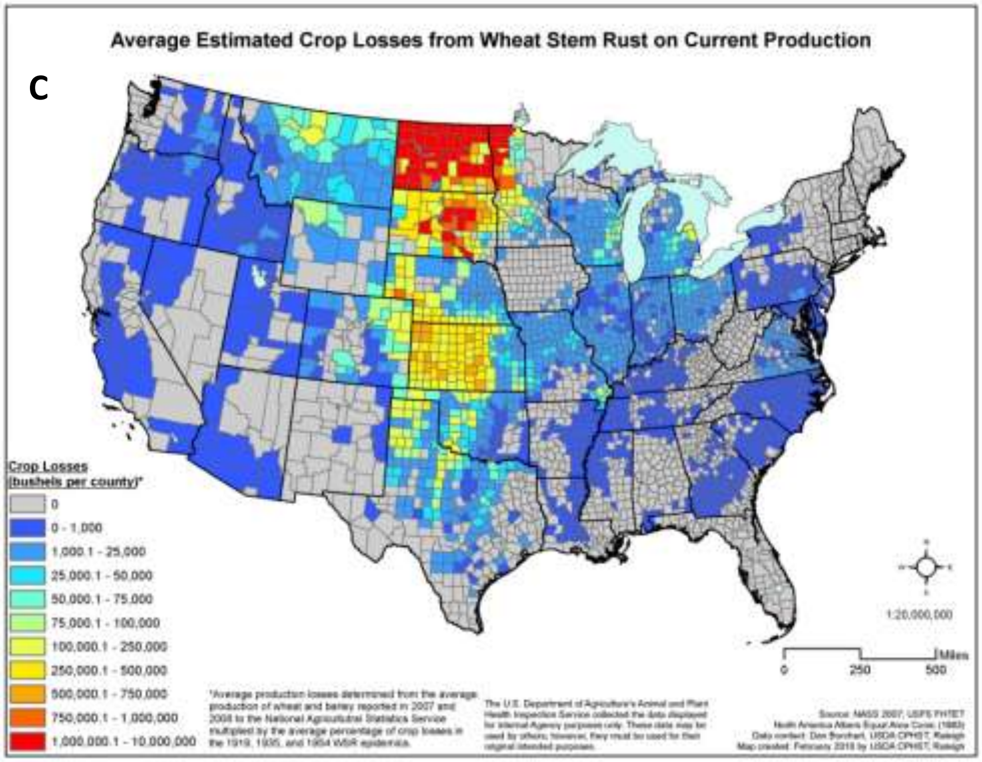
Potential for movement within the Western Hemisphere: Simulations were conducted using meteorological data from the same 10 year period and the Sonora and Chihuahua wheat producing areas of Mexico as the source of *Pgt* spores since these are the only significant areas of wheat production north of the equator in the Americas besides the US and Canada. The results demonstrate that the potential for spread of *Pgt* spores from these areas to wheat growing areas in the southern and central US is relatively high. This implies that Ug99 would likely spread through the air into wheat producing regions of the US within a few years if it was introduced into Mexico.

Mapping potential risk: A host acreage map for the contiguous US (Fig. 4A) was created using county acreage data available from USDA-NASS 2007 Agricultural Census for all classes of wheat and barley. The 2007 and 2008 wheat and barley production in bushels per county were also obtained from USDA-NASS for production calculations. The production per county (in bushels) was calculated by taking the average county wheat and barley production in 2007 and 2008. Historical data (Roelfs, 1978) on losses was used to construct a map showing estimates

Figure 4. Risk maps for potential impact of wheat stem rust based on acreage of wheat and barley production (A), historical crop losses (B), and estimated production losses (C).







of average percent losses for the epidemic years 1919, 1935, and 1954 (Fig. 4B). These years represent some of the worst recorded wheat stem rust epidemics in the US.

The estimated potential crop loss map (Fig. 4C) is derived from the average percent loss in affected fields in a state during the 1919, 1935, and 1954 epidemic years multiplied by current production (bushels per county). Use of fungicides and resistant cultivars is not considered and therefore, this model represents an estimate of the worst case scenario. Of greatest concern are situations where a "perfect storm" exists, i.e., the combination of a large overwintering pathogen population, extensive planting of wheat and barley cultivars susceptible to current races, and favorable climatic conditions. Avoiding such scenarios in the event of Ug99 introduction to the US depends on reducing overwintering inoculum in southern North America, growing resistant wheat cultivars that reduce the rate of reproduction of the pathogen and, to the extent possible, deploying different resistance genes in cultivars from south to north within North America (gene deployment).

IV. Diagnosis and Differentiation

Preliminary field diagnosis of stem rust is usually based on symptoms of the disease and parts of the plant that are infected, along with specific characteristics of the lesions (pustules) (Murray et al., 1998). Stem rust infections on cultivars that are resistant to common stem rust races in North America may indicate the occurrence of novel races and constitute "suspect" samples. Plant disease specialists at land-grant universities and/or the National Plant Diagnostic Network (NPDN) would likely examine all suspect samples in a laboratory and confirm the preliminary diagnosis by looking at spore morphology under a microscope and verifying identity of the cultivar. Suspected samples would then be promptly forwarded to the USDA-ARS CDL for race identification.

Race identification currently uses an infection bioassay on a set of wheat lines that contain different resistant genes (called differentials). The current North American stem rust race nomenclature system uses 20 differential wheat lines to designate races of the wheat stem rust pathogen (Jin et al., 2008). Race identity is determined by recording whether each differential line is susceptible or resistant following inoculation with the test isolate. This traditional method of differential-based race identification has been the primary method used in race surveys throughout the world to differentiate Ug99 from known races, as well as detecting and designating new variants of Ug99. A DNA-based polymerase chain reaction (PCR) method has been developed that can rapidly differentiate the Ug99 lineage from races of *Pgt* currently found in North America, but cannot distinguish individual races within the Ug99 lineage. This PCR diagnostic assay is currently available only at the CDL due to technological constraints. The CDL is developing another diagnostic test based on technologies that are transferable to NPDN laboratories.

V. Survey and Detection

The CDL conducts annual surveys of wheat, oat, barley, and rye stem rust, as well as wheat leaf rust and oat crown rust. Scientists make survey trips through representative areas of the Great Plains, Midwest, and Southeast to collect samples of the pathogens and monitor rust development in the cereal crops. The CDL survey is supplemented with samples collected by crop scientists from land-grant universities and private-sector scientists throughout the US. Samples are then tested at the CDL to determine the frequency and distribution of rust races.

Observations of disease severity and crop growth stage collected by the survey, as well as the monitoring observations from cooperators are distributed electronically to over 350 recipients via an e-mail listserv at the CDL. An interactive map for wheat stem rust observations and race identifications from the CDL is available online. Observations and results of the race identification assays also are distributed in the Cereal Rust Bulletin, which is produced at 2-week intervals from April to August and is distributed electronically. Extension specialists and crop advisors use this information to warn farmers of disease risk and potential disease related yield losses. Beginning in 2010 these observations will be available on the CDL public website with new tools to better visualize disease monitoring results, forecast disease, and access the control recommendations of extension specialists.

VI. Response

The response to all plant health emergencies in the US is under the auspices of USDA-APHIS-Plant Protection and Quarantine, with authority delegated by the Secretary of Agriculture under the Plant Protection Act of 2000.

After a detection of *Pgt* Ug99 that has been confirmed by a USDA-APHIS-PPQ recognized authority, APHIS, in cooperation with the appropriate State department(s) of agriculture, is in charge of the response. The response will begin with an initial assessment. A Rapid Assessment Team consisting of state and federal wheat and barley rust experts and regulatory personnel may be deployed on-site to take additional plant samples, conduct epidemiological investigations, and initiate environmental delimiting surveys outside of an infested area. Possible, but unlikely, actions include quarantines of infested or potentially infested production areas, prohibiting movement of infected or potentially infected articles in commerce, host removal and destruction, requiring adherence to sanitary practices and the application of registered fungicides and disinfectants. The Rapid Assessment Team will also attempt to ascertain if the introduction was intentional or accidental.

The USDA-APHIS-PPQ response will depend on where race Ug99 of *Pgt* is found (experimental plot or commercial field) and how widespread it is based on the initial assessment by the Rapid Assessment Team and associated delimitation surveys. It is unlikely that eradication or regulation will be attempted because *Pgt* Ug99 spreads rapidly by wind and the likelihood for widespread dispersal is high. An attempt will be made by PPQ to implement the *ipm*PIPE system in a manner similar to the initial response to soybean rust, caused by *Phakopsora pachyrhizi*.

VII. USDA Pathogen Permits

USDA-APHIS-PPQ permit and registration requirements for plant diseases and laboratories fall under the authority of the Plant Protection Act (7 CFR Part 330). The Plant Protection Act permit applies to all plant pests and infected plant materials, including diagnostic samples, regardless of their quarantine status that are shipped interstate and require that the receiving laboratory have a permit. For further guidance on permitting of plant pest material, consult the PPQ Permit website or contact PPQ Permit Services at (301) 734-8758.

USDA-APHIS-PPQ regulates (Black Stem Rust Quarantine, 7CFR 301.38) the propagation, importation, export and inter-state shipping of rust-susceptible ornamental barberry cultivars to prevent them from being planted in major wheat growing states. The regulation insures that only resistant cultivars are marketed by the nursery industry in all the major wheat producing states. At present 17 states are listed as protected states. Before any new ornamental barberry cultivars are marketed, they are screened for resistance to stem rust at the CDL. Nurseries dealing in ornamental barberry cultivars are inspected by state nursery inspectors under compliance agreements. The major black stem rust-resistant ornamental species in the market is *Berberis thunbergii,* which was initially imported (1890s) into the US as a replacement for *B. vulgaris.*

VIII. Economic Impact and Compensation

Stem rust of bread wheat, durum wheat, and barley has been one of the most important diseases of cereal crops since the emergence of western civilization (Peterson 2001). In the US, regional epidemics of wheat stem rust occurred numerous times in the 20th century including

1904, 1916, 1923, 1925, 1935, 1937, 1953, 1954, and 1965 (Stakman and Harrar 1957, Roelfs 1978) with losses of over 50% recorded in Minnesota and North Dakota in 1935. Total losses due to stem rust in Minnesota, North Dakota and South Dakota were estimated at over 100 million bushels in 1935 and over 150 million bushels, combined over 1953 and 1954, which represents nearly $3.7 billion (adjusted to 2009 dollars) in lost production in those three seasons alone. Although the most devastating stem rust epidemics occurred in the northern Plains, yield losses to stem rust have been substantial in some areas of the central Plains, the Mississippi River valley, and eastern states where soft red and soft white winter wheat are grown. Annual yield loss estimates for rust diseases in wheat, barley, oat, and rye for all cereal-producing states in the US are compiled by the CDL.

Worldwide, 82 and 75 countries grow wheat and barley, respectively, with 27 developing countries producing more than 247,000 acres (100,000 hectares) of wheat annually (Saari and Prescott, 1985). Historically, stem rust has been a major problem in the wheat-producing regions of Africa, the Middle East, Asia (except Central Asia), Australia, New Zealand, Europe, and North and South America (Saari and Prescott, 1985). Major yield losses to stem rust occurred in Kenya, near where Ug99 was first detected, in the 2007 crop season. It is anticipated that Ug99 and its derivatives will spread from Iran, where it is now present, into Asia where 124 million acres (50 million hectares), one-quarter of the world's wheat acreage and about 20% of its production occurs (Singh et al., 2008). Based on cultivar ratings studies conducted in Kenya in 2005 and 2006, cultivars resistant or moderately resistant to Ug99 are produced on 5% of the area from 18 African and Asian countries and susceptible or moderately susceptible cultivars are produced on 54% of the area; the reaction cultivars produced on the remaining 41% of the area is unknown (Singh et al., 2008). The impact of a severe stem rust epidemic would be two-fold including both direct losses to growers and families depending on the production, which would be felt locally, and the indirect effects on world wheat stocks, which could have a worldwide impact.

The USDA Risk Management Agency (RMA) provides insurance protection through approved private crop insurance companies. Growers must be enrolled to be eligible for benefits and applications must be made by the sales closing date. Compensation is based on the grower's actual production history less any production to count. Indemnities are paid for those who sustain crop damage resulting from several different perils as a result of a naturally occurring event or acts of nature. Disease is a covered peril as long as it is not a result of insufficient application of disease control measures. Growers should contact a local crop insurance agent, which may be located through the RMA Website.

In 2008 RMA insured 76.8% of the wheat acres planted. Wheat insurance programs are currently available in 45 states. An outline of the crop insurance programs that are available for wheat producers, depending on county and state, are as follows:

- Crop Revenue Coverage - Wheat (04-CRC-WHEAT). (7/03).
- Crop Revenue Coverage - Winter Coverage Endorsement (04-CRC-WWO). (5/03).
- Group Risk Plan - Wheat (00-111).
- Group Risk Income Protection - Wheat (06-GRIP-WHEAT).

- Group Risk Income Protection - Harvest Revenue Option Endorsement (04-GRIP-HRO).
- Group Risk Income Protection - Wheat Commodity Exchange Endorsement (08-GRIP-WHEAT-CEE).
- Multiple Peril Insurance Program - Wheat - Small Grains. 04-011.
- Multiple Peril Insurance Program - Winter Coverage Endorsement (04-011A).
- Revenue Assurance - Wheat (04-RA-Wh). (7/03).
- Revenue Assurance - Winter Wheat Coverage Endorsement (04-RA-WWE).

Table 1. Wheat liabilities, total premiums, premium subsidy, indemnities paid and loss ratio for the most recent five years.

Crop Year	Liabilities, $	Total Premium, $	FCIC Subsidy, $	Indemnity, $	Loss Ratio
2008	8,743,039,151	1,594,163,980	937,376,207	1,145,305,358	0.72
2007	5,382,649,040	897,030,418	525,466,751	862,570,654	0.96
2006	4,001,579,182	624,267,800	364,108,169	800,832,812	1.28
2005	3,871,190,525	577,204,182	336,704,306	344,018,380	0.60
2004	3,905,397,268	560,172,477	325,341,285	509,360,907	0.91

RMA provides crop insurance programs to producers. RMA develops and/or approves the premium rate, administers the premium and expense subsidies, approves and supports products, and reinsures the companies. The approved private crop insurance companies sell and service the policies. The companies and their agents can respond promptly to meet the service needs of local producers.

For more information on risk management and insurance programs available visit the RMA website. Total wheat acres were obtained from the USDA National Agricultural Statistics Service (NASS), Agricultural Statistics Board.

IX. Mitigation and Disease Control

Resistance. Genetic host resistance is the most desirable method of disease control because it is the most effective, least expensive, and environmentally benign approach. Developing and deploying cultivars with new sources of stem rust resistance effective against Ug99 will take about 10 years. The quickest way to reduce the risk of stem rust is to identify very susceptible cultivars and discourage their production in areas prone to stem rust epidemics. Several types of disease resistance exist; the advantages and disadvantages of each are described below.

All-stage resistance. All-stage resistance, sometimes called seedling resistance, is controlled by one or a few genes that confer highly effective resistance during the entire life of the wheat plant (Hare and MacIntosh, 1979; Roelfs et al. 1972; Rowell and McVey, 1979; Sunderwirth and

Roelfs, 1980). This type of resistance is relatively easy to transfer by conventional breeding techniques, and resistant lines are relatively easy to identify using artificial inoculation tests at the seedling stage. Many of the genes that control all-stage resistance come from alien species (wild wheats), which makes it easier to identify molecular markers linked to the genes and to combine several genes (pyramid) into the same cultivar using marker assisted selection. Furthermore, all stage resistance is minimally influenced by environmental conditions (temperature, light, dew duration, etc.), host (plant nutrition, vigor, and growth stage), and pathogen (inoculum density) effects that can have a major influence on other types of resistance.

There are two main disadvantages with all-stage resistance. First, all-stage resistance genes that originate from alien species are often associated with genes that have negative effects (linkage drag) on yield, quality, susceptibility to other diseases, and other undesirable agronomic characteristics. It usually takes many years of breeding to separate the resistance genes from the undesirable genes. Second, all-stage resistance genes usually are race specific, i.e. they are effective against some races of the pathogen but ineffective against others. Widespread use of these genes can put selection pressure on the pathogen population to change in favor of mutants that render the specific resistance genes ineffective. Currently, it is not possible to accurately predict the durability of these resistance genes. Some all-stage genes are overcome by new races before being deployed in commercial cultivars. However, other genes like *Sr31*, the all-stage resistance gene overcome by Ug99, have been durable and provided useful resistance globally for several decades.

Most, if not all, known stem rust resistance genes in wheat have been tested in seedling and adult plants for reaction to Ug99 (Jin et al., 2007). Results indicated that 17 of the 46 genes were effective in seedling and adult plants to Ug99, 25 were ineffective, and 4 were inconclusive. However, variants of Ug99 with virulence to additional *Sr* genes have been detected (Jin et al., 2008; Jin et al., 2009), which emphasizes the need to aggressively pursue identification of novel, stem rust resistance genes that provide effective all-stage resistance.

Adult plant resistance. Plants with adult-plant resistance (APR) are susceptible as seedlings but become resistant as they mature. Cultivars with APR generally have intermediate levels of stem rust in the field. Compared to a very susceptible cultivar with no APR, the level of APR can be low (susceptible), moderate (moderately susceptible) or high (moderately to fully resistant). Moderate and high levels of APR would be useful wherever wheat is prone to stem rust epidemics, and even low levels of APR may be sufficient to prevent losses in areas that are marginal for stem rust development.

Identification of APR is more time-consuming than all-stage resistance because wheat plants need to be grown to maturity, often in multiple environments, and determining the level of resistance is more difficult. Molecular markers can be used to “tag” APR genes, which would allow plants containing APR genes to be identified as seedlings. However, finding molecular markers that are closely linked to APR genes is more difficult than for all-stage resistance genes because APR is more difficult to identify.

Many sources of APR to stem rust have been described in the literature, but little is known about the genes controlling it. Some sources of APR to other wheat rusts are race specific, whereas others appear to be race nonspecific. Adult-plant disease ratings from nurseries in Kenya can be used to estimate the level of APR to Ug99. However, environmental (temperature, light, and dew duration), host (plant nutrition, vigor, and growth stage), and pathogen (inoculum density) conditions likely influence expression of APR. It would be useful to evaluate US cultivars and advanced breeding lines at several locations in the US for APR to locally prevalent races of *Pgt* on the assumption that most APR resistance would be race non-specific and therefore, should be effective against Ug99. It would also be useful to develop genetic maps for the genes controlling APR in winter wheat in the US and develop molecular markers to facilitate their transfer into new cultivars. Nurseries inoculated with common US *Pgt* races specifically designed to identify APR are being established in Louisiana and North Carolina for the 2009-2010 growing season for this purpose.

Durable resistance. By definition, durable resistance is that which remains effective after commercial use over a large area for a long period of time across environments where epidemics of the disease are common. There are many reasons why resistance is "durable." Often durable resistance is achieved when an APR gene is combined with other adult plant or all-stage resistance genes. One such example is *Sr2*, which was combined with other *Sr* genes resulting in the "*Sr2*-Complex" (Singh et al., 2009) that continues to provide durable, partial resistance since it was transferred into hexaploid wheat in the 1920s (McFadden, 1930) .

Sr31 is perhaps the best example of a single all-stage resistance gene that conferred durable resistance. Unfortunately, this gene is no longer effective where Ug99 and its variants occur. Nevertheless, it provided decades of protection to millions of acres of wheat around the world. It is currently impossible to predict which all-stage resistance genes might be the next great success story. Additional research is needed to better understand the mechanisms that might contribute to durable resistance of individual genes like *Sr31*.

Gene Combinations or Gene Pyramids. Combining resistance genes, or gene pyramiding, should provide more durable resistance than single genes based on the hypothesis that mutations to virulence in the pathogen are rare and independent events (Schaffer and Roelfs, 1985). If the probability of mutation to virulence for one gene is one in a million, then the probability of mutation for two genes is one in a million times one in a million, or one in a trillion. With three genes, that probability increases to one in a quintillion (one followed by 18 zeros). Thus, as more genes are added to the pyramid, the probability of simultaneous mutations to virulence becomes extremely unlikely. Gene pyramiding depends on having many genes available for use by breeders that are effective and which have not already been overcome by the pathogen. Increasing the availability of molecular markers for stem rust resistance genes will facilitate gene pyramiding efforts (Liu et al., 2010; Olson et al., 2010).

Cultivar mixtures and multiline cultivars. Growing a mixture of wheat cultivars that possess different race-specific resistance genes can both slow an epidemic within a field and delay the time it takes for the pathogen to overcome a new resistance gene. Norman Borlaug developed this methodology for the control of wheat stem rust in the 1950s and demonstrated that it can be very effective (Borlaug, 1959).

A similar approach is the use of multiline cultivars wherein a wheat breeder develops closely related lines within a cultivar, each containing a different resistance gene or combination of resistance genes. This approach has been used successfully to control stripe rust of wheat in the Pacific Northwest (Allan et al., 1993).

Gene deployment. Regional deployment of resistance genes, or gene deployment, is the geographic distribution of resistance genes among different wheat-producing regions so that each will have effective resistance genes that are not used in other regions. The idea behind this strategy is that inoculum (spores) produced in one region will not be adapted to or "match" the resistance genes used in another region and therefore, be unable to infect the cultivars present, thus minimizing spread of the disease (Frey et al., 1977).

A gene deployment strategy is applicable to the Puccinia pathways running from southern Texas to Canada and from the Florida Panhandle northward up the East Coast, but has had limited implementation. A similar situation exists with stem rust infecting wheat in the fall in the Gulf Coast States and subsequently spreading northward along the Atlantic coast. Deploying different *Sr* genes across these regions has the potential to limit disease spread and development.

Implementing a gene deployment strategy for stem rust control in the US would likely be voluntary because currently there is no legislation governing the use of resistance genes. In addition, sufficient numbers of effective resistance genes would need to be available in adapted germplasm to meet these requirements. A similar situation exists in the rest of the world.

Escape. Although not a form of disease resistance, escape occurs when a susceptible plant is not infected as the result of such factors as random chance and maturity date. In most areas, stem rust develops late in the growing season when conditions become conducive for disease development. Therefore, cultivars that mature early may escape severe stem rust. This strategy has been used effectively in several regions of south-central and the southern US. Escape is an important consideration, especially across the southern US where a shift to later-maturing cultivars or later maturity due to late planting likely would increase severity of stem rust and provide spores to initiate epidemics in the central and northern US.

Chemical control. As previously mentioned, development of enough cultivars with effective resistance to Ug99 may take 10 years or more. Consequently, chemical control will likely be an important tool if the new races of stem rust arrive prior to widespread deployment of new resistant cultivars. Several fungicides have US federal registration for wheat and barley, although not all are currently marketed for this use. Few of these products have been studied extensively for efficacy against stem rust, and those that have been tested in the US were evaluated using US races of *Pgt* (or *Puccinia graminis* f. sp. *avenae* in oats); however, preliminary results indicate that several products are highly effective in controlling Ug99 (Table 2). Products containing a triazole fungicide were generally the most effective in limiting disease development and/or reducing disease severity. Differences in efficacy were noted among individual triazole fungicides, indicating that not all provide the same degree of control. Studies using US races are consistent with field results from Africa for Ug99 (Wanyera et al., 2009). Additional studies are needed to determine the effectiveness of new fungicides, appropriate timing of their application relative to crop growth stage, and which application technologies provide optimal control. It is also likely that the efficient use of fungicides will require an accurate forecasting system, knowledge of cultivar susceptibility, and integration with control practices for other diseases.

Table 2. Preliminary stem rust efficacy estimates for the fungicides currently labeled on, and being marketed for small grain cereals in the United States.

Class	**Fungicide**				**Restriction(s)[2]**	**Registered[3]**
	Active Ingredient(s)	**Product Name(s)**	**Rate/A**	**Efficacy[1]**		
Strobilurin (Group 11)	Azoxystrobin 22.9%	Quadris 2.08 SC	6.2 - 10.8	G	Feekes 10.5 and 45 days	WBT
	Pyraclostrobin 3.6%	Headline 2.09 EC	6.0 - 9.0	G	Feekes 10.5	WBT
Triazole (Group 3)	Metconazole 8.6%	Caramba	10.0 - 17.0	VG	30 days	WBTOR
	Propiconazole 41.8%	Tilt 3.6 EC PropiMax 3.6 EC Bumper 41.8 EC	4.0	F	40 days	WBTOR
	Prothioconazole 41%	Proline 480 SC	5.0 - 5.7	E	Feekes 10.52 and 30 days (32 for B)	WB
	Tebuconazole 38.7%	Folicur 3.6 F	4.0	E	30 days	WB
	Prothioconazole19% Tebuconazole 19%	Prosaro 421 SC	6.5 - 8.5	E	Feekes10.52 and 30 days	WB
Multiple (Group 3/11)	Propiconazole 11.7% Azoxystrobin 7.0%	Quilt 200 SC	14.0	G	Feekes 10.5 (and 45 days for BT)	WBT
	Propiconazole 11.7% Azoxystrobin 13.5.0%	Quilt Xcel	14.0	G	Feekes 10 (and 45 days for BT)	WBT
	Propiconazole 11.4% Trifloxystrobin 11.4%	Stratego 250 EC	10.0	G	Feekes 10.5 and 35 days (40 for BO)	WBO
	Metconazole 7.4% Pyraclostrobin 12%	TwinLine	6.0 - 11.0	G	Feekes 10.5	WBTOR

1. Efficacy: P=Poor; F=Fair; G=Good; VG=Very Good; E=Excellent. Preliminary estimates are based on currently available data with more available for Tebuconazole and Propiconazole. When products have only been evaluated in a few studies, ratings are based in part on efficacy against other cereal rust diseases.
2. Apply no later than the growth stage and/or number of days listed in the pre-harvest interval. Additional restrictions might be present on the label. Please consult individual labels for more information.
3. Crops on label: W = wheat, B = barley, T = triticale, O = oats, and R = rye.

A potential issue concerning the control of stem rust with fungicides is the development of fungicide resistance in the *Pgt* population. The Fungicide Resistance Action Committee considers *Puccinia* species to be at low risk of developing resistance to fungicides; however, the strobilurin class of fungicides is considered at high risk for development of resistance with other fungi, and shifts in sensitivity to certain triazole fungicides have been noted for the stripe rust pathogen, *P. striiformis*, in laboratory experiments. The US *Pgt* population is currently small and under little selective pressure for developing fungicide resistance. Consequently, there appears to be a low to moderate risk of resistance developing in *Pgt* to the fungicides currently available. However, this risk would increase if Ug99 were to become established in the US over a large area since many growers would likely spray to control disease. Given this scenario, evaluation of fungicides from other classes against stem rust is recommended to diversify the products available.

X. Experts and Infrastructure Listing

Infrastructure. A wheat and barley disease research infrastructure exists to study rust diseases. That infrastructure could be directed to answer several important issues listed in the next section on research, education, and extension priorities. The primary federal centers of wheat and barley stem rust research are at the Cereal Disease Laboratory in Minnesota, Hard Winter Wheat Genetics Research Unit in Kansas, Plant Science Research Unit in North Carolina, and Wheat Genetics, Physiology, Quality, and Disease Research Unit in Washington. Research programs on stem rust are ongoing at state experiment stations at Cornell University, Kansas State University, University of Minnesota, Ohio State University, Pennsylvania State University, South Dakota State University, and Washington State University. According to the USDA/CSREES Current Research Information System, $21.4 million dollars were allocated for wheat and barley stem rust related research in 2008, the last year with complete figures. Of this amount, $5.8 million were spent on research projects directed specifically at stem rust.

Experts. The following stem rust experts and their areas of expertise have been identified:

Marty Carson – host resistance and population genetics
USDA-ARS Cereal Disease Lab, University of Minnesota, 1551 Lindig Street, St Paul, MN 55108-1050, (612) 624-4155, fax (651) 649-5054, marty.carson@ars.usda.gov

Ronnie Coffman – breeding for disease resistance
College of Agriculture and Life Sciences, 252 Emerson Hall, Cornell University, Ithaca, NY 14853, (607) 255-2554, fax (607) 255-1005, wrc2@cornell.edu

Scott Isard – pathogen dispersal and detection
Pennsylvania State University, Plant Pathology Department, 205 Buckhout Lab, University Park, PA 16802, (814) 865-6290, fax (814) 863-7217, sai10@psu.edu

Yue Jin – population biology, race dynamics and disease resistance
USDA-ARS Cereal Disease Lab, University of Minnesota, 1551 Lindig Street, St Paul, MN 55108, (612) 625-5291, fax (651) 649-5054, yuejin@umn.edu

Kurt Leonard (retired) – population biology and genetics of stem rust
University of Minnesota, Plant Pathology Department, 1991 Upper Buford Circle, St Paul, MN 55108-1050, (612) 651-4822, kurtl@umn.edu

David Long – surveillance and detection
USDA ARS Cereal Disease Lab, University of Minnesota, 1551 Lindig Street, St Paul, MN 55108-1050, (612) 625-1284, fax (651) 649-5054, davidl@ars.usda.gov

Pierce Paul – fungicide control of stem rust
Ohio State University, OARDC - Plant Pathology Department, 1680 Madison Ave, Wooster, OH 44691, (330) 263-3842, fax (330) 263-3841, paul.661@osu.edu

Alan Roelfs (retired) – stem rust biology
14500 Ferry Road, Grantsburg, WI 54840-7202, (715) 463-5626, fax (651) 649-5054, alanro@grantsburgtelcom.net

Brian Steffenson – population biology, races and disease resistance in barley
University of Minnesota, 495 Borlaug Hall - Plant Path Dept, 1991 Upper Buford Circle, St Paul, MN 55108-6030, (612) 625-4735, fax (612) 625-9728, bsteffen@umn.edu

Jeff Stein – epidemiology and fungicide control of stem rust
South Dakota State University, 107 Plant Science Bldg - Box 2108, 1205 Jackrabbit Dr, Brookings, SD 57007, (605) 688-5540, fax (605) 688-4024, jeff.stein@sdstate.edu

Les J. Szabo – genomics, genetics, and molecular diagnostics
USDA-ARS Cereal Disease Lab, University of Minnesota, 1551 Lindig Street, St Paul, MN 55108-1050, (612) 625-3780, fax (651) 649-5054, Les.Szabo@ars.usda.gov

In addition to the experts listed above, expertise on the cereal rusts exists in two national Extension and Research Activity committees, WERA-97 and NCERA-184, which address diseases of small cereal grains in the US including wheat stem rust and together with the experts listed above, constitutes the majority of expertise in the US on wheat stem rust.

XI. Research, Extension, and Education Needs

It is imperative that the extension and educational responses in the US to the potential introduction of Ug99 and related stem rust races into North America are coordinated and based on sound research. Important gaps exist in our knowledge that affects these extension and education efforts. Current understanding of stem rust is based largely on 50+ year-old data that must be re-examined. Updated research is needed to improve our understanding of stem rust in the context of contemporary cropping practices, wheat cultivars, and pathogen characteristics.

Research. There are four high priority themes for research on stem rust: Breeding for host resistance to emerging races with new virulence patterns; improving our ability to detect and identify new races with biological and molecular tools; increasing our understanding of stem rust epidemiology to augment and develop decision-support systems and predictive models; and control with fungicides since they will be a critical tool that must be available until wheat and barley cultivars with effective host resistance are available and widely planted. Specific areas of research within these general themes are described below.

1. Breeding for host resistance in wheat and barley
    a. Incorporate known resistance sources into adapted germplasm lines, develop DNA markers, and develop new resistant commercial cultivars using marker-assisted selection.
    b. Identify new resistance sources that confer effective and durable stem rust resistance at all stages of crop development in germplasm collections and wild relatives of wheat.
    c. Characterize known adult plant resistance in current cultivars adapted for the US Develop genetic maps for APR genes to improve efficiency in transferring them in breeding programs.
    d. Develop a better understanding of 'Genotype X Environment' interactions and their influence on the expression of stem rust resistance genes. This information is needed to predict whether evaluation of resistance in Africa is relevant to the US.
2. Detection of new races
    a. Identify or develop differential cultivars to be used as biological indicators for loss of effectiveness of specific resistance genes in field plots and observation nurseries.
    b. Develop molecular methods to rapidly identify new races of *Pgt*.
    c. Augment the existing surveillance network with additional locations and observers to improve our ability to rapidly detect newly emerging or introduced races of stem rust.
3. Epidemiology
    a. Develop models describing pathogen survival and stem rust development in epidemiologically important regions of the US using historical data and verify accuracy for emerging races of the pathogen.
    b. Clarify temperature requirements for spore germination, infection, and disease development by historical and currently prevalent North American races and emerging African races of the stem rust pathogen.
    c. Construct and validate spore dissemination models to predict the risk of pathogen movement on both inter- and intra-continental scales.
4. Fungicides
    a. Identify fungicides and application timing and technologies that provide the most effective control of stem rust.
    b. Seek new fungicides with alternative modes of action to reduce the risk of fungicide resistance and allow rotation of products as needed. Continue the screening of new products in multiple environments.
    c. Develop decision support tools to guide fungicide application by integrating risk with local and regional disease occurrence and atmospheric movement models.

Extension. The threat of Ug99 and other newly emerging races of stem rust ultimately will be controlled by growers, agriculture professionals, decision makers and other stakeholders on farms across the country. Therefore, education of these stakeholders is important to maximize their impact for controlling stem rust. The current generation of growers, agricultural professionals and decision makers have either not had to control stem rust or have not considered the implications of these new races. As such, extension activities need to inform them so they can make the best disease control decisions possible.

Effective in-season control of stem rust in wheat and barley could benefit from a state-of-the-art IT platform that links people and computers so the best possible information and guidelines are available when decisions must be made. A Cereal Rust IT platform is currently under construction and will have functionality similar to that of the USDA *ipm*PIPE (Isard et al., 2006), but that reflects the current CDL-led surveillance network and the needs of specialists, wheat and barley producers, and other stakeholders to rapidly detect and respond to the anticipated introduction of Ug99.

In the future, most disease control decisions will likely be made based on local and regional surveillance reports. Education focused in the following areas will improve the ability of stakeholders and growers to make informed decisions:

1. Identify and differentiate among the three cereal rusts. Characterize disease reaction in existing cultivars so growers will understand the potential impact of stem rust on their cultivars and have the information needed to select the best cultivars for effective stem rust control.
2. Surveillance and monitoring is critical to knowing where stem rust inoculum is coming from and when it might arrive at a given location and, therefore, is a key element of forecasting and risk analysis. Monitoring can be enhanced by maintaining the existing USDA race survey, expanding monitoring in Gulf Coast and southeastern states, and establish monitoring on barberry, which can serve as a potential source of new races.
3. Fungicide decision tools (decision tree) will help producers analyze risk and make decisions to protect their crop that will satisfy crop insurance criteria. Education on effectiveness of individual fungicides and combinations, optimal application timing and method, and use of 'Good Farming Practices' risk assessment tools approved by USDA-Risk Management Agency will be needed.
4. Educate the new generation of farmers, agriculture professionals, decision makers, and the lay public with no experience with stem rust about the importance of barberry. Nearly 30 years have passed since the barberry eradication program ended in 1981, but most organized survey ended in the 1970s. Some re-emergence of barberry has occurred, but that threat is not well defined. If available, State and Federal agricultural agencies can refer to the original Barberry Eradication Program survey data (L-forms) for specific information on previous locations of eradication.
5. Develop a Standard Operations Protocol (SOP) for diagnostics and communication of results to growers and professionals. Standard diagnostic procedures and policies implemented through the National Plant Diagnostic Network labs will be critical in assuring the ability to

manage sample surge, competency and correct diagnoses, and execution of proper chains of communications.

Education. Although stem rust is a classic teaching example in plant pathology courses, its relevance has been lost to students and professors alike because it is so rarely encountered in the field today. New students must be made aware of the economic and biological importance of stem rust. This issue can be addressed with the following activities:

1. Field short courses to help farmers and agriculture professionals and decision makers evaluate regional and local scouting reports and make field-level diagnosis based on visual symptoms.
2. Encourage the use of real-world data on stem rust as a relevant example of the co-evolution of pathogen and host populations when teaching foundation courses in general biology, microbiology, plant science, environmental science, and agricultural science. The APSnet Education Center *Plant Health Instructor* could be a delivery mechanism to share teaching resources across universities.
3. Reinforce the importance of barberry in the stem rust life cycle in graduate and undergraduate programs. Develop virtual and literal classroom curricula to bring stem rust into the classroom. Many graduate students in plant pathology and most undergraduate plant science-based majors complete their education without ever actually seeing stem rust. This trend must be reversed if we are to be in a position to respond to the disease when it is in the field.

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Web Resources

Borlaug Global Rust Initiative

Common Barberry Bush Identification aid

Durable Rust Resistance in Wheat

Ug99 Rust Mapper

USDA-APHIS *Berberis* species and cultivars

USDA Cereal Disease Laboratory

USDA Coordinated Approach to Address New Virulences in Wheat and Barley Stem Rust - Pgt-Ug99

USDA National Plant Disease Recovery System

Black stem rust biology and threat to wheat growers

World Wheat Supply Threatened