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Global Status of Ug99 Spread and Efforts to Mitigate the Threat

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Abstract

Race Ug99, or TTKSK, of fungus *Puccinia graminis tritici*, causing stem or black rust disease on wheat (*Triticum aestivum*) has been recognized as a major threat to wheat production. First detected in Uganda in 1998 and now spread throughout East Africa, Yemen, Sudan and Iran and its further predicted spread towards North Africa, Middle East, and Asia and beyond has raised serious concerns of major epidemics that could destroy the wheat crop in various areas. Detection of two new Ug99 variants TTKST and TTSSK, detected in Kenya in 2006 and 2007 with virulence to genes *Sr24* and *Sr36*, respectively, also show that Ug99 is evolving. The TTKST variant caused severe epidemics in 2007 in some regions of Kenya and rendered about half of the previously known Ug99-resistant global wheat materials susceptible. This has further increased the vulnerability globally. Rigorous screening since 2005 in Kenya and Ethiopia of wheat materials from 22 countries and International Centers has identified low frequency of resistant materials that have potential to replace susceptible cultivars. Diverse sources of adequate resistance, both race-specific and adult-plant type, are now available in high-yielding wheat backgrounds and are being used in breeding. Ug99 threat in most countries can be reduced to low levels by urgently identifying, releasing and providing seed of new high yielding, resistant varieties.

Introduction

Stem or black rust of wheat, caused by fungus *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn. Historically is known to cause severe devastation periodically and was most feared disease in various countries in all continents where wheat is grown. According to Saari and Prescott (1985) stem rust was historically a major problem in all of Africa, the Middle East, all of Asia except Central Asia, Australia and New Zealand, Europe, and the Americas (both North and South). Although the last major stem rust epidemics occurred in Ethiopia during 1993 and 1994 when a popular wheat variety

“Enkoy” suffered major losses, the rest of the world has practically remained unhurt from stem rust for over three decades.

Stem rust appears as elongated blister-like pustules, or uredinia, most frequently on the leaf sheaths of a wheat plant, but also on true stem tissues, leaves, glumes, and awns. Stem rust pustules on leaves develop mostly on the lower side, but may penetrate and produce limited sporulation on the upper side. On the leaf sheath and glumes, pustules rupture the epidermis and give a ragged appearance. Masses of urediniospores produced on the pustules are brownish-red in color, and easily shaken off the plants. As infected plants mature, uredinia convert into telia; changing color from red into dark brown to black, thus the disease is also called black rust. Teliospores are firmly attached to plant tissue. Urediniospores disseminate to newly emerged tissues of the same plant or adjacent plants to cause new infections, or can be transported to long distances through wind.

Current distribution of race Ug99

Ug99 was first identified in Uganda in 1998 (Pretorius et al. 2000), although there is some evidence indicating that the race may have been present in Kenya since 1993, and had spread to most of the wheat growing areas of Kenya and Ethiopia by 2003. In 2005, Ethiopian reports confirmed its presence in at least six dispersed locations. The East African highlands are a known “hot-spot” for the evolution and survival of new rust races. The favorable environmental conditions and the presence of host plants year-round favor the survival and build up of pathogen populations. Available evidence indicates that Ug99 has exhibited a gradual step-wise range expansion, following the predominant air flows.

The confirmed range of Ug99 continues to expand, with new sites being recorded beyond the previously confirmed three East African countries Uganda, Kenya and Ethiopia. In early 2006 (February/March), stem rust was reported from a site near New Halfa in eastern Sudan. Later the same year (October/November), reports were obtained from at least two sites in western Yemen. Subsequent race analysis of samples from these sites confirmed the presence of Ug99 in these countries. Samples of stem rust collected at two field sites in Iran during 2007 were also confirmed to be the Ug99 race by K. Nazari (Plant Disease, *in press*). The observed expansion into new areas is in-line with previous predictions on the likely movement of Ug99 (Hodson et al. 2005, Singh et al. 2006) and fits the step-wise dispersal model following prevailing winds. Severe drought in Iran in 2008 resulted in severe production losses as well as unfavorable

weather conditions for rust development. This situation probably does not mean that Ug99 will not be found in Iran the coming crop season if weather conditions are favorable.

Avirulence/virulence genes in Ug99

Race Ug99 is the only known race of *P. graminis tritici* that has virulence for gene *Sr31* known to be located in the translocation 1BL.1RS from rye (*Secale cereale*). It was designated as TTKS by Wanyera et al. (2006) using the North American nomenclature system (Roelfs and Martens, 1988) and more recently as TTKSK after a fifth set of differentials was added to further expand the characterization (Jin et al., 2008). The most striking feature of race Ug99 is that it not only carries virulence to gene *Sr31* but also this unique virulence is present together with virulence to most of the genes of wheat origin, and virulence to gene *Sr38* introduced into wheat from *Triticum ventricosum* that is present in several European and Australian cultivars and a small portion of new CIMMYT germplasm (Table 1, Jin et al., 2007). This virulence combination might have accounted for the wide-spread Ug99 susceptibility in wheat varieties worldwide. A variant of Ug99 with added virulence to *Sr24* was detected in 2006 in Kenya. It is anticipated that mutation toward more complex virulence will likely occur as the fungal population size increases and selection pressure is placed on the population by resistant varieties.

Predicting Ug99 migration to other wheat areas

Detailed analysis of potential onward movements of spores from a site can be undertaken using the HYSPLIT air-borne particle trajectory model developed by NOAA (Draxler and Rolph, 2003). These studies supports previous hypothesis that Yemen is a staging post for onward movement into the Middle East and Asia. Figure 1 illustrates 72 hour air-borne particle trajectories in 2006-2007 crop season using the confirmed Ug99 site Al Kedan in Yemen as sources of urediniospores. The trajectories shown are for weekly intervals during the crop season for a period in which wheat stem rust would be present in Yemen and green wheat crop in other areas. During this period there was a clear tendency for air-borne trajectories, originating at Al Kedan, to follow a north-easterly routing heading towards the wheat producing areas of Saudi Arabia, Iraq and Iran. Similar trajectories from Ug99 sites in Iran indicate that Iran can be gateway for Ug99 to migrate to Afghanistan, Pakistan, Central Asia, Caucasus, Russia, etc.

Immediate onward movements from eastern Sudan are potentially less problematic as airflow models indicate that direct movements in a northerly direction into

the important wheat areas of the Nile valley are unlikely. However, given the uncertainty and complexity of air-flows in this region the possibility of spores reaching these areas can never be totally excluded. In addition, there is a very real risk that spores could move northwards up the Arabian Peninsula from Yemen, enter the Nile Delta and then cycle back south down the Nile Valley. The *Yr9*-virulent stripe rust race did reach Egypt soon after its detection in Yemen. Sudan had escaped stripe rust because wheat is grown under relatively warm conditions, which is unfavorable for stripe rust survival.

At present, no known long-distance, single event "random jump" type movement (assisted or natural) has been recorded for Ug99. But with an expanding known range for the pathogen and the high mobility of people both regionally and internationally, there is a clear need for continued monitoring and surveillance in wheat areas beyond the immediate at risk region. Presence of the *Sr24*-virulent variant of Ug99 present in Kenya since 2006 has not yet been confirmed beyond Kenya, even though it was widespread in epidemic form in Kenyan highlands during 2007 on the *Sr24* carrying variety "Kenya Mwamba".

Resistance/susceptibility of current wheat germplasm

Extensive screening of global wheat varieties for resistance to Ug99 has been undertaken at key sites in Kenya and Ethiopia (principally Njoro, Kenya and Kulumsa or Debre Zeit, Ethiopia). Available screening data has been linked via known pedigrees to databases on areas planted to known varieties. By the end of 2006, the screening dataset had been extended to include germplasm from 18 countries in the region, including China, with more detailed resistance/susceptibility ratings obtained on varieties covering an estimated 75 million ha. Varieties exhibiting any observed resistance to Ug99 only account for 5% of the total estimated area in the 18 countries. The huge areas observed in India and Pakistan result from the predominance of "mega-cultivars" 'PBW343' and 'Inqualab 91' in the two countries, both of which are susceptible to Ug99. Further screening of additional varieties from 22 countries undertaken in Kenya during 2007 indicated a similar low frequency of resistant materials. The seemingly favorable environmental conditions, coupled with the extensive coverage of susceptible wheat varieties is a grave cause of concern if Ug99 does spread unchecked.

Strategies to mitigate the threat from Ug99 and achieve a long-term control of stem rust

Reducing the area planted to susceptible cultivars in risk areas of East Africa, Arabian Peninsula, North Africa, Middle East and West-South Asia is the best strategy if

major losses are to be avoided. The "Borlaug Global Rust Initiative" is using the following strategies to reduce the possibilities of major epidemics: 1) monitoring the spread of race Ug99 beyond eastern Africa for early warning and potential chemical interventions, 2) screening of released varieties and germplasm for resistance, 3) distributing sources of resistance worldwide for either direct use as varieties or for breeding, and 4) breeding to incorporate diverse resistance genes and adult plant resistance into high-yielding adapted varieties and new germplasm.

The best long-term strategy to mitigate the threat from Ug99 is to identify resistant sources among existing materials, or develop resistant wheat varieties that can adapt to the prevalent environments in countries under high risk, and release them after proper testing while simultaneously multiplying the seed. An aggressive strategy to promote these resistant varieties in farmers' fields is the only viable option as resource poor as well as commercial farmers in most of Africa, Middle East and Asia can not afford chemical control or may not be able to apply chemicals in the event of large scale epidemics due to their unavailability for timely application. A reduction in disease pressure in East Africa, Yemen and Iran will likely reduce chances of migration beyond these areas to other risk areas however it is unlikely that further range expansion of Ug99 can be stopped at this stage.

Potential epidemics following the spread of Ug99 or its variants can be avoided if current susceptible cultivars occupying most of the wheat areas in the primary risk areas in the predicted migration path are reduced. Screening in Kenya during 2005, 2006 and 2007 has identified a few resistant released varieties or advanced breeding materials at various stages of testing in most of the countries that submitted their materials for screening. One strategy is to find ways to ensure that the best, high-yielding resistant materials occupy at least 5% of total wheat area distributed throughout the wheat region and are readily available. This might be via seed supply through procurement in the case that Ug99 establishment is evident in a particular country. However, it will be very difficult to promote resistant varieties on a large scale if they are inferior to the current popular varieties or because farmers have not seen stem rust. Moreover, growing inferior, resistant varieties is not an option as it will affect wheat production at a time when global wheat supply is at its lowest level causing sharp increases in wheat prices.

Identification and promotion of new stem rust resistant varieties that have significantly enhanced yield potential than current varieties, in conjunction with other desirable traits is probably the best strategy to ensure their fast adoption and thus to

succeed in replacing the existing popular but susceptible varieties. This is an achievable objective as most of the current popular varieties were developed during early to mid. 1990s and yield potential of new spring wheat germplasm has progressed significantly since then. Testing of new wheat lines with adequate resistance to Ug99 in various countries has indicated that new wheat materials with higher yields than current varieties can be a reality. High emphasis is currently being given to seed multiplication of these wheat lines.

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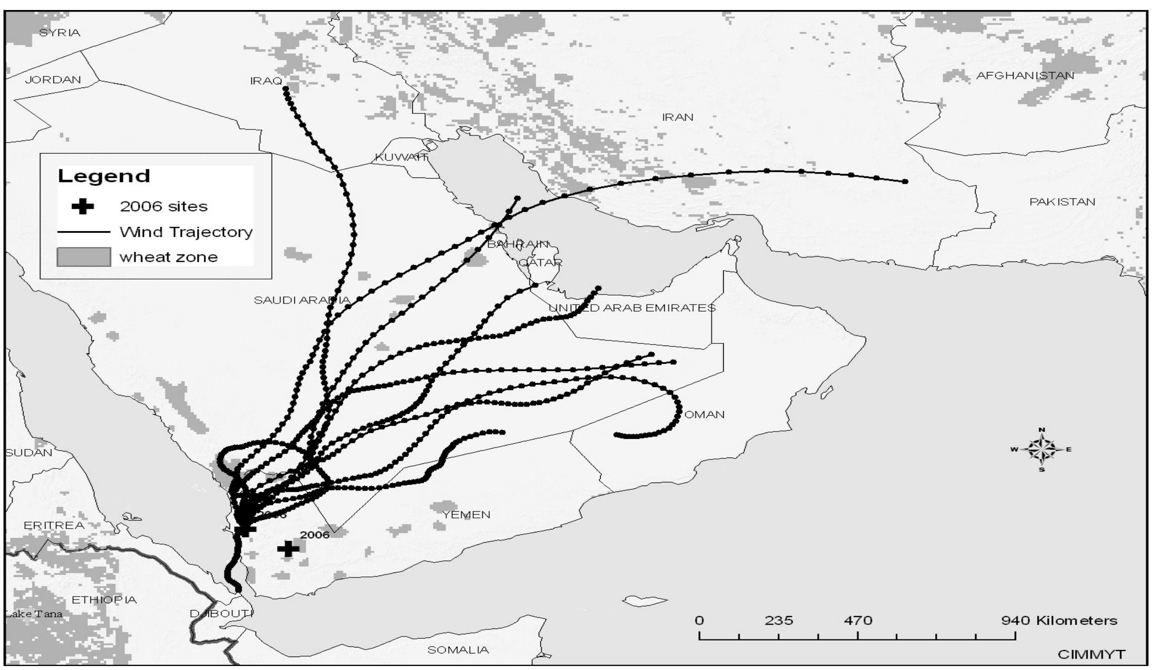
Table 1: Origin and usefulness of designated *Sr*-genes in conferring seedling and/or adult plant resistance to Ug99 race of stem rust pathogen *Puccinia graminis* f. sp. *tritici*

	Stem rust resistance (*Sr*) genes	
Origin of *Sr* genes	**Ineffective**	**Effective**
Triticum aestivum	*5, 6, 7a, 7b, 8a, 8b, 9a, 9b, 9f, 10, 15, 16, 18, 19, 20, 23, 30, 41, 42, Wld-1*	*28[1], 29[2], Tmp[1]*
Triticum turgidum	*9d, 9e, 9g, 11, 12, 17*	*2[2], 13[1,2], 14[1]*
Triticum monococcum	*21*	*22, 35*
Triticum timopheevi		*36[1], 37*
Triticum speltoides		*32, 39*
Triticum tauschii		*33[2], 45*
Triticum comosum	*34*	
Triticum ventricosum	*38*	
Triticum araraticum		*40*
Thinopyrum elongatum		*24[1], 25, 26, 43*
Thinopyrum intermedium		*44*
Secale cereale	*31*	*27[1], 1A.1R[1], R*

[1] *Virulence for the gene is known to occur in other races.*
[2] *Level of resistance conferred in the field usually not enough.*

Figure 1: Air-borne particle trajectories, derived from the HYSPLIT model, originating from the confirmed Ug99 site of Al Kedan, Yemen (trajectories represent weekly 72 hour movements for the period 1st December 2006 to 28th February 2007)



STATUS AND IMPACT OF TTKS (UG99) IN KENYA

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Wheat (*Triticum aestivum*) is among the most important crops grown in Kenya. It is among the cereal crops that contribute significantly to food security in the country. It ranks second after maize in Kenya. The crop has greater potential in the country because it is grown in varied agro-ecological zones. The current area of production is estimated at 150,000 ha. The consumption stands at 750,000 metric tons and this is expected to increase to 1000,000 metric tons by 2015. The demand for consumption rises at an estimated 7 % per year, driven by population growth, increased urbanization and changing diets. The annual production is about 350,000MT, yet the demand stands at 750,000MT. This means the local production meets only 40% of the total consumption; hence Kenya imports 60% of its wheat requirements.

The production has been increasing steadily over the last 20 years. The annual production increased from an average of 1.9tons/ha in 1987 to 2.5 tons/ha in 2005. This increase was credited to improved varieties for various agro-ecological zones. This trend is bound to change due to the appearance of the new stem rust disease Ug99 combined with an increase in agricultural prices. Since the beginning of wheat production in Kenya in 1927 up to early 1980s, stem rust caused by *Puccinia graminis* f.sp. *tritici* was undoubtedly the most serious disease of the three rusts and therefore, was given a high research priority by the breeding team. Many races appeared early and most of the cultivars broke down and by 1983, twenty-three stem rust races had been reported in East Africa. Due to widespread use of resistant varieties, the disease was not a significant problem until traces of this disease were recorded in some variety trials in Kenya between 1985-1988. Severe epidemics have continued to occur on commercial bread wheat and introductions since 1992.

In 1999, a new stem rust race known as Ug99 was reported in Uganda. This virulent race has been confirmed in Kenya and Ethiopia since 2005 and has spread to Yemen, Iran.

Today, stem rust is a serious threat to all the wheat commercial cultivars grown in Kenya because all the cultivars are susceptible. For example, wheat cultivars screened in the year 2003 and 2004 were infected with stem rust and the level of infection varied from cultivar to cultivar in all the three sites (Njoro, Mau-Narok and Eldoret).The infection of

wheat by the new race is capable of reducing the quality and quality of wheat grain within a few weeks.

Stem rust had been recorded and known to occur mainly in the low altitude areas of 1800 meters above sea level. The disease outbreak is now widespread in all the wheat growing areas in the country, in low, medium and high altitude areas. This means the disease is now present in high altitude areas (2700-3000 meters above sea level). The disease buildup has increased over the years that in the year 2007, epidemic levels were observed in farmers' fields. Most farmers were taken by surprise because they had not seen the disease before and also, there were no fungicides specifically developed for stem rust control. From the work done and recent surveys in the wheat growing areas indicate, that stem rust epidemics are causing grain losses of up to 70% in experimental plots and over 70% in farmers' fields. This is yield of sprayed vs. unsprayed wheat crop. Spraying only reduces but does not eliminate the disease. It is therefore possible to get yield losses higher than this when relative to a clean crop. In the year 2007, farmers who never controlled the disease at all, lost 100% of their crop regardless of the variety.

Today, much of Kenya's wheat variety breeding is managed by the Kenya Agricultural Research Institute (KARI) at the Njoro Research Centre, which is a statutory authority funded by the Kenyan Government and other International donors. Following the identification of Ug99, extensive surveys have been conducted widely and rust collections made since 2002 and all the wheat growing areas in Kenya have a problem of stem rust infection. Through the surveys one of the commercial wheat variety, KS Mwamba, carrying Sr 24 gene was identified to have broken down in the year 2007. This particular variety occupies a very large area in the wheat growing regions. Race analysis is/has been through the collaboration effort between Kenya Agricultural Research Institute-Njoro and the Cereal Rust Laboratory, University of Minnesota, St. Paul, USA. Other than TTKSK (Ug99) and TTKST (Ug99+Sr24 virulence) one race has been identified and confirmed to be TTTSK (Ug99+Sr36 virulence).This year, about 42 stem rust collections have been sent to the Cereal Research Center, Agriculture and Agri-Food Canada and 20 to the Cereal Rust Laboratory.

KARI- Njoro has been able to screen over 20,998 (both spring and winter habits) wheat lines in the main season nurseries of 2008 from over 20 collaborating countries of the world. This year, the disease pressure and epidemics were too severe that the severity ranged from TR-100S.

Over 200 selections showing some level of resistance have been made from the International nurseries. Harvesting of these selections is in process. Disease notes are still being taken for the late maturity lines and for the winter habits.

For the 2008/2009, over 5,574 lines (excluding the CIMMTY entries), both spring and winter habits are targeted for the off-season nursery to be grown under irrigation. Field screening of commercial cultivars, old varieties, has continued at Kari-Njoro, Mau-Narok and Uasin-Gishu areas.

Disease surveillance concepts, practices including GIS imagery and tracking

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Wheat rust diseases continue to be among the most devastating plant pathogens globally. The most common rusts are the wheat stem rust or black rust *(Puccinia graminis* f. sp. *tritici)*, the stripe or yellow rust (*Puccinia striiformis tritici*), and the leaf or brown rust (*P. recondita*). Though their optimum environmental conditions are slightly different, these rusts are present globally, wherever wheat is grown. They are often present together in one field, during different stages of the wheat development and in different severities. Rusts, especially the stem and stripe rusts are considered as the most important biotic constraint to sustainable wheat production in developing countries. This is due to the ability of the pathogen to evolve rapidly into new races and to migrate long distances by air-borne dispersal.

The world has experienced in the 1980's and 1990's a series of major epidemics of the wheat yellow rust (stripe rust) caused by *Puccinia striiformis*. (Fig1 Yr9 Virulence pathway)). This was the result of a breakdown of the yellow rust resistance gene *Yr9*, present in several high yielding cultivars grown in South, West and Central Asian countries, as well as unknown gene(s) present in several Chinese cultivars. The virulent strain of this rust moved from East Africa through Yemen to the Near East into Central Asia, Pakistan and India. This has caused crop losses amounting to several hundred million dollars and impacted the livelihoods of millions of poor farmers. The potential impact of wheat rust is particularly serious, especially in the regions of Central and South Asia, the Near East and North Africa, which accounts for some 23% of the global wheat area. In 1999 a severe form of wheat stem rust pathotype evolved in the highlands of Uganda, now designated as Ug99. This pathotype is highly virulent and capable of causing devastating damage to most world wheat varieties. This would include most of the popular varieties in countries like Kenya, Ethiopia, Yemen, Egypt, Sudan, Turkey, Iran, Afghanistan and Pakistan, all of which fall within the potential pathway of Ug99. Monitoring the evolution and migration of the new virulent stem rust race "Ug99" has become a high priority because: 1) several currently grown cultivars carry race-specific resistance genes that has a short-term life span; 2) the same cultivars are being grown

over large areas in more than one country; 3) the same genes conferring resistance to several rusts are deployed in cultivars grown in different countries, and 3) majority of currently worldwide grown cultivars. Table 1 show examples of reaction of wheat varieties from countries at immediate risk, when exposed to Ug99 virulence at Njoro, Kenya.

In 1995 Zadoks established the first experimental rust field survey though an "International Yellow Rust Trial Project". This project comprised testing experimental varieties at several sites in Europe and elsewhere. He demonstrated that pathogenic variation related to multi-location filed testing of differential varieties has provided reliable information on yellow rust occurrence and relative pathogenic variation. This has been completed by the race analysis that has been established by Dr. late Ron Stubbs who then with late Dr. Gene Saari of CIMMYT was able to provide information to all concerned national programs. The multiplication testing has been adopted by CIMMYT since the early 1970's and has included monitoring of the rusts.

The large scale migration of rust pathogens and the lack of facility and expertise in CWANA countries gave rise to the need for regional rust networks. In mid-1980's ICARDA has launched its first net work in the Nile Valley and Red sea that was not previously covered by Saari's network and includes the countries of Egypt, Ethiopia, Sudan, and Yemen,. More rust networks have established in the CWANA region in 1990's and have extend to cover all rusts early 2000; as of 2005 more emphasis has been on stem rust to monitor the spread of Ug99.

1 Cereal Rust Surveillance Network in CWANA

Cereal rust monitoring has been conducted by ICARDA and NARS since the 1980's. Nile Valley and Red Sea Cereal Rust Network has been among the oldest network that has been funded by ICARDA's core and special project funds.

- Cereal rust network for Nile Valley and Red Sea Region that included Egypt, Ethiopia, Sudan and Yemen; was established in mid-1980.
- Cereal rust and Disease Network has been established in West Asia and North Africa in mid-1990's and included the countries of Morocco, Algeria, Tunisia, Syria, Iraq, Iran, and Turkey.
- Yellow rust network for Central West Asia has been established after the first Regional Yellow rust Conference held in Iran in 2001. This network included Caucasus (Azerbaijan, Armenia, Georgia), Central Asia (Kazakhstan,

Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan) , and West Asia (Lebanon, Iran, Pakistan, Syria, Turkey), has been partially funded by ACIAR and in collaboration with PBI (Australia), SPII (Iran), ICARDA and CIMMYT

The foundation of the rust network was based on field surveys and evaluation of rust trap nurseries.

Concepts Cereal rusts trap nurseries

The trap nursery includes differential lines, near isogenic lines cultivars with known resistance genes in different background, cultivars that are grown over large areas in target countries, and elite cultivars. Composition of trap nursery will revised and updated every 3 years

a. Target trap nursery to be referred to as Ug99 trap nursery (Ug99SRTN), that includes key stem rust diagnostic single gene lines, to be planted along the expected Ug99 path for quick detection and action (Table 2); likewise for Yr27YRTN that will target monitoring of Yr27 virulence in Central ,West Asia, Caucasus, and South Asia
b. Comprehensive trap nursery referred to as stem rust trap nursery (SRTN) or Yellow rust trap nursery (YRTN)that includes selected SR and YR resistance genes and cultivars with know resistance genes for eventual determination of effectiveness/ineffectiveness at different locations (Table 3)
c. National rust trap nurseries are assembled by NARS to dispatch to different ago-climatic zones within the country. These nurseries include a wider range of local germplasm (cultivated and elite varieties) and selected known rust resistance genes. Such trap nurseries have been established in Morocco, Iran, Ethiopia, Pakistan as well as India and possibly China

The use of trap nurseries 1) would allow countries that do not have laboratory facilities and expertise to assess variation of rust populations (race, analysis, seedling and adult plant tests using artificial inoculation) ; 2) In addition to assessment of race-specific seedling resistance genes, trap nurseries provide additional valuable information on field responses of adult-plant resistance genes and or sources of APR genes; 3)Interaction of resistance genes/ resistance sources to environmental conditions in different high yielding background cultivars can be assessed under natural infections; hence the effectiveness/ineffectiveness of resistance genes; 4) Sampling from infected individual

resistance genes for race analysis where practical will provide preliminary information on pathogen change; 5) Rust infection under natural field condition can be assessed on the biological differentials and would allow Observation of changes of infection types on differentials and commercial cultivars as well assess effectiveness of resistance genes within country; 6) Information from national program allows to generate annually information from various locations within each country that is shared at regional levels ; 7) Annual meeting are organized and information is presented by national program coordinator

2. Field Surveys

Cereal rust surveillance program will include not only testing of biological trap nurseries (morphological analysis of rust fungal populations, and assessment of effectiveness/ineffectiveness of resistance genes);, but also will develop GIS maps similar to those developed for locust monitoring would allow the development and implementation of a global warning and decision support systems that permits timely planning of control measures and targeted management of the rust diseases. Once implemented, the combined information would enable national programs to monitor the wheat rust annual status, and would provide timely information on the distribution and composition of rust populations in key wheat zones within a country, region, and eventually worldwide through regional/global cooperation

***Regional/Global cooperation in monitoring the evolution and migration of new races of rust fungi**:*

Monitoring the evolution and migration of new, virulent races should be a high priority especially because: 1) the spores of these fungi can move freely over long distances; 2) several current widely grown cultivars are susceptible to Ug99 (Table 2); 3) the same cultivars are being grown in more than one country the eepidemics on Veery#5-derived cultivars (associated with Yr 9) is a good example where over 60 varieties cultivated world wide under different names are of Veery origin and carry the same Yr9 resistance gene. Kauz Popularity with breeders may/will lead to epidemics. Kauz carries Yr9, Yr27, and Yr 18 and has several derivatives such as: “Inquilab 92 carries *Yr27*; PBW343 carries combination of *Yr9* and *Yr27*; Bakhtawar 94 (Pakistan); WH542 (India); Cham 8 (Syria); Seyhan 95 (Turkey); Atrak (Iran); Nabta (Sudan); Mahdia (Morocco)”

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Political tensions in the region often do not permit scientists in some countries to collaborate and communicate with each other directly and hence the presence of

politically neutral institutions such as ICARDA and CIMMYT is important to coordinate such efforts. It will also be necessary to test cultivars at hot-spot locations outside the region, as virulence for important resistance genes may already be present in pathogen populations in these regions. Collaboration with advanced research institutions on DNA-fingerprinting techniques of rust isolates are necessary for analyses of cereal rust pathways due to a very rapid evolution of virulence in cereal rusts. For instance, in yellow rust it has recently been established that virulence (races) evolves two-three orders of magnitude faster than random DNA. A Reference rust lab is being established in Denmark

Early warning and decision support systems-The Link

The immediate threat posed by Ug99 will make it a priority for framework development with primary target regions being major wheat producers in Africa (east, south and north) and the Middle East. The cost of inaction will far outweigh the cost of early action. A decision support system (DSS) will help avert major epidemics. DSS will be the link all major component of the project as well as the subsequent expansion to incorporate other rusts and a wider geographical area. GIS will effectively serve as integrating environment, speeding up the connection between disparate datasets and hence decision-making. Modeling of airborne pathogen trajectories based on current meteorological conditions, integration of remote sensing, agricultural statistics and other secondary data for better targeting of areas at risk. DSS will be also based on the accurate information on new race development and their subsequent spread; the effectiveness of resistance genes; the promotion and adoption of newly tolerant (durable resistant) varieties will ensure sustainability of production for small holding farmers. Safe use of chemical when and where economically feasible will be considered in emergency case to allow reduction of inoculum load and subsequent spread of virulent races of rusts; hence DSS will need to be closely linked to socioeconomic activities to further ensure adequate use of inputs in an economically feasible manner.

Create national surveillance systems networked into a global surveillance system

The building blocks of a global surveillance network are functional national surveillance efforts. National surveillance systems are consequently critical outputs. National systems require: 1) active surveillance and trap nursery teams in at-risk areas; 2) protocols for maintaining and distributing trap nurseries; 3) pathotyping laboratories with

trained staff that can collectively manage analysis of samples submitted by surveillance teams; and 4) protocols for submission, quality control, storage, and access to data on the incidence, severity, and composition of rust infections detected in the crop at large, and in trap nurseries. Targeted countries include major wheat producing countries in East Africa (Ethiopia, Kenya, Sudan, and Eritrea), Nile valley and Red Sea (Yemen, Egypt, Saudi Arabia) an secondary target that include India, Pakistan, Morocco, Tunisia, Algeria, Turkey, Syria, Kazakhstan, Uzbekistan, and Azerbaijan. These nations have varying degrees of the expertise and physical resources required to implement rust surveillance of their wheat crops. CG Scientist would facilitate and design the implementation and continuation of the national surveillance systems. International scientists would also coordinate the requisite training, data acquisition, and analysis of the data. They would also ensure a supply of seed of appropriate trap nursery genotypes.

In order to alleviate/stop the threat of Ug99 and to avoid/limit the development of more complicated races of trans-boundary wheat rusts; there is an urgent need to develop a global tracking system of cereal rust diseases and eventually establish an early global warning and decision support systems that would permit to avoid tremendous crop losses, that could not be sustained by poor resource farmers in Africa nor by corporate farmers that would have to revert to use of chemicals that would not only increase the production cost but would also impact the environment.

NARS understanding of pathogenic and genotypic variations of rust fungi upgraded through capacity building; national rust surveillance teams established in different agro-ecological regions; regular national surveys during crop season undertaken; coordinating unit at FAO for surveillance and data management established; permanent national testing sites of rust trap nurseries established; permanent service within ICARDA and/or CIMMYT for maintenance of wheat seed genotypes of trap nursery; harmonization of the surveillance teams through regular training and interactions; capacities of national surveillance programs enhanced through intensive training of technical field staff and farmers.

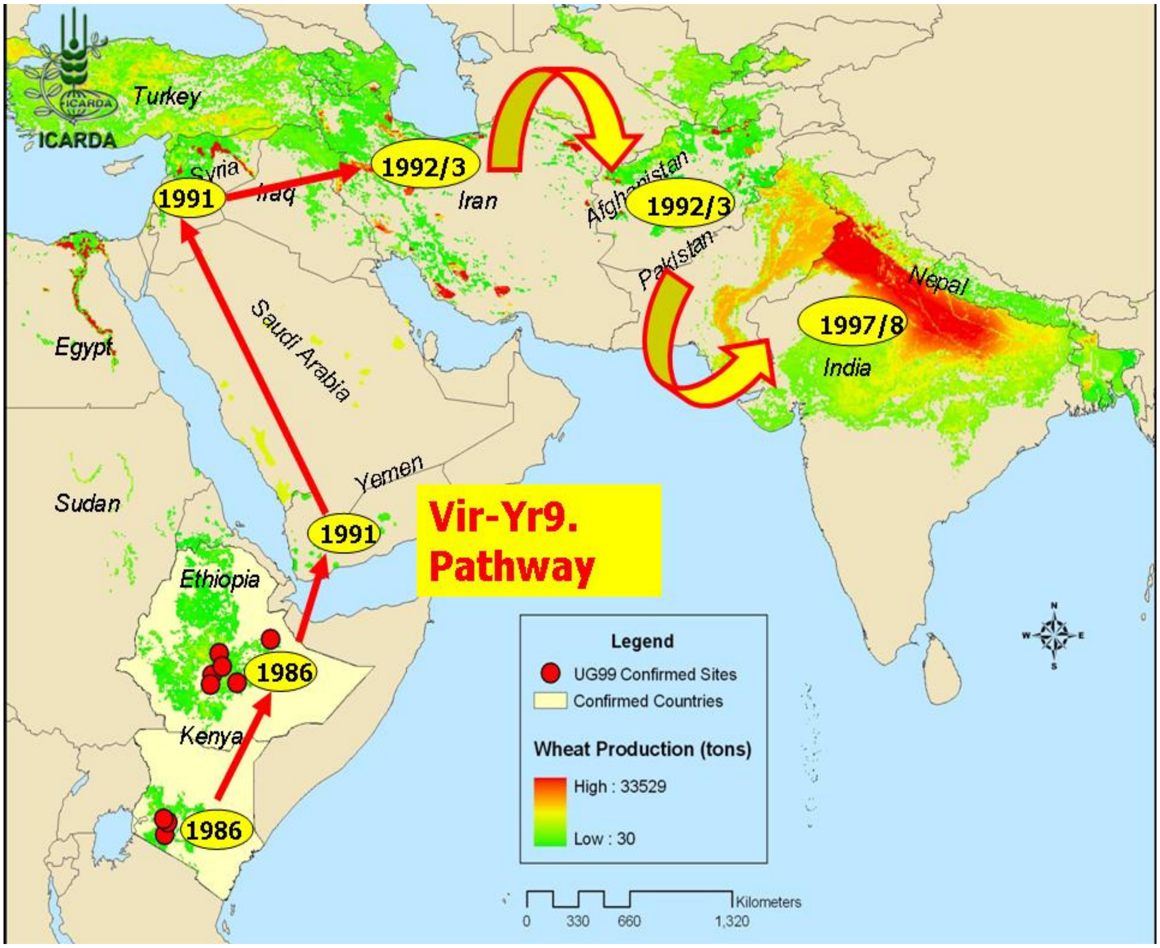

Figure1. Pathway of yellow rust Yr9 virulence

Table 1: Levels of resistance among wheat cultivars and elite breeding lines tested at Njoro, Kenya in 2006

Country	Total No.	R/MR	S	Country	Total No.	R/MR	S
Bangladesh	84	3	81	Iran	100	2	98
China	118	2	116	Nepal	105	2	103
Egypt	149	3	146	Pakistan	105	6	99
India	102	23	79	Russia	35	1	34

Table 2: Stem rust trap nursery targeting Ug99 (Ug99 SRTN)

Genotype	Sr. Gene	Genotype	SR. Gene
Morocco	Susc.Check	Pavon 76	Sr 2 complex
Seri 82	Sr 31	Buck Buck	Sr 2 , Sr 23
PBW343	Sr 31	Lamillo (Durum)	
LcSr24Ag	Sr 24	Rihane (Barley)	
St24(Agent)/9*LMPG	Sr 24	ISr6-Ra	Sr 6
W2691 SrTt-1	Sr 36	Vernstein	Sr 9e
Eagle	Sr 26	St46Sr13	Sr13
Super Seri	Sr 25	Sr22/TB	Sr 22
LcSr25Ars	Sr 25	CnSSrTmp	Sr Tmp
Coorong (Triticale)	Sr 27	Bt/Wld	Sr Wld-1
Bakhtawar 94 (Kauz)		Line A Seln	Sr 14
Cook	Sr 36	W2691Sr28Kt	Sr 28
Altar (Durum)			

Table 3: Testing site (Country/number of location) of rust trap nurseries 2007-2008 Crop Season

Country	**Trap nurseries (No. of testing sites/country)**				**Trap nurseries (No. of testing sites/country)**		
	4 th ISRTN	**2 nd Ug99ISRTN**	**3 rd IYRTN**	**Country**	**4 th ISRTN**	**2 nd Ug99ISRTN**	**3 rd IYRTN9**
Uzbekistan	**1**	**1**	**1**	Tunisia	**2**	**2**	**2**
Kyrgyzstan	**-**	**1**	**1**	Morocco	**2**	**3**	**2**
Azerbaijan	**1**	**2**	**4**	Algeria	**2**	**3**	**3**
Tajikistan	**1**	**1**	**1**	Egypt	**3**	**4**	**3**
Kazakhstan	**-**	**2**	**1**	Sudan	**2**	**1**	**2**
Turkmenistan	**-**	**-**	**1**	Yemen	**3**	**5**	**3**
Turkey	**3**	**4**	**4**	Eritrea	**2**	**-**	**2**
Iran	**3**	**4**	**4**	Ethiopia	**3**	**3**	**4**
Georgia	**1**	**1**	**2**	Kenya	**2**	**1**	**1**
Armenia	**1**	**1**	**2**	South Africa	**3**	**5**	**1**
Pakistan	**3**	**3**	**4**	Uruguay	**1**	**-**	**1**
Bangladesh	**1**	**2**	**3**	Oman*	**-**	**2**	**-**
Bhutan	**1**	**-**	**1**	S.Arabia*	**-**	**4**	**-**
Nepal	**2**	**-**	**4**	Syria	**5**	**1**	**7**
India	**4**	**4**	**8**	Lebanon	**1**	**1**	**1**
Total	**22**	**26**	**41**	Total	**31**	**35**	**32**

* Nursery to be tested in 2009

Stem Rust Resistance in Wheat – The Australian Experience

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History

Stem rust was recognized as the most damaging disease of wheat in Australia by William Farrer. The possibilities for breeding for resistance against rust diseases started in the 19th Century. Farrer produced early maturing wheat's that did not have stem rust resistance but effectively escaped infection due to early maturity. The early maturity was transferred from Indian wheat's. Rust resistant wheat cultivars Fedweb, Hofed and Eureka were bred by W.L. Waterhouse (University of Sydney) and S.L. Macindoe (NSW Agriculture). The stem rust resistance in Eureka (*Sr6*) was rendered ineffective in 1942 by a new variant of stem rust pathogen. Despite maintenance of resistance by Fedweb and Hofed, Waterhouse was aware of evolutionary potential of the stem rust pathogen. Field station in the stem rust prone north-western NSW was set up at Curlewis, NSW, in 1945 to run resistance breeding program. The NSW State Wheat Research Committee facilitated the establishment of the Northwest Wheat Research Institute (now IA Watson Research Centre) in 1961. Stem rust resistant cultivars Fedweb and Hofed, Eureka, Gabo were released prior to 1950. Hofed carried the durable adult plant resistance gene *Sr2*. The next generation of stem rust resistant cultivars included Eagle (*Sr9g, Sr26*), Mendos (*Sr7a, Sr11, Sr17, and Sr36*), Timgalen (*Sr5*, *Sr6*, *Sr8a*, *and Sr36*), Gatcher (*Sr2, Sr5*, *Sr6*, *Sr8a*, *Sr9g*, *Sr12*) and Gamut (*Sr6, Sr9b, Sr11, SrGt*). This was followed by Banks (*Sr8a, Sr9b, Sr12, and Sr30*), Condor (*Sr5*, *Sr8a*, *and Sr12*), Shortim (*Sr5*, *Sr6*, *Sr8a*, *and Sr36*) and Festiguay (*Sr30*).

As a result of the 1973 stem rust epidemic in eastern Australia, the National Wheat Rust Control Program (NWRCP) was proposed (Figure 1) and came into operation in 1975 with funding from the Wheat Research Council. The mandate of the program was to provide rust screening services to all wheat breeding programs in Australia, to introduce new genetic variation for rust resistance in white seeded Australian wheat's and to monitor the rust populations for pathogenic changes that would affect both deployed

cultivars and resistance breeding activities. The main emphasis of the program was to keep ahead of pathotype changes through anticipatory breeding. Cultivars released from NWRCP developed germplasm included Torres (white seeded *Sr24*), Vasco (white seeded *Sr24*), Diaz (*Sr9e, Sr36*), Grebe (*Sr31*), Schomburgk (*Sr22*), Perouse (white seeded *Sr24*), Sunbri (*Sr36, Sr38*), Sunvale (*Sr36, Sr38*), Sunlin (*Sr26+Sr38*),Trident (*Sr38*), Datatine (white seeded *Sr24*), Camm (*Sr38*), Thornbill (*Sr45*), QAL2000 (*Sr24, Sr38*), QALBis (*Sr24, Sr38*) and CastleRock (white seeded *Sr24*).

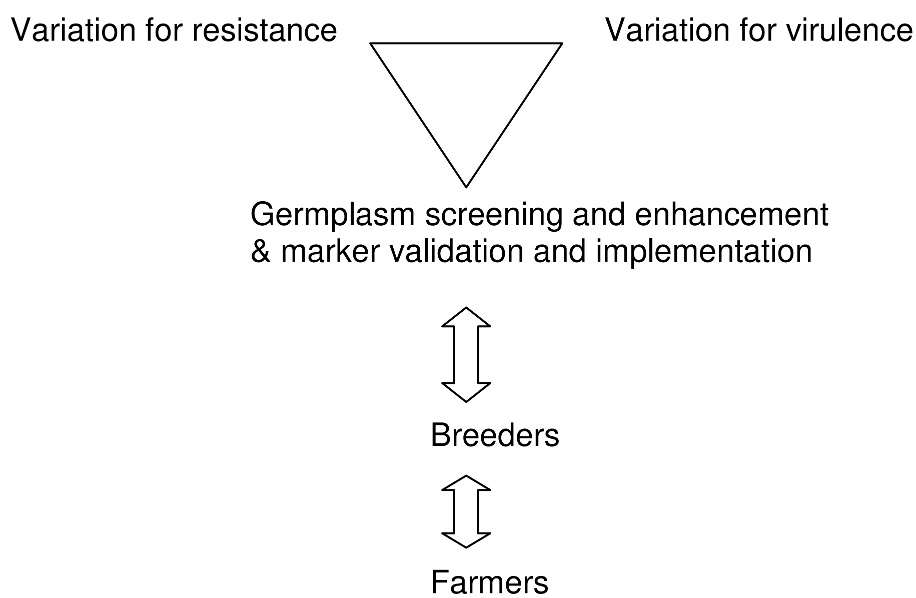

Figure 1: Flow chart of national co-ordination of breeding for rust resistance in Australia through the Australian Cereal Rust Control Program

Current genetic diversity for rust resistance genes

Common wheat

A great majority of the modern cultivars grown globally carry resistance genes *Sr2*, *Sr24*, *Sr30*, *Sr31* and *Sr36* that were effective either alone or in combinations prior to the detection of Ug99 and its derivatives. *Sr29* is present in some winter wheat. The adoption of CIMMYT germplasm worldwide promoted the use of germplasm carrying stem rust resistance genes *Sr2, Sr8a, Sr9g, Sr17, Sr30* and *Sr31* in various

combinations. Stem rust resistance gene *Sr38* was used worldwide due to its linkage with *Lr37*, *Yr17* and *Cre5*. Uncharacterized seedling and adult plant stem rust resistance genes, however, have been selected by chance in commercial wheat cultivars. An APR gene located on chromosome 5B in Swiss wheat cultivar Arina was identified recently by Australian workers. The APR genes for stem rust resistance in Indian wheat cultivar HD2009 and WL711 were also identified. The APR gene in WL711 is likely to be contributed by the North American cultivar Chris.

In Australia, wheat cultivars in Queensland and northern NSW have four main combinations namely; *Sr2+Sr36+Sr30*, *Sr24+Sr36*, *Sr38+Sr36* and *Sr2+Sr38+Sr30.* Cultivar Sunlin carries *Sr38* and *Sr26* in combination. Some cultivars in these states possess resistance genes *Sr2*, *Sr24, Sr30, Sr31, Sr33* and *Sr45* alone. Victorian and South Australian wheat's carry *Sr30*, *Sr24* and *Sr15*. Western Australian wheat cultivars carry *Sr2+Sr30*, *Sr8a +Sr15* and *Sr38*. *Sr13* also contributes towards resistance in WA cultivars. Tests conducted in Kenya suggest the presence of APR in some Australian wheat cultivars.

Durum wheat

There are at least 2–3 stem rust resistance genes in durum cultivars. Of these only *Sr13* is effective against Ug99. An APR gene derived from durum landraces, *Sr GH*, was identified in Australia. *Sr8b*, *Sr9e* and *Sr13* are present in different combinations in commercial durum cultivars.

Synthetic hexaploids

The synthetic hexaploid germplasm produced by CIMMYT and other organizations is combining genes from durum, predominantly *Sr9e*, *Sr8b*, *Sr13* and the *Triticum tauschii* derived genes *Sr33*, *Sr45* and *Sr46*. It is likely that uncharacterized gene(s) for seedling and adult plant resistance may have been transferred. The range of infection types observed among a set of CIMMYT synthetics is presented in Figure 2.

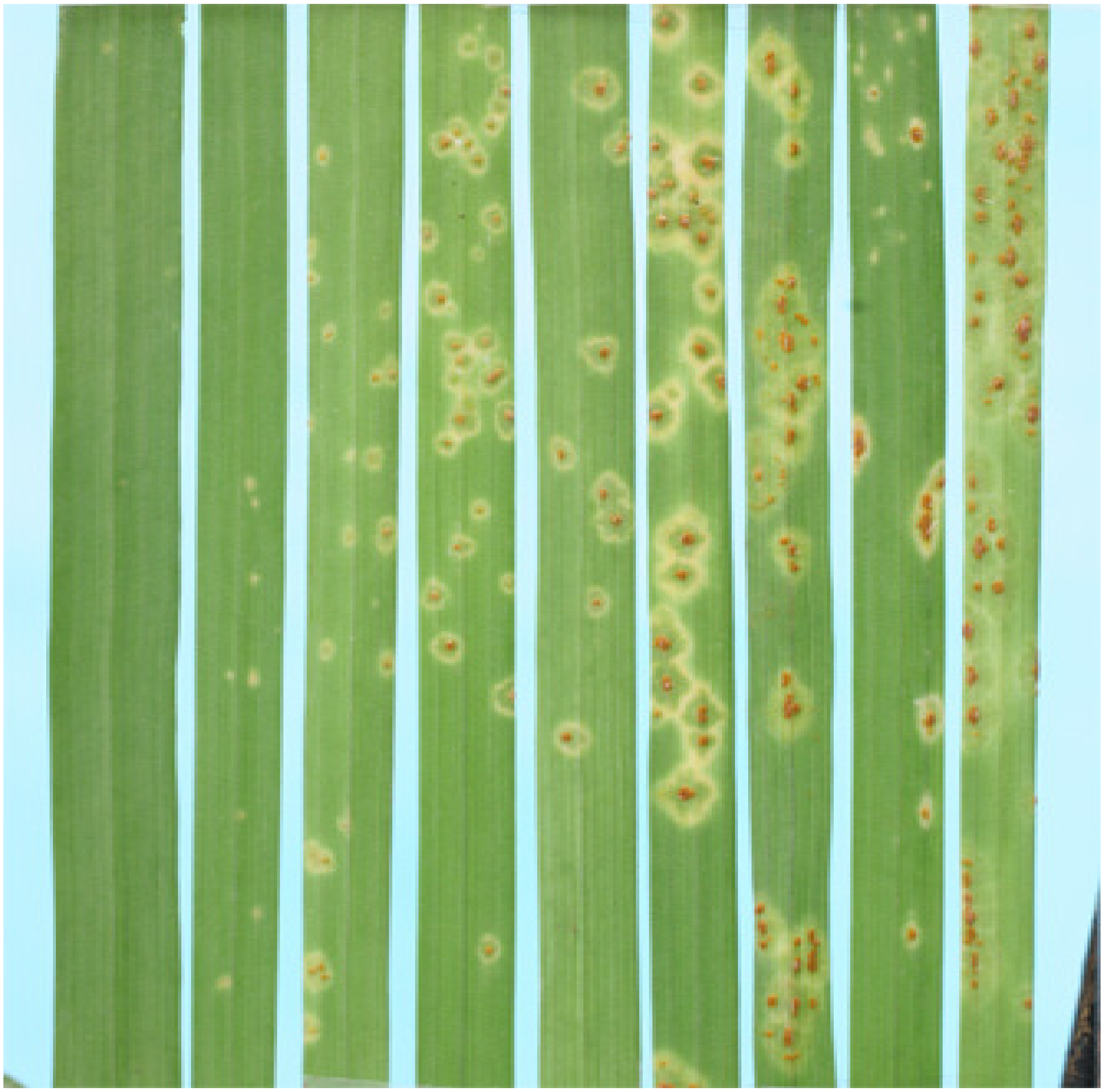

Figure 2: Stem rust response variation among synthetic hexaploids

DNA marker technology

Markers linked with several stem rust resistance genes have been reported. These include stem rust resistance genes *Sr2, Sr22, Sr32, Sr33, Sr36, Sr39* and *Sr45* that are effective against Ug99 and its derivatives either singly or in combinations. These markers can be used in generation of gene combinations in future wheat cultivars.

Future directions

An old collection of tetraploid and hexaploid wheat cultivars/landraces, collected in 1920s was screened and found to carry uncharacterized sources of seedling and adult plant resistance (APR) to stem rust. The APR genes detected in this population by

Australian workers are different to *Sr2*. These sources are currently being transferred to commercial wheat's. Genetically diverse sources of stem rust resistance that were not exploited in breeding programs earlier are being transferred to commercial genetic backgrounds. A global commitment to release wheat cultivars with combinations of resistance genes would be necessary to ensure sustainable wheat production. The combined use of genotypic (marker based) and phenotypic (greenhouse and field based) technologies would be essential to produce cultivars with combinations of major and minor resistance genes.

Acknowledgements

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Adult Plant Resistance in wheat to Ug99 Race of Stem Rust and its Utilization

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Abstract

Race Ug99 of wheat stem rust pathogen *Puccinia graminis* is not just spreading beyond East Africa but also evolving to overcome additional race-specific resistance genes. Use of non race-specific, adult plant resistance (APR) conferred by multiple minor genes is therefore considered to be a better strategy to curb evolution. Screening of wheat materials in Kenya and Ethiopia from 22 countries and International Centers has identified low frequency of lines that have high to adequate levels of APR and can be deployed as varieties. Shuttle breeding schemes with Kenya or Ethiopia are currently being used by CIMMYT and ICARDA to enhance the selection of new high-yielding wheat lines with high level of APR.

Historical account of the use of adult plant resistance

Strong emphases to identify resistance to stem rust and to breed resistant wheat varieties were initially given in the US, Canada, Australia and Europe. The most successful control of stem rust came when H. K. Hayes in the University of Minnesota and E. S. McFadden in South Dakota State University transferred the stem rust resistance from tetraploid sources “Iumillo” durum and “Yaroslav” emmer, respectively, into bread wheat that gave rise to hexaploid wheat varieties “Thatcher” and “Hope” (Kolmer 2001). Although several race-specific resistance genes are present in Hope and Thatcher, the most effective component of the resistance in these two varieties is due to adult plant resistance. Thatcher and Hope, Hope sib “H44-24a”, and other varieties derived from these parents such as “Selkirk” and “Chris” combined resistance to stem rust also from other sources. Efforts to find a solution to the stem rust problems facilitated global collaboration amongst wheat scientists who shared, grew and evaluated wheat germplasm in the quest of finding different sources of resistance to stem rust. Resistant wheat materials developed at Njoro, Kenya through the support from Canadian scientists in 1960s and 1970s contributed substantially to international

breeding efforts. Resistance from Hope and Chris formed the foundation of the high-yielding, semidwarf wheat varieties that led to "Green Revolution" in the 1970s.

The adult plant resistance gene *Sr2* confers slow rusting. Combination of *Sr2* with other unknown slow rusting resistance genes possibly originating from Thatcher and Chris, commonly known as the "*Sr2*-Complex", provided the foundation for durable resistance to stem rust in germplasm from the University of Minnesota in the United States, Sydney University in Australia, and the spring wheat germplasm developed by Dr. N. E. Borlaug (McIntosh 1988, Rajaram et al. 1988). Unfortunately, not much is known about the other genes in the *Sr2* complex and their interactions. Knott (1988) has shown that adequate level of multi-genic resistance to stem rust can be achieved by accumulating approximately five minor genes.

Adult plant resistance to Ug99 in old and new wheat

Durable stem rust resistance of some older US, Australian and CIMMYT spring wheat's is believed to be due to the deployment of *Sr2* in conjunction with other unknown minor, additive genes that could have originated from Thatcher and Thatcher-derived line Chris. *Sr2* can be detected through its complete linkage with pseudo-black chaff phenotype, which can be prominently expressed under certain environments leading to its elimination in some breeding programs. However, under the same environmental conditions negligible to high expression of pseudo-black chaff is observed in advanced breeding materials indicating that it is possible to select lines with *Sr2* with negligible pseudo-black chaff. On wheat lines that displayed pseudo-black chaff, we observed varying degrees of disease severity in Kenya ranging from traces to about 60-70% compared to 100% severity for highly susceptible materials. Reaction types varying from MR to S (moderately resistant to susceptible) on the same internodes of *Sr2* bearing plants clearly indicated that *Sr2* did confer at least some resistance.

Sr2 was detected in several highly resistant old, tall Kenyan cultivars and CIMMYT-derived semidwarf wheat's "Pavon 76", "Parula", "Kritati" and "Kingbird'. Pavon 76 and Kiritati were resistant since the initiation of rigorous screening in 2005 at Njoro, Kenya with maximum disease scores of 20MR-MS (20% severity with MR-MS host reaction). Kingbird, a new advanced line, is at present the best known source of adult plant resistance in semidwarf wheat with maximum score recorded to be 5MR-MS during the same period. Because these wheat's are susceptible as seedlings with race Ug99, their resistance is speculated to be based on multiple additive genes where *Sr2* is an important component.

With the exception of *Sr2*, little is known on the genes involved in durable adult plant resistance, however earlier work done by Knott (1982), knowledge on durable resistance to leaf and yellow rusts (Singh et al. 2004), and observations made on breeding materials and a F_6 mapping population involving Pavon 76 all indicate that the rate of rust progress is a function of the cumulative effect of the number of minor genes present in a genotype and individual effects of each gene (Figure 1). Accumulation of between 4 and 5 genes is therefore expected to retard disease progress to rates that result in negligible disease levels at maturity under high disease pressure, described as "near-immunity" by Singh et al. (2000).

Accumulating such complex resistance will be cumbersome but not impossible in the absence of disease pressure caused by race Ug99 at most breeding sites and lack of molecular markers associated with genes contributing to resistance. Molecular markers linked to the slow rusting resistance gene *Sr2* are known and can be used in selection; however this gene can also be identified in the field under most environments from its linkage with pseudo-black chaff phenotype. *Sr2* is present in about 60% of the current CIMMYT spring wheat germplasm including some of the most recent high-yielding wheat's that have high level of resistance to leaf and stripe rusts and desirable end-use quality characteristics.

High yielding wheat lines with adult-plant resistance to Ug99

Information on resistance to stem rust in resistant spring wheat germplasm distributed worldwide by CIMMYT during 2006, 2007 and 2008, through the newly initiated 1st, 2nd and 3rd Stem Rust Resistance Screening Nurseries (SRRSN) is summarized in Table 1. A total of 29 (28%), 48 (37%) and 67 (65%) lines in these three nurseries, respectively have shown from high to moderate levels (up to 30% stem rust severity when the susceptible materials show annihilation following 100% severity) of resistance in at least two seasons of evaluation under high disease pressure in Kenya. Entries included in the 2nd and 3rdSRRSN have high yield potential in combination with various other desirable traits. These improved wheat materials have the potential to be released directly or be used by breeding programs worldwide.

Shuttle breeding to develop high-yielding wheat with near-immune level of APR

Because a large portion of International Center's high-yielding spring wheat germplasm does not carry effective race-specific stem rust resistance genes to Ug99 and lines were identified to carry at least moderate levels of resistance, this was viewed as a perfect opportunity to reconstitute high levels of adult plant resistance in newer

wheat materials. In the absence of molecular markers for adult plant resistance genes and the absence of Ug99 race in Mexico, a shuttle breeding scheme between Mexican field sites (Ciudad Obregon in northwestern Mexico during winter, and Toluca or El Batan in highlands near Mexico City during summer) and Njoro, Kenya was initiated in 2006 to transfer adult-plant resistance identified in semi-dwarf CIMMYT wheat's to a range of important wheat germplasm. Two crop seasons per year in Mexico and Kenya will accelerate the breeding. The "single-backcross, selected-bulk" breeding approach is being applied for transferring multiple minor genes to adapted backgrounds. Simple and three-way crosses, where one or more parents carry adult-plant resistance, are being used to breed new high-yielding, near-immune wheat materials.

In the single-backcross approach we crossed resistance sources with the adapted high yielding wheat's and then a single backcross was made with the recurrent parent to obtain about 400 BC_1 seeds. BC_1 plants were then selected for desired agronomic features and resistance to leaf and stripe rusts, and harvested as bulk. F_2 plants derived from BC_1, simple and 3-way crosses with desired agronomic features and resistance to leaf and stripe rusts were selected for agronomic traits and resistance to other diseases at Cd. Obregon or Toluca and harvested as bulk. If F_2 populations were grown at Cd. Obregon, where quarantine disease "Karnal bunt" is known to occur, the F_3 populations were grown at Toluca for another round of selection. About 1000 seeds of each of the F_3 and F_4 populations obtained from harvesting materials at Toluca were grown densely in Njoro, Kenya for selection under high stem rust pressure during the off-season. After removing tall plants, the remaining populations were bulk harvested and about thousand plump grains selected to grow F_4 and F_5 populations during the main season in Kenya under high disease pressure. Because stem rust affects grain filling, we expect that plants with insufficient resistance will have shriveled grains. About 400 plump seeds harvested from the selected plants were grown at Cd. Obregon, Mexico and final selection as individual plants in the F_5 and F_6 generations was carried out. Small plots of these advanced lines were grown in El Batan and Toluca field sites to select them for agronomic characteristics and resistance to leaf and yellow rusts. About 700 advanced lines will be tested for grain yield performance at Cd. Obregon and for resistance to stem rust at Njoro during the forthcoming 2008-2009 crop season. Second group of shuttle breeding F_5 and F_6 populations will also be planted in Cd. Obregon and the 3rd group of F_3 and F_4 in Kenya.

We expect that the frequency of advanced lines which carry high yield potential, maintain wide adaptation, end-use quality characteristics and high level of resistance to all three rusts will increase over time through the use of the Mexico-Kenya shuttle. Moreover, the proposed approach is expected to rebuild the durable resistance in modern wheat germplasm. Genetic analyses are also underway to understand the number and type of resistance genes involved in sources contributing the slow rusting, adult plant resistance. Genomic locations of minor, additive resistance genes, determined through molecular mapping, is expected to not only result in molecular markers for some of the slow rusting genes but also will be useful to establish and enhance genetic diversity for such genes in the global spring wheat germplasm and will allow their incorporation in facultative and winter wheat materials.

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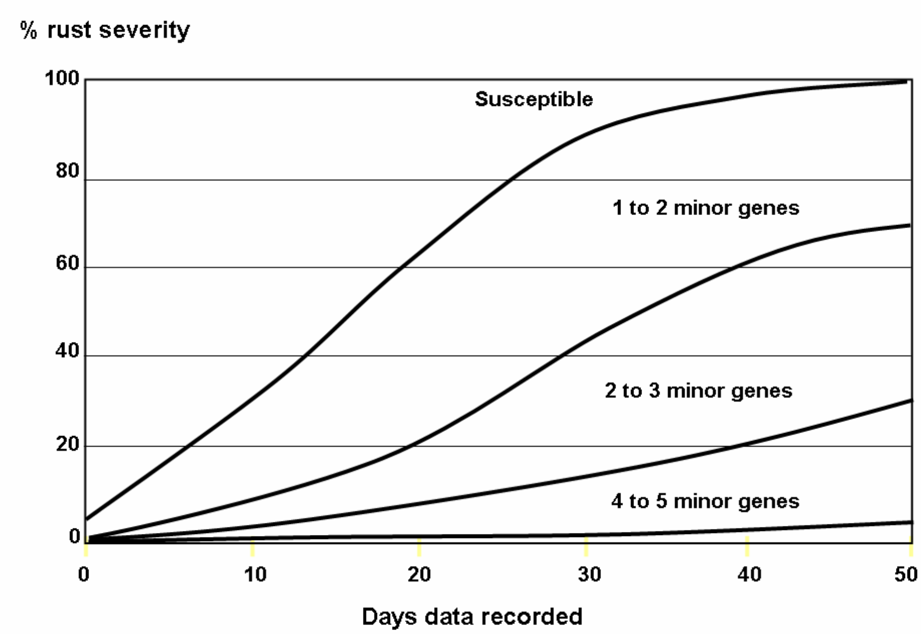
Table 1: Stem rust resistance of entries included in 1st, 2nd and 3rd SRRSN (Stem Rust Resistance Screening Nursery)

Resistance	1stSRRSN		2ndSRRSN		3rdSRRSN	
Category	Number	%	Number	%	Number	%
Adult-plant[1]:						
R (5-10% severity)	4	4	0	0	3	3
R-MR (15-20% severity)	19	18	26	20	33	32
MR (30% severity)	6	6	22	17	21	20
MR-MS (40% severity)	2	2	15	12	0	0
MS (50-60% severity)	0	0	17	13	0	0
S (70-100% severity)	0	0	4	3	0	0
Race-specific:						
Sr24	39	38	0	0	0	0
Sr25	17	17	0	0	11	11
Sr36 (+*Sr24*)	0	0	0	0	4	4
Sr1A.1R (+*Sr24*)	2	2				
SrTmp	0	0	25	20	6	6
SrSynt	4	4	8	6	5	5
SrSha7	9	9	8	6	4	5
SrND643	0	0	0	0	12	12
Sr Unknown	1	1	3	2	5	5
Total	**103**		**128**		**104**	

[1] *Adult plant resistance categories include lines that are susceptible in seedling greenhouse tests and with highest rating recorded during multiple years/seasons testing (2005-2007) when the susceptible entries annihilated after 100% stem rust severity based on the modified Cobb Scale.*

Figure 1: Graphical representation of the additive effects from estimated number of minor genes in retarding rust progress in the field



Operation of Rust Screening Facilities in East Africa

Davinder Singh, Bedada Girma, Ruth Wanyera, Peter Njau

Introduction

Safeguarding world wheat by development of stem rust resistant varieties with durable resistance to Ug99 requires accurate field screening which in turn needs adequate critical facilities. These critical facilities help in management and manipulation of host germplasm and pathogen races. Eastern Africa has always played a vital role in relation to stem rust epidemiology probably because of geographical location and climatic conditions of the region, and the continuous cultivation of the wheat throughout the year providing green-bridge for inoculum survival. The environment of the East African highlands enables large populations of stem rust to persist year round and this situation contributes to the problem of evolution of new physiological races. In fact, East Africa is known to be hot-spot for origin of new virulent races of rust (Singh et al., 2006). In 2006, a variant of Ug99 with added virulence on stem rust gene *Sr24* has further increased the vulnerability of wheat to stem rust worldwide (Jin et al., 2008).

Recently, the East Africa program under Borlaug Global Rust Initiative (BGRI) has been launched to minimize scale and scope of stem rust epidemics in Kenya and Ethiopia, and to warrant that new virulent and dangerous forms originating from this region do not leave East Africa. Considering this, the East African program has been designed to monitor further migration of Ug99 and its variants, facilitate field screening of international wheat germplasm, understand the genetic basis of resistance, in particular the durable type, carry out targeted breeding program to incorporate resistance genes into germplasm of interest, and enhance the capacity of national programs in breeding for rust resistance.

This paper reports on current screening facilities in Kenya and Ethiopia, and the operations, opportunities and challenges to manage these programs.

Screening Operation at Kenya Agricultural Research Institute (KARI)

From 1960-70, Canada government made significant investments in KARI Njoro to monitor the occurrence of cereal rust variants followed by CIMMYT until the 1990s, after which the research slowed down and the facilities deteriorated when international presence ended as a result of financial constraints. However, the detection of Ug99 and its variants and their virulence on most currently cultivated varieties world-wide,

and the launch of BGRI have brought Kenya back into international cereal rust research focal point for screening and breeding of wheat germplasm resistant to Ug99.

KARI screening activities are coordinated across two seasons (Main = June to October and Off-season = November to April). Twelve hectares of irrigated land has been dedicated to field screening (4 hectares available per season to accommodate a 3-year rotation) managing more than 20,000 entries per main season. The germplasm evaluated includes spring wheat (mainly bread wheat and limited durums) and winter wheat covering advanced breeding material, landraces, local cultivars, mapping populations and historical germplasm.

For phenotyping, the entries are planted as double 1-m-rows. To facilitate inoculum build up and uniform spread within the nursery, clumps of spreaders (a mixture of susceptible cultivars) are planted adjacent to entries. The spreader rows are inoculated either by dusting them with a mixture of talc powder and urediniospores or by syringe inoculations as outlined in McIntosh et al. (1995).

Screening Operation at Ethiopia Institute of Agricultural Research (EIAR)

Ethiopia's involvement in BGRI started in January 2005 when Dr. Noman Borlaug's ‘Sounding the Alarm’ memorandum reached Ethiopia. EIAR understood the seriousness of the ‘Alarm’ and swiftly established a ‘Stem Rust Taskforce’ which was entrusted with monitoring and evaluation of the disease situation in the country. Since then, Ethiopia initiated screening of international and national wheat materials aggressively. Although the main focus is stem rust, EIAR follows a holistic approach of monitoring and screening for all three rusts.

EIAR screening activities are coordinated across two seasons (Main = June to November and Off-season = January to April) across all three research centers, namely Ambo, Debre-Zeit and Kulumsa. Ambo Plant Protection Research Center is responsible for coordination of annual rust survey and rust race analysis. Debre-Zeit takes care of shuttle breeding and finger-printing of durum wheat, screening of international wheat materials, and screening and testing of wild tetraploids for adult plant resistance (APR).

Achievements and Opportunities

The screening groundwork in East Africa has established opportunities associated with operational facilities in Kenya and Ethiopia. East Africa remains the only region where currently field screening for response to the Ug99 lineage can be conducted. Wheat producing nations throughout the world participated in testing the reaction of wheat (over 70,000 research plots) in both the main and off seasons in Kenya and Ethiopia

since 2005 and the resistance status of these lines has since been well documented. This effort determined global wheat vulnerability to the Ug99 lineage and also determined the effectiveness of the known stem rust resistance genes against Ug99. Good progress has been made in identifying diverse sources of resistance to Ug99 and its variants in international germplasm including minor gene APR which has reputation of durability. Deployment of high yielding wheat's with durable resistance in various countries in the migration path of Ug99 should reduce the risks of epidemics and its further evolution. More than 300 sets in form of three stem rust resistance screening nurseries (1st SRRSN, 2nd SRRSN and 3rd SRRSN) have been distributed or under process of distribution. Some promising lines with very good agronomic traits and resistance to Ug99 and its variants have been identified and are under further evaluation/tests for release and registration.

Challenges and Needs

Fully operational Critical Facilities in East Africa require investments in field, greenhouse, laboratory facilities and equipment, as well as operational support for mission-dedicated teams of national and international scientists. Currently these facilities are being supported by BGRI, but the long-term funding needs to be secured for sustainability and commitment to global efforts for stabilizing yield losses via breeding for Ug99 resistance wheat.

Objectives of BGRI and collaborations with NARS public sector elements are, in principle, not subject to screening-fees. However, there is a need to develop a fee for service model for private companies and the industrialized countries for screening the germplasm which in return will sustain the activities of the facilities and will provide quality assurance of the data generated.

Vernalization protocols of winter wheat have improved but need further refinement for absolute results. There is a room for further improvement of protocols and guidelines for seed importation, irrigation and land use, efficient screening, and data distribution and delivery.

Vision

Protection of world wheat through development of varieties durably resistant to Ug99 cannot be achieved without continuation and expansion of recently initiated collaborative research conducted in East Africa. Neither the conventional breeding nor the molecular breeding nor any other activity that depends on accurate field screening can be successful without these collaborations and the essential and vital critical facilities.

However, if these efforts sustained, within next one year, the critical facilities in Kenya and Ethiopia will be high caliber components of an integrated world effort to minimize the destabilizing effects of rusts on world wheat production and food security. In another five years, varieties carrying durable rust resistance selected at these critical facilities will defend world wheat production. By 2020, varieties with new sources of durable resistance will be identified, selected and cultivated globally.

Global Rust Website

For further information on operations of rust screening facilities in east Africa, visit www.globalrust.org

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Gene discovery, diversity and molecular markers for stem rust resistance in wheat

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Rust resistance genes

Genetic resistance to wheat stem rust (*Puccinia graminis* f.sp. *tritici*,) has largely been based on two types of resistance; seedling and adult plant resistance. Seedling resistance genes (which also work at the adult plant stage), also referred to as major genes usually confer strong resistance response but not to all rust races. *Sr31* is a good example. Adult plant resistance (APR) or post-seedling resistance often provide a partial resistance response and tend to be race non-specific. Some of the APR genes have also been described as "slow-rusting" due to the longer latency period from infection to the full development of rust epidemic or sporulation. Of the 46 catalogued stem rust resistance genes in wheat only one, *Sr2*, falls into the APR category. A few more APR genes have been described for resistance to wheat leaf and stripe rust caused by *Puccinia striiformis* and *Puccinia triticina*.

Only a single plant stem rust resistance gene has been cloned to date, which is the protein kinase encoding barley *Rpg1* gene. A few seedling leaf rust resistance genes have been cloned in wheat and other cereals and are predominantly from the nucleotide binding site-leucine rich repeat (NB-LRR) class of major resistance (R) genes extensively studied in the flax rust system [1,2]. Research conducted at CSIRO by Ellis, Dodds, Lawrence and colleagues on the flax-flax rust model system have shown that during rust infection, rusts secrete a multitude of different proteins (effectors) into plant cells. Many of these proteins are most likely involved in blunting the host plant's natural immunity. The seedling type rust resistance genes, NB-LRR, code for protein receptors called resistance proteins located inside the plant cell detect and lock onto the secreted rust proteins which then trigger a sort of immune response associated with localized cell death at the pathogen entry site.

Nothing was known about the molecular basis of the slow rusting APR genes until the recent cloning of the leaf and stripe rust APR genes Lr34/Yr18 and Yr36. The nature of these APR genes is quite different from the seedling resistance proteins and therefore augers well for exploiting different mechanisms within the innate immune system of wheat in efforts at developing more durable rust resistance. Excellent progress is being made towards cloning of *Sr2* by W Spielmeyer, R Mago and colleagues at CSIRO.

While a number of seedling resistance genes effective against Ug99 stem rust have been identified, the search for other additional APR genes to complement *Sr2*, are going to be pivotal in strategies for ensuring durable stem rust resistance [3]. Successful examples of such an approach has been adopted for leaf and stripe rust resistance in wheat. For

example, the cumulative/additive effects of *Lr34* and 3-4 additional slow rusting genes, results in high levels of resistance comparable to immunity and forms the basis of durable resistance to leaf and yellow rusts in the spring wheat germplasm developed by CIMMYT [3].

Genetic diversity of rust resistance genes from wheat gene pool

A multi-prong approach in search for additional seedling and APR genes effective against Ug99 stem rust and its derivative is being pursued by the Australian Cereal Rust Control Program and the Cornell Durable Rust Resistance in Wheat project. The entire primary, secondary and tertiary gene pools of wheat have been targeted to enrich for genetic diversity for stem rust resistance. Of the current list of catalogued stem rust resistance genes effective against Ug99, most of them are found in the secondary and tertiary gene pool (Figure 1). Landraces of bread wheat hold lots of promise in unearthing additional stem rust resistance genes within the primary gene pool [4] and are also the likely source of uncharacterized APR genes.

The current spread of Ug99 stem rust race into Iran offers opportunities to tap into the unexploited stem rust APR genes that are likely to be present in the secondary gene pool sources of *Aegilops tauschii*, the D genome progenitor of wheat. From surveys in over 200 accessions of *Aegilops tauschii* for seedling stem rust resistance, most of the seedling resistance was confined to genotypes located in the Caspian Sea region (Lagudah ES and McIntosh RA). Similar observations were made in studies about seedling leaf rust resistance conducted by BS Gill and colleagues at Kansas State University. Of more significance from the leaf rust resistance studies was that a large proportion of the seedling susceptible genotypes were found to possess leaf rust APR. If such APR observations can be demonstrated for Ug99 stem rust in Iran where some of the diverse forms of *Aegilops tauschii* are located , it will serve as reservoir of potentially new and diverse source of stem rust APR for wheat improvement. Furthermore genetic analysis of the stem rust APR in *Aegilops tauschii* will not be confounded by other homoeologous genomes and the genes can be transferred by simple homologous recombination into bread wheat.

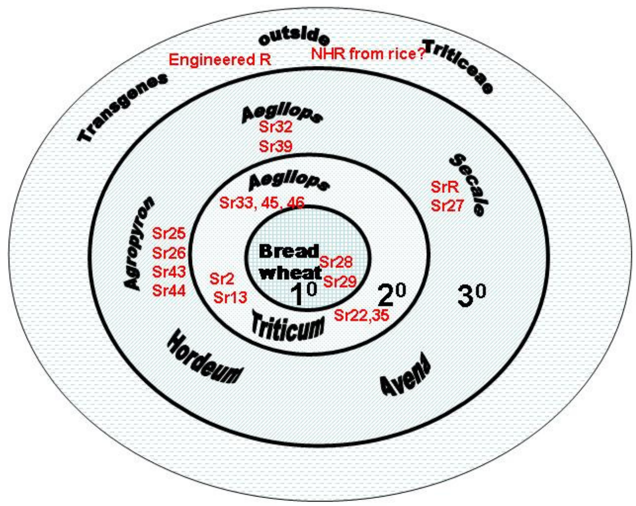

Figure1: Total gene pool (primary-1⁰, secondary-2⁰ and tertiary-3⁰) spanning the Triticeae genera (Triticum species, Aegilops, Agropyron senso lato, Avena, Secale and Hordeum) available to bread wheat from which effective genes for Ug99 stem rust resistance can be sourced. Non host resistance (NHR) from rice is potential sources of transferring immunity to rust into wheat beyond the wheat relatives from the tertiary gene pool.

Gene stacking through breeders markers

A variety of molecular marker systems are currently available to analyze wheat genomic regions containing targeted stem rust resistance genes. In addition to random DNA markers across the genome, markers targeting disease resistance gene analogs (RGAs) based on NB-LRR genes provide entry points for isolating candidate genes co-segregating with stem rust resistance phenotypes. RGA based markers can also be used as a tool in allele mining for simple and complex R gene loci and compared against resistance specificities within wheat and its wider gene pool. The increasing resources from physical maps generated from BAC contigs of wheat chromosome specific libraries, comparative genomics resources from model grasses such as rice and *Brachypodium* are speeding up the process of delineating resistance gene targets.

The key challenge still remains the identification of tightly linked markers to effective stem rust resistance that can be used in different wheat cultivar backgrounds; we refer to this class of markers as 'breeder's markers'. In the short term, the way to get effective and durable resistance against Ug99 stem rust is to stack multiple resistance genes together in one variety. This is not always an easy process, but by combining different stem rust

resistance genes using these breeders DNA markers we can now accurately assemble any combination of these genes in any wheat variety by conventional breeding.

Acknowledgements

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Gene Deployment: Indian Experience

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Gene deployment is the strategic usage of resistance genes over a large area to reduce the threat of epidemics. There are many ways of deploying resistance genes to create diversity but none is distinct from the other and all of them are "convenient points along the continuum". Many approaches like intra-field diversity, inter-field diversity, regional deployment of resistance genes and temporal diversity have been put forwarded by researchers in the past. However, we would share our views on some of key components like regional deployment of resistance genes and temporal diversity with regards to wheat rusts in the country. In India, like many wheat programmes in the world, both race specific and adult plant resistance genes have been used against wheat rusts. The following information would deal with the usage of this approach and its impact on the wheat rusts control.

The race specific resistance was suggested for rust control in spring wheat in Great Plains of United States of America and Canada if the same gene was not used in the South. Breaking "Puccinia Path" of oat crown rust by deploying different race specific resistance in three different geographical zones was also suggested in North America. The basic aim of this strategy was to create diverse host population which could be either through intra -field diversity or inter-field diversity. All these suggestions were based on the reasoning that rust pathotypes produced in one area would be avirulent on the crops of another area as different genes for resistance would be deployed.

In India, the Wheat Improvement Programme encompasses diverse activities that are aimed at wheat rust control and developing better wheat's. These activities include pathogenicity surveys and evaluation of germplasm for rust resistance. The evaluation of resistance in pre- breeding lines is achieved through intensive rust screening using most virulent pathotypes. Indirectly, this screening has achieved diverse rust resistance in Indian wheat. These focused activities have proved the strength of system in the past and we hope that these would also help us in future.

Gene deployment schemes with aim to prevent large-scale build up of wheat rusts were also proposed in India. The delineation of three different areas for leaf rust was first demonstrated and was based on the prevalence of different pathotypes in the different zones. It was suggested that these three areas should be planted to different rust resistance genes. Of course, it would be rational to use combinations of different genes to prevent evolution of a super race. Later, these areas were divided into six distinct zones based on the agro-climate, ecological conditions and prevalence of different

pathotypes. It clearly indicated that demarcation of these areas was transitory and was likely to change with evolution of new variations.

In order for the gene deployment to be effective, information on some of key areas

- pathogenicity surveys with in the country,
- information on virulence of exogenous pathotypes
- Epidemiological studies must be acquired and made available.

The pathogenicity surveys form integral part of this strategy. Such surveys have been in operation in the country since 1930s. With the information now available from these surveys, it has been possible to trace the evolution of pathotypes of wheat stem rust since the first detection. During 1930s, tall Indian wheat's were being cultivated. Systematic work on wheat breeding was initiated with pure line selection and hybridization of resistance sources with NP series was started. At this time the pathotypes virulent on Einkorn, Vernal, Khapli and Kota were detected. First isolates were virulent in *9d* and *9g*. It was interesting to see that all the isolates, which even evolved later, retained this characteristic feature. Contrastingly, for another allele like *Sr9e*, the differential behavior has existed ever since the first detection. During the second period resistance from *Sr11* (Gabo, Ridley) and others were introgressed. Many biotypes were then intercepted and new races virulent on *Sr30* (Mentana and Festiguay) were detected at that time. Further variation within these lineages was observed following the introgression of *Sr11*. The introduction of dwarf wheat's, though indicated further variation but their was no major change. Interestingly, some of these changes could either be related to host whereas others could not be related to the host. Two major and relevant changes in stem rust have been the detection of *Sr24* and *Sr25* virulences which has impacted our breeding strategies even against Ug99.

In order for the gene deployment to be effective, it is very essential that role of exogenous inoculum is ascertained. Breakdown of Kalyansona, Sonalika and *Yr9* resistance against stripe rust was traced to Eastern Africa, Turkey, Syria, Iran and Pakistan. Another challenge now is that similar route of migration has also been predicted for Ug99. Therefore, it would be very vital for us to know the characteristic features of such pathotypes which are predicted to enter in our country.

Epidemiological studies of stem rust in India have established the role of the source areas for the rust dissemination. Since we are holding conference on Ug99, it would be relevant to have a look at wheat stem rust. Survival and dissemination of this rust is a key component that needs to be assessed to make the deployment strategy successful. Earlier studies have shown that Nilgri and Palney hills in the south play an important role for stem rust. The inoculum from these hills spreads up to Central India depending on

weather patterns and rainfall. Another important focus of infection is the hills of Karnataka where wheat is grown as a summer crop. Stem rust is able to survive in these hills and due to the presence of susceptible local durums; the infection is almost endemic in this area. Though acreage sown to wheat is very small yet new variation has been observed. For example 3 variants have been detected in last 5 years from this area. Hence, there is a need to verify the role of this focus of dissemination to have a long term effective strategy. The spread of stem rust is more common from hills of Karnataka than it appears. Whereas, the spread of inoculum from Nilgiri hills though possible but appears to be less likely. In the north of the country, central Nepal hills are very important for stem rust as this rust has been observed to break out at the earliest in foot hills and plains along Nepal Border in Uttar Pradesh. Thereafter, it spreads to the fields of north India where it breaks out towards the end of crop growing season as coolness of North hills is suggested to delay/ prevent the early infection of this rust. Higher hills of North India, though harbor stem rust infection on volunteer plants and off season wheat yet these foci have not been suggested to play any role in epidemics of north India. It has been argued that due to very low temperature, this source of stem rust is merely an over-summer and spread from these hills is unlikely. Though north hills have been shown to be passive for stem rust epidemics yet some of the observations can not be explained on this reasoning. For example, these hills were implicated as active foci for break out of local epidemic of stem rust at Sanchore in Rajasthan in 1973-74 crop seasons. It was explained that dissemination of stem rust from north hills was responsible for this outbreak which was aggravated by the early sown crop i.e. in the month of August- September. Certainly, this rust can disseminate from these areas but for prevailing temperature in the hills. Much has changed since these explanations were advanced. Farmers now prefer short duration wheat varieties due to more remunerative wheat -paddy crop sequence in the Indo-Gangetic plains. So lot of changes has occurred since then and wheat cultivation has undergone a vast change. Therefore, we feel that there is a need to have a relook at some of these observations since some of the gaps are still unexplained. So we need to keep in view these observations to suggest gene deployment in future.

Compilation of the aforementioned information reveals that certain boundaries can be drawn for suggesting use of different genes in different area.

The information generated from these activities in the past was used to suggest the cultivation of rust resistant wheat’s in the country.

Some of the case studies would prove that it has been usefulness strategy for the country since no major development of rust was observed in the country for two decades.

A successful, though unintentional, deployment for stem rust resistance is the large scale cultivation of HD2189 in Peninsular India. Presently, this cultivar is resistant to Indian stem rust pathogen. Another *Sr31* -cultivar (DWR162) being cultivated in Karnataka area of this zone is also resistant. So the inoculum which spreads from Karnataka or Nilgiris is not able to multiply as it lands on the resistant gene. Consequently, three popular cultivars of Central Zone namely Lok-1, Sujata and WH147, though susceptible but are protected against any transported inoculum.

Our studies have further revealed that prevalence of pathotypes in specific region is also influenced by host and prevailing weather conditions. This knowledge can also be used for the gene deployment. The isolates of stem rust in last decade were found to be Einkorn, Kota and Reliance – virulent. These were prevalent for some time in the nature. Later, the surveys revealed that virulence for some of the genes like *Sr13* and *Sr30* have receded and are not prevalent in nature any longer. So both these genes, along with others like *Sr32*, *35*, *39* and *43 could* be easily used in Peninsular and Central India. Likewise, *Sr24*- virulent culture, detected from Wellington has remained confined to this area for more that ten years. Even within Nilgiris this virulence is not predominant even though present. So one could use this gene in the areas where such virulences have not been detected/ migrated yet. Similar observations have also been made with brown rust. It is, therefore, evident that epidemic development of stem rust can be curtailed in the country through adopting such measures.

Another case of success story that must be referred here is the story of stripe rust in North Western Plains Zone. Historically, the introduction of dwarf varieties saw cultivation of *Yr2* wheat's (Kalyansona- 8156 types of wheat's) followed by *Yr2+ A* (Sonalika) wheat's. When Sonalika became susceptible in this zone, another genotype carrying *Yr2+A* and additional gene/s (HD2329) was released. Then *Yr9* –virulence, suggested to have migrated from West Asia in 2001 was picked up. Before this virulence could cause yield losses, PBW343, another resistant variety was released for cultivation. So the information from pathogenicity surveys ensured that the resistant varieties were in the field for cultivation. Heavy infection of *Yr9* -virulence was observed in some of the adjoining countries where this gene deployment/ variety replacement could not be practiced.

Selection for PBW343 at the time of prevalence of *Yr9*- virulence proved very useful as it was found resistant. Now, PBW343- virulent cultures are present in nature but still this cultivar has expressed delayed and slow -rusting and is kind of tolerant in the field.

Whereas, other *Yr9*- possessing cultivars like UP2338, HS240 are very susceptible to stripe rust, and are gradually being phased out of farmers fields or are occupying very small acreage.

With guidance from past efforts, the threat of Ug99 has also been addressed with the same enthusiasm through strategic initiatives like evaluation of Indian wheat's at Kenya against Ug99 and resistance breeding. With these efforts combined with knowledge from surveys and breeding activities, we hope that we would be able to protect our crops against Ug99 through deployment of resistant cultivars.

Seed Production of UG 99 Resistant Varieties

Tom Osborn, FAO

Introduction

UG 99 is a serious threat to global wheat production. The development of resistant varieties, surveillance systems and effective plant protection strategies are important element of a wheat rust strategy that need to be urgently implemented. However to effectively counteract the threat of UG 99, a range of resistance varieties need to get into the hand of farmers quickly in areas at risk. The key elements in the rapid dissemination of UG99 resistant varieties to farmers include the following:

1. Effective Planning (Contingency Planning related to seed production)
2. Rapid Variety Evaluation and Release (normally requires several seasons)
3. Rapid Seed Multiplication (an initial target of seed for 10% of wheat producing area in many countries can be achieved in several years)
4. Variety Awareness and Seed Distribution to Farmers (ongoing activity)

Description of the key elements

1. Effective Planning (Contingency Planning)

Contingency planning for seed production is part of the larger contingency planning that is necessary for the threat of UG99. Effective planning will require engaging all the stakeholders including the national plant protection service, plant breeders from the agricultural research institutes, seed sector (both public and private), extension services, and farmer organizations. Workshops will need to be conducted at the national level, province/state level, district level to engage the stakeholder to raise awareness and develop action plans that include role & responsibilities, staffing requirement, supplies and equipment, land requirements with suitable infrastructure i.e. irrigation for effective seed multiplication. It is anticipated that there would be substantial involvement of private sector seed companies and farmer organization in the planning process since the scope of the effort will require a strong commitment from all stakeholders. The participatory process will start with workshops that assign multi-disciplinary / multi-institutional working groups with developing the action plans to include the elements described below.

2. Rapid Variety Evaluation and Release

After promising crop varieties are developed and tested by planting breeders, the new crop varieties must go through a variety evaluation and release system before they can be multiplied and used by farmers. It is anticipated there will be numerous lines of UG99 resistant wheat varieties adapted to a range of agro ecological zones and with different organoleptic characteristics from international breeding efforts for UG99. National programmes tasked with responsibility to screen UG99 resistant varieties will be able to

source the most promising varieties to evaluate for release and to use in national UG99 resistance breeding programmes. Similarly it is anticipated that countries will be able to share promising UG99 resistant lines in order to accelerate the process of testing and releasing a wide range of UG99 resistant wheat varieties. It will be important for national varietal testing systems to be strongly linked with international information sources on varietal data and performance under a wide range of agro ecologies. Given the global scope of the disease epidemics and the need for a global response, efforts should be made to consider a policy for joint release within regions or in the absence of a region release to have a clause for exception of compulsory registration of wheat resistant variety coming from outside of the region with similar agro-ecological conditions. The serious threat of UG99 means that variety evaluation and release may need to be streamlined so that it is efficient and effective but at the same time carry out in as short a time frame as possible. Variety evaluation and release should not be an element in the system that slows down getting resistant varieties to farmers.

The following activities should be considered:

- Assessment of global UG99 nursery results, in addition to multi-locational trials and varietal registration with the view of identifying how it can be improved and standardized between countries to facilitate the exchange of germplasm and varietal data as well as facilitate joint release of varieties resistant across agro-ecological locations regardless of the political boundaries.
- Based on national assessments, to strengthen and streamline national multi-location adaptation and pest and disease resistance trials for UG99 rust resistant varieties
- Review and strengthen policy and national varietal release procedures
- Ensure that Plant Variety Protection and Intellectual Property Rights issues related to the UG99 resistant varieties are addressed

3. Rapid Seed Multiplication

Once UG99 resistant wheat varieties are nationally or regionally registered and ready for release, a national strategy should be in place for the seed multiplication and distribution of quality seed of rust resistant varieties to replace rust susceptible varieties in high risk areas or hot spots. This is not one off or short term effort since it is anticipated that a range of UG99 resistant varieties will be released over time from both international and national breeding programmes. In addition it will be essential to maintain the diversity of wheat varieties with a broad genetic base to avoid other potential disease threats or the breakdown of resistance. As a starting point, the initial target for rapid seed multiplication is 10% of the wheat production area. In most countries this can be accomplished in 3-4 generations (see Table 2). The actual targets for rapid seed multiplication will depend on the actual and potential threat of UG99 that will be elaborated as part of the contingency planning and

surveillance system. The national rapid seed multiplication strategy will also include the province/state level and district level since much of the seed multiplication will be undertaken at the province and district level. Though some of the countries at threat of Ug99 already have a system for seed multiplication, modifications may be needed to cope with the urgency of rapid large scale multiplication and distribution of the Ug99 resistant varieties, especially to the most vulnerable small farmers. Urgency should not compromise the production of quality certified seeds and this will require a strong role for the national seed service and related seed certification agencies to ensure the inspection, testing and certification of the seed. Some countries may need to strengthen their seed certification services to respond to this demand through training and other support. In addition inputs and equipment such as tractors, implements, irrigation equipment, combines etc may be needed to ensure the maximum yield obtained from the early generation seed multiplication. A review of equipment and facilities for seed storage and seed conditioning (processing) should be undertaken to ensure that this element is not a constraint to the rapid multiplication, processing and distribution of quality seed. Partnerships with private sector seed companies may be the quickest and most cost effective strategy for seed multiplication. A well coordinated system for rapid seed multiplication will require an effective partnership and high level of coordination in order to be successful.

Table 1: Planting rate of 100kg/ha with varying yields (3T/ha, 4T/ha and 6T/ha)

Generation	**Qty of seed produced in Tons with different Seed Multiplication Ratio**		
	1:30	**1:40**	**1:60**
Initial seed Qty	**0.05**	**0.05**	**0.05**
First	**1.5** (*0.5 ha*)	**2.0** (*0.5 ha*)	**3.0** (*0.5 ha*)
Second	**45** (*15 ha*)	**80** (*20 ha*)	**180** (*30 ha*)
Third	**1,350** (*450 ha*)	**3,200** (*800 ha*)	**10,800** (*1800 ha*)
Fourth	**40,500** (*13,500 ha*)	**128,000** (*32,000 ha*)	**648,000** (*108,000 ha*)
Fifth	**1,215,000** (*405,000 ha*)	**5,120,000** (*128,0000 ha*)	**38,880,000** (*648,0000 ha*)

(*Figures in parenthesis indicates the area that will be required to produce the seed of the concerned generation*)

To provide an idea of the number of generations, area needed for seed multiplication and area the seed can cover at various multiplication factors, the above tables will provide some basic information of a seed multiplication systems starting with 50kg of nucleus seed. The importance of intensive production of seed through optimum management practices and water management to achieve higher multiplication factors emphasizes this strategy for increasing the speed of seed multiplication. In addition the large areas required for seed

multiplication provide an idea of the scope of the seed multiplication needed in order to address the UG99 threat.

Table 2: Area under Wheat Cultivation, 10% Target Area and % Area covered after 4 generations at a Multiplication Factor of 30, 40 and 60

S. No.	Country	Area under Wheat cultivation 2007	10% of the wheat area	% Area that will be covered after 4 generations with following Multiplication Factors		
				1:30	**1:40**	**1:60**
1.	Afghanistan	2,190,000	219,000	18.4	58.4	100
2.	Algeria	1,785,000	178,500	22.6	71.7	100
3.	Armenia	113,300	11,330	100	-	-
4.	Azerbaijan	486,990	48,699	83.4	100	-
5.	Bangladesh	805,000	80,500	50.3	100	-
6.	China	30,000,000	3,000,000	1.4	4.3	21.6
7.	Egypt	1,139,000	113,900	35.6	100	-
8.	Ethiopia	1,351,000	135,100	29.9	94.7	100
9.	Georgia	61,000	6,100	100	-	-
10.	India	28,035,000	2,803,500	1.4	4.6	23.1
11.	Iran	6,400,000	640,000	6.3	20.0	100
12.	Iraq	531,210	53,121	76.2	100	-
13.	Jordan	30,000	3,000	100	-	-
14.	Kenya	150,000	15,000	100	-	-
15.	Kyrgyzstan	354,500	35,450	100	-	-
16.	Lebanon	48,000	4,800	100	-	-
17.	Libya	257,000	25,700	100	-	-
18.	Morocco	1500,000	150,000	27.0	85.3	-
19.	Nepal	472,000	47,200	85.8	100	-
20.	Oman	275	27.5	100	-	-
21.	Pakistan	8,494,000	849,400	4.8	15.1	76.3
22.	Saudi Arabia	462,000	46,200	87.7	100	-
23.	Sudan	250,000	25,000	100	-	-
24.	Syria	1,850,000	185,000	21.9	69.18	100
25.	Tajikistan	330,000	33,000	100	-	-
26.	Tunisia	974,000	97,400	41.6	100	-
27.	Turkey	8,600,000	860,000	4.7	14.9	75.3
28.	Uganda	11,000	1,100	100	-	-
29.	Uzbekistan	1400,000	140,000	28.9	91.4	100
31.	Yemen	114,030	11,403	100	-	-

This second table focuses on providing an idea of indicative quantities of seed that may be needed in each country. A tentative target of seed to cover 10% of the total area in wheat is included. In addition the percentage of the area that can be covered by 4 generation of seed production at multiplication factor of 30, 40 and 60 demonstrates the need to undertaken intensive wheat seed production in order to reduce the time to reach the target quantities.

3.1 How to accelerate seed multiplication?

Many countries will want to consider how to speed up the seed multiplication process. Here are a few strategies to consider.

- Seed multiplication can be started before the variety is officially released so that further multiplication can start with a larger quantity of seed.
- Seed multiplication estimates were based on an initial quantity of 50 Kgs. If a larger quantity of seed is available then the target quantity can be reached much rapidly.
- Intensive management of the initial seed multiplication can raise the multiplication factor from 30 to 50 or more. This will require excellent crop management i.e. seed bed preparation, precision planting, excellent weed control, high levels of soil fertility, irrigation, pest control as well as timely harvesting. Fertility management must be precise to prevent lodging of the crop
- Some countries are able to produce 2 crops per year and this is a major advantage in accelerating seed multiplication. There could also be cooperative agreements between countries to produce more than one crop a year.
- Importation of large quantities of seed from reliable sources to kick start seed multiplication. This will require that a Pest Risk Assessments are carried out.
- Establish a regional approach to accessing the varieties that you need in the quantities necessary. Specific countries could specialize in producing specific UG99 resistant wheat varieties

3.2 Seed Storage

Wheat seed can be effectively stored without losing it vigour and germination if well known precautions are taken. Safe storage of wheat seed is possible as long as the moisture percentage is below 13, the humidity is low, ambient storage temperature is not excessive and the infestation with storage insects is minimized. Small quantities of seed can be stored for long periods in cold rooms. The excellent storability of wheat seed provides the option of rapid seed multiplication of UG99 resistant varieties and establishing a strategic seed reserve even before UG99 has threatened wheat production in the country. With this strategy the UG99 resistant wheat varieties can be quickly released when it is needed. Similarly as new UG99 resistant varieties are developed they can be rapidly multiplied and added to the strategic seed reserve to have different sources of resistance and wider genetic diversity.

4. Variety Awareness and Getting Varieties to Farmers

Farmers need to become aware of the threat of UG99 and get to know the UG99 resistant varieties. In order to do this it will be necessary to establish demonstration plots to create awareness of the UG99 resistant varieties and UG99 management practices with farmers though the farmer organization.

- Work with extension services, plant protection services, and seed companies to create awareness of adapted rust resistant varieties amongst farmers through seed campaign including field demonstration plots. Initial targeting should be in zones that have a high potential for he development of UG99. The demonstration should also be linked to monitoring and detecting UG99 and to production practices and other strategies to limit the spread of UG99.
- With national authorities develop and support a decentralized strategy for the multiplication and distribution of quality seed of rust resistant varieties to replace rust susceptible varieties through both the public and private sector.
- Strengthen the database of the National Seed Certification Agency, national variety registry to include attributes such as plant quarantine pest/diseases, particularly Ug99 rust strains to which the variety is resistant.

Key points for Immediate Action for Policy Makers as part of Contingency Planning

- Establish Contingency Planning with wide participation, clear roles and responsibilities and necessary resources
- Ensure that systems are in place for the Rapid Release of UG99 Resistant Varieties
- Ensure that the capability and system are in place for the initial and sustained rapid multiplication of UG99 resistant varieties
- Determine the appropriate methods to accelerate seed multiplication such as intensive management, off season production, and importation of UG99 resistant varieties
- Put systems in place with the public and private sector and farmers' groups for UG 99 awareness raising and demonstration of UG99 resistant varieties to farmers

CHEMICAL AND CULTURAL MANAGEMENT OF TTSK (UG99) OF WHEAT STEM RUST PATHOGEN IN KENYA

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Stem rust of wheat (*Triticum aestivum* L.) caused by *Puccinia graminis* f.sp. *tritici* Eriks & E. Henn. is widely spread in the wheat growing areas of Kenya. Stem rust epidemics occur frequently when environmental conditions during the growing season are favorable. An epidemic of stem rust swept through the highlands regions in 2003 and destroyed wheat crops grown by both small and large scale farmers. Most of the commercial wheat varieties are now highly susceptible to the new race (TTSK (UG99) of stem rust that it is not possible to grow a crop of wheat without realizing heavy grain losses without the application of a fungicide.

While resistance is the most effective method of controlling stem rust, there are no commercial varieties in Kenya with adequate resistance. Therefore, fungicides as foliar or seed treatments will play a role in the integrated management of the disease until new varieties with improved resistance are released. The disease buildup has increased over the years that in the year 2007, epidemic levels were observed in farmers' fields. Most farmers were taken by surprise because they had not seen the disease before and also, there were no fungicides specifically developed for stem rust control.

Stem rust epidemics are causing grain losses of up to 70% in experimental plots and over 70% in farmers' fields. This is yield of sprayed vs. unsprayed wheat crop. Spraying only reduces but does not eliminate the disease. It is therefore possible to get yield losses higher than this when relative to a clean crop. In the year 2007, farmers who never controlled the disease at all, lost 100% of their crop regardless of the variety.

Short term control of stem rust can be achieved with standard application of fungicides, provided the infection is not severe. Some of the foliar fungicides recommended for the control of yellow and leaf rusts can also be used to reduce/suppress the stem rust disease. Because most farmers are not able to identify the rust, it is recommended to apply two sprays, 60 days and 75-80 days respectively, after planting. Thereafter, the farmers can start scouting for the disease on the stems on a weekly basis. A third spray will be required if the disease is observed on the crop. The rate of application for each fungicide is higher than the standard label recommendation for yellow and leaf rusts.

All the fungicides used in Kenya are supplied by a number of Agro-chemical companies. Bayer Crop Science East Africa commands about 48% of the total fungicide market share in cereals in Kenya. The rest is taken up by Syngenta East Africa (23%), and Amiran Kenya Ltd. The others are Osho Chemical Industries, Twiga Chemical Industries, Prestige,

FarmChem, among others. The bulk of the fungicides used in wheat are in the triazole class, a few are in the Strobilurine family. The majorities of the fungicides are recommended for the control of yellow (stripe) rust caused by *Puccinia striiformis* and leaf (brown) rust caused by Puccinia *recondita*.

The impact of fungicide-use in the management of stem rust was well illustrated in three trial sites. Significant differences were found among fungicides in their ability to control stem rust. The study showed that stem rust could severely reduce the wheat grain yield of susceptible varieties in Kenya and that foliar fungicides can be used to suppress stem rust in wheat as a short term control strategy. Farmers in Kenya can effectively reduce/suppress stem rust by the application of foliar fungicides and still benefit.

Development of Trap Nurseries: Cooperative Screening, Evaluation, Virulence Monitoring, Variants Detection

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Introduction

The three rusts of wheat continue to be diseases of major importance in most wheat growing areas of the world. Because of their strategic significance, an international program to test disease resistance (s) was initiated in the 1950's. This resulted in the establishment of the International Rust Nursery (IRN) distributed by the US Department of Agriculture (Saari and Nayar, 1997). This nursery was created to test for rust resistance (s), but it also became a mechanism for the distribution of germplasm, and a source of information on various aspects of wheat adaptation. It allowed researchers to consider factors related to genetics of resistance, their stability and durability.

Efforts to promote "alleviation of hunger" in the third world countries began after World War II, and it involved numerous organizations and countries. As part of this effort, a series of International Agricultural Research Centers were created. The International Maize and Wheat Improvement Center (CIMMYT) in Mexico, is one of these Centers, and it is committed to research on maize and wheat. CIMMYT became involved with the Indo-Pak subcontinent and wheat production issues in the mid-1960. This cooperation encouraged the regular exchange of germplasm, nursery data and the exchange of scientists.

Germplasm exchange and the sharing of information on yield potential, adaptation and disease resistance (s) has helped to promote food production and security. This international network has also given the scientific community a better understanding of the host-pathogen genetics, diversity of pathogenicity, and the stability or durability of resistance (s).

The rusts have been the most important wheat diseases of the Indo-Pak subcontinent and other parts of the world through the 1960's. Records from the 1800's indicate that black or stem rust caused by Puccinia graminis f. sp. Tritici was the dominant disease. Because of its global importance, a major international effort was initiated to develop and identify stem rust resistant wheat varieties after the end of World War II. This international effort involved wheat breeders and pathologists in many countries. Germplasm was distributed through the International Stem Rust Nursery (ISRN). This nursery and subsequent rust nurseries were organized by the USDA. These nurseries helped to identify resistant sources, varieties and measure their adaptation.

The frequency and magnitude of leaf and yellow rust epidemics, has been declining in recent years due to the widespread use of resistance, variety diversification and national efforts for disease monitoring.

There is a need to join regional and international efforts for cooperative disease screening, evaluation and exchange of germplasm, virulence monitoring and continued exchange of information.

Importance of Disease Monitoring in Preventing Epidemics

For the purpose of preventing epidemics it is possible to monitor the disease itself, and any one or more of its components (Young et al., 1978). The term epidemic has been defined in many ways. The most accepted definition has been given by Van der Plank, 1963, Zadoks, 1972, and Kranz, 1974. Certainly, magnitude is one of the most important considerations. The farmer whose field was destroyed has had an epidemic, whether his neighbors, the state, national or international economies were affected or not. Be that as it may, the squeaking wheel gets greased and the major epidemics of major crops receive the attention. All of our crops at one time or another has been subjected to major epidemics. Wheat has had several epidemics of leaf rust and yellow rust in West and South Asia (Saari and Nayar, 1997).

Our present knowledge concerning epidemics has come from monitoring their natural development as well as from experimentation. It is therefore logical that we should use monitoring as a tool in epidemic control. Several methods of disease monitoring have been described by Young et al, 1978. The most important ones being: the use of phenology, the measurement of weather parameters, the measurement of inoculum, field surveys, collection of plant material, analysis of race patterns, and the use of trap plots (trap nurseries).

Successful Experience with Management of Rust Trap Nurseries

Trap plots or trap nurseries, have been the foundation of the program of wheat disease monitoring in several US, Australian and European wheat breeding programs for many years. These nurseries have been valuable not only for providing the requisite information for the rust forecast, but also for evaluating disease resistance sources much more thoroughly than can be done in the greenhouse or inoculated test plots. It permits to monitor changes in virulence in the pathogen populations and serves as a source of pathogen cultures to be used for evaluating new germplasm. One important spin-off is that it permits wheat researchers to keep informed about the performance of various commercial cultivars under production practices. As a result, wheat researchers are better prepared to answer questions that come through the extension service or directly from farmers.

One of the most successful early nurseries of this type was the Regional Disease Trap Nursery (RDTN) which was established to assist in establishing national wheat disease surveillance programs which can be useful in stabilizing wheat production by minimizing the potential loss caused by epidemic diseases. It has the following specific objectives:

1. Monitor and establish disease development probability curves for each of the major wheat growing areas.

2. Determine the virulence spectrum of the pathogen populations within the region and determine their distribution relative to the sources of resistance available.
3. Determine the influence of commercial varieties on the inoculum potential and their effects upon pathogen populations.
4. Provide information on which varieties can be recommended and determine those varieties that are potentially endangered and should be withdrawn from commercial production.
5. Detect new changes in the virulence patterns at the earliest possible date and determine the potential importance of these shifts.
6. Search for new sources of resistance to the new virulences that may evolve.
7. Assist in mapping the movement and geographical spread of diseases, especially those that transit international borders.
8. Determine the environmental components that limit or confine disease spread and development.

In the early 1980's, reduction in the number of nurseries grown by many cooperators while still maintaining a high degree of disease surveillance was accomplished by combining the following rust nurseries: (a) the International Yellow Rust Trial, (b) the European Leaf Rust Nursery, (c) the Egyptian Trap Nursery, and (d) the Regional Disease Trap Nursery (RDTN). The RDTN was sent too many countries in North and East Africa, as well as West and South Asia. The RDTN was divided into "A" and "B" sets. The "A" set was composed of about 50 extensively grown cultivars in the region. It was used to help determine the prevalent rust race flora, and to measure the potential for disease development in each of the major wheat areas. Some of those entries were too early or late, tall or dwarfed, too light-sensitive or susceptible to disease. These factors made it difficult for some cooperators to grow the nursery and to obtain useful results. The "B" set consisted of the "A" set plus about 50-60 selected single combination gene lines or certain important sources of rust resistance. The "B" set was an attempt to measure the virulence patterns (races) and potentials in each area, and determine effective sources of resistance. An effort was always made to include in the "A" set of the nursery a representative sample of the commercial wheat varieties grown throughout the region. Wherever possible, the disease susceptible checks were inspected each week until the date of appearance of the major diseases was established. Cooperators were encouraged to make periodic disease scorings on the nursery, or at least the susceptible checks. Such information was used to plot disease development curves for each locality. A summary report was issued and distributed each year. Similar trap-nurseries are currently operated by CIMMYT and ICARDA, including national nurseries implemented by India and other countries. Monitoring with trap nurseries is a very labor intensive affair and care of the lines used is paramount.

A trap nursery is more useful for a pathogen that shows the presences of races because breeding against the new virulence is a way to overcome the new problem. Trap nurseries are useful if displayed at key locations only. The major problems are: lack of attention given to accurate data recordings, lack of attention in maintaining lines pure, mixtures at sowing etc. In some NARS, seed of trap nurseries becomes irrelevant rapidly; the nursery is lost and leads to wrong information. Care of the lines is paramount. Similarly, replenishing and sending new seed everywhere from a single source is costly (actual time to produce them + shipping). Another aspect is that if isolines are in a spring wheat background it is OK to use them in fall planting countries. If it is in a winter background, producing and keeping seed is even more complicated.

Some of the successes of the CIMMYT Wheat Program in the area of germplasm development are related to the incorporation of the rust resistance. The incorporation of stem rust and leaf rust resistance has been a high priority since the earliest times. Much of the early work was guided by data collected through the International Nursery Systems. Multi-location data was used to assess the “strength” of the resistance’s, and variability of the pathogen. The international work of rust resistance at CIMMYT was initiated by Dr. N.E. Borlaug, continued through the efforts of the late Dr. R.G. Anderson, Dr. S. Rajaram, Dr. M.v. Ginkel and Dr. R.P. Singh, and now carried forward by Dr. Singh.

The introduction and expansion of the semi-dwarf wheats into India and Pakistan in the 1960’s, and their spread to other countries of West Asia and North Africa in the 1970’s was successful because of yield potential, and adaptability. An important factor in the acceptance of semi-dwarf wheat varieties was the low level of rust disease. It is doubtful, if they would have been grown, and used so extensively, if rust resistance had not been incorporated. This was especially true in the case of stem rust, which was considered the limiting disease after World War II. The rapid spread of the semi-dwarf wheats placed strong pressure on pathogen populations. This was measured through a number of nurseries, including disease trap nurseries, established for this purpose.

The study and survey of wheat rusts in India has a long and well-documented history (Nagarajan and Joshi, 1985; Nayar et. al. 1994 b). India has established itself as a leader in the studies on epidemiology, host pathogen interactions and genetics of resistance. This capacity could not have been accomplished without support and development of facilities and expertise. This support will be increasingly important in the years to come if yield gains are to be assured and stabilization of production guaranteed. Many do not fully appreciate the complexity of the host-pathogen system in the rust diseases. It is a highly specific, natural system, which is as specialized as any other molecular marker system in biotechnology. A current problem facing rust laboratories is the expenses to maintain and update facilities. The successful ones have a strong infrastructure and trained manpower.

However, in many developing countries, rust laboratories are being phased out, and this may be a reflection of too much success.

The cooperative wheat research work conducted between India and Nepal involves the identification of rust collections from Nepal at DWR Rust Laboratory at Flowerdale, Shimla. The leaf rust samples identified from Nepal suggest they are similar and associated with those of India. Nepal plays a critical role in the over summering of the leaf rust fungus and in the initiation of the epidemiology of the leaf rust disease in the subcontinent, especially in the Northeastern Plains Zone (Mahato, 1996; Sharma, 1997; Nayar et. al., 1996b; Nayar et. al., 1994b). The leaf rust developments in this area of the Indo-Gangetic Plains subsequently has a major influence on the leaf rust developments in Northwest India (Nagarajan and Joshi, 1985) and has obvious implications for rust developments in Pakistan.

The large scale adoption of semi-dwarf wheats in West and South Asia in the 1960's created a situation that allowed for the recording of an exodermic infusion of a yellow rust pathotype into the subcontinent. The wide spread cultivation of semi-dwarf cultivars and the exposure of the Yr2 gene made it was possible to track the "new" virulences associated with those cultivars. The first report of the Yr2 virulence was noted from Turkey in 1967 (Oskan and Prescott, 1972). Subsequently, it was reported from Lebanon, Iran, Afghanistan, Pakistan, and India (Sharma, et. al., 1972) and eventually from Nepal (Karki, 1996, personal communication). The tracking of the sequential appearance of the Yr2 virulence was possible because of the newness of the Yr2 gene in the host population, and the international network of nurseries cooperation.

Conclusions

Disease monitoring is the backbone of disease control and pest management programs. Regional and international cooperation, with disease information and germplasm exchange is important and has provided multiple benefits. Due to early disease monitoring work, different sources and types of resistance are now well recognized. Some sources have been determined to impart general or durable resistance and these durable sources have become the cornerstone of the germplasm pool for resistance breeding. The role of multi-location testing and international cooperation has paid large dividends in terms of development of rust resistant cultivars. The Indian National Wheat Program and the cooperating institutions have contributed and derived benefits from this cooperation. In order to meet future projected food needs, more extensive and intensive cooperation will be needed. The Indian Wheat Program is in a strategic position to provide critical leadership in this effort in South Asia and other countries. There is a need to join regional and international efforts for cooperative disease screening, evaluation and exchange of germplasm, virulence monitoring and continued exchange of information.

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Database generation and exchange of information

Keith Cressman and Dave Hodson, FAO

Introduction

The intelligent management of plant pests – used in the broader sense to include insects and diseases – requires the undertaking of regular surveillance activities (surveys) in the field that generate information for decision makers to intervene (control) in a timely and appropriate manner in order to mitigate negative impacts on households and food security. A well-designed pest monitoring system considers the biology and behaviour of the organism and its relationship to the environment. Seasonal pests that may be present at varying levels every year in crops and do not travel long distances can be monitored and controlled locally, for example, by farmers. On the other hand, migratory or transboundary pests – those that can travel long distances across international borders, regions and continents – require a different approach, one that provides a larger overview. In both cases, information collected in the field is the foundation of the monitoring system. If information is provided in real-time and if there is sufficient knowledge of the pest and its relationship to the environment, then early warning can be provided to allow decision makers additional time for planning appropriate response actions.

Stem rust was historically the most feared disease of wheat. Use of genetic materials with effective resistance decreased the incidence of stem rust to almost non-significant levels by the mid 1990's. A significant breakdown of that resistance with the emergence of a new race of wheat stem rust, Ug99, now threatens global food security. Ug99 was first identified in Uganda in 1999 and, since then, its spores have spread to Kenya and Ethiopia (2004), Yemen and Sudan (2006) and Iran (2007) (Fig. 1). Stem rust spores arriving on winds as late as one month before harvest can turn a previously healthy crop into a tangled mass of stems that produces little to no grain. As the winds cannot be stopped, there is a high probability that Ug99 will reach major wheat growing areas of Asia and other regions, threatening up to one-third of global wheat production with annual losses that could reach US$ 3 billion. Of additional concern is the changing nature of the pathogen, with two new variants already recorded in Kenya? One of these variants, exhibiting virulence to another key resistance gene (Sr24), resulted in stem rust epidemics in Kenya during 2007. Loss of this resistance gene significantly increased the global vulnerability of wheat germplasm, as approximately half of global germplasm previously considered resistant to Ug99 was rendered susceptible by this change. Any effective monitoring system therefore has to include information on the new variants emerging in the Ug99 lineage.

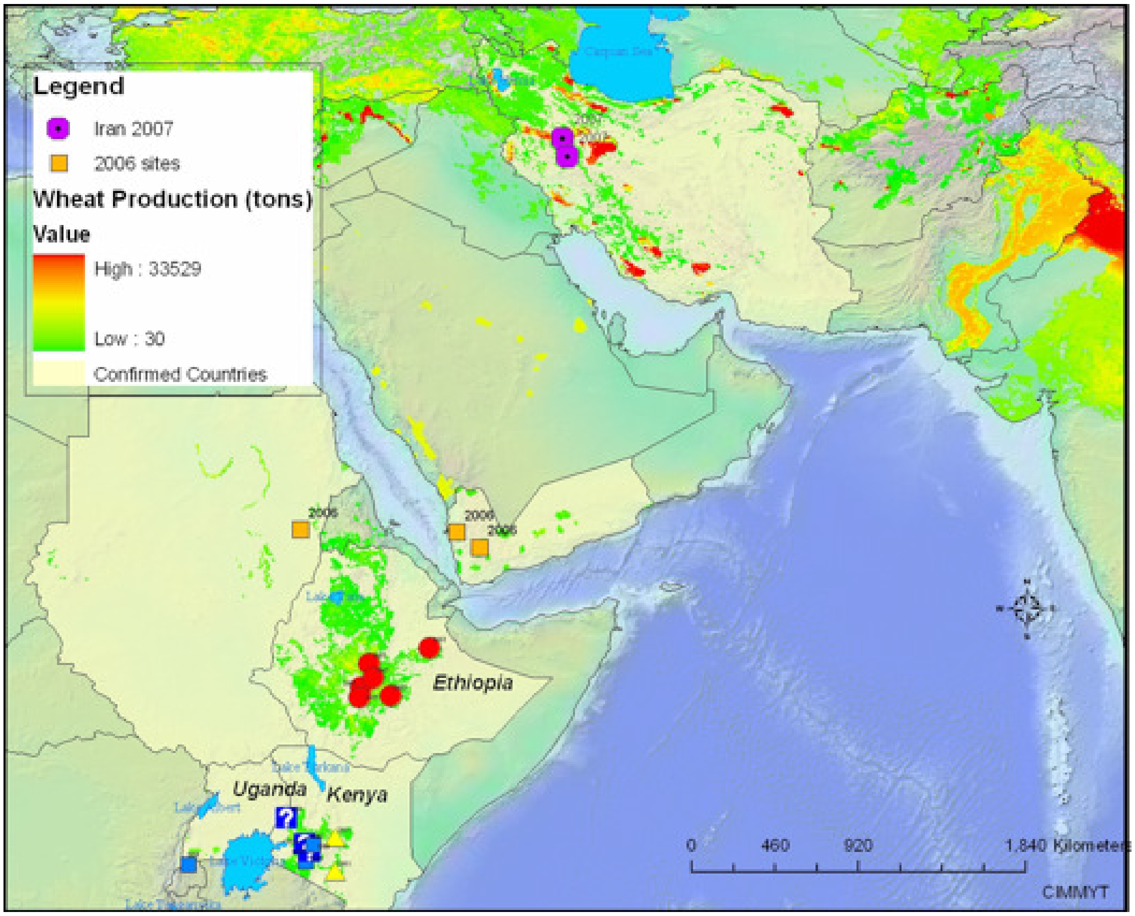

Figure 1: The spread of Ug99 from East Africa to southwest Asia, 1999-2008 ***(source: CIMMYT)***

Surveillance and tracking system

To combat the potential menace of Ug99, wheat varieties with durable resistance to stem and other rusts need to be developed and distributed to farmers but this will take several years. In the meantime, vigilant monitoring of the incidence and nature of stem rust is required in countries thought to be Ug99-free today and in those where Ug99 is already established. The stark reality is that we do not know how far Ug99 has migrated. No framework exists for acquiring and sharing data on incidence, severity, and genetic composition of stem rust infections in the developing world. There is no singular source of information on the spatial and temporal distribution of wheat. Lack of this knowledge impedes resolution and adoption of appropriate national and international policies, investments and strategies in plant protection, plant breeding, seed systems, and research on the stem rust pathogen. To address these deficiencies, surveillance and tracking system, the Global Cereal Rust Monitoring System (GCRMS), is being established as a means of conducting a coordinated defense against Ug99 in order to identify those areas that are currently infested and at risk, and to monitor the spread of Ug99. The information generated by GCRMS will

aid decision-makers and researchers in evaluating different management options.

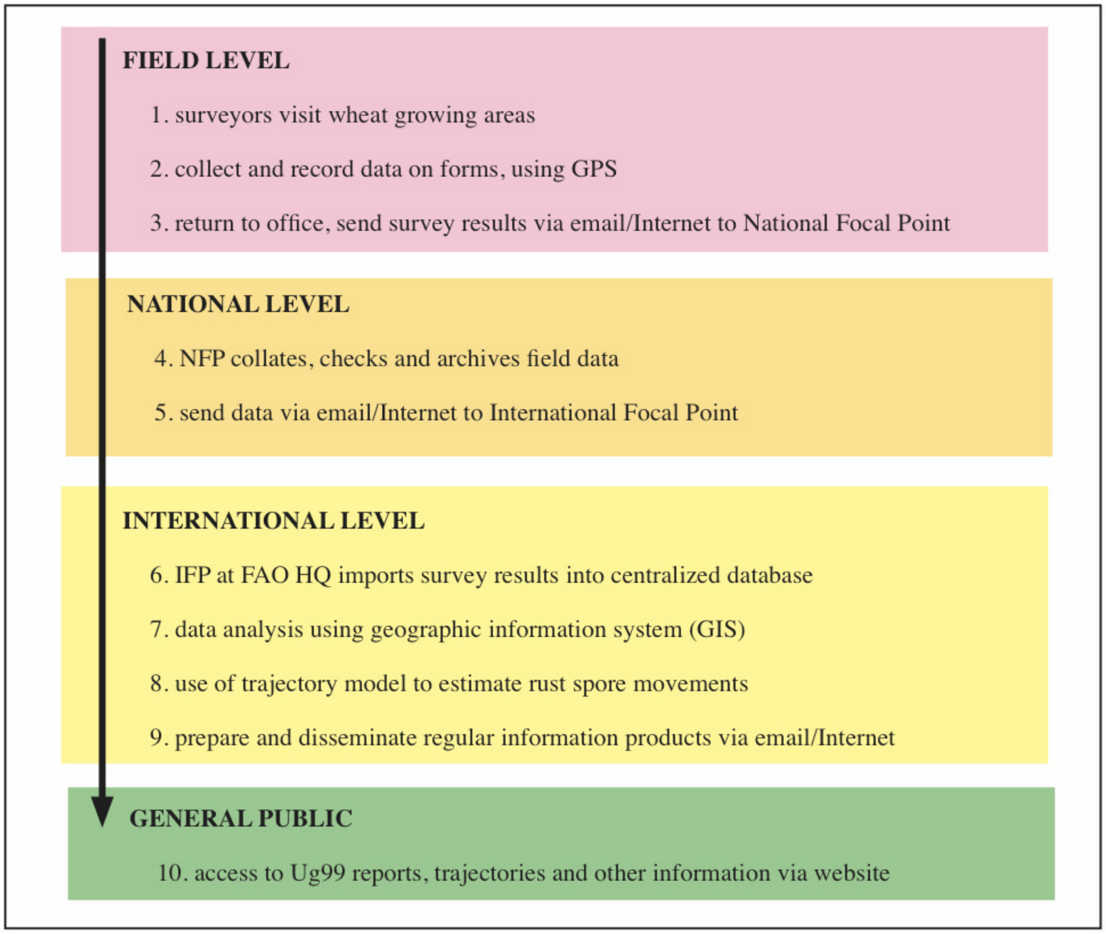

Figure 2: A collaborative monitoring and information network

GCRMS will network capabilities and operations in North and Sub-Saharan Africa, the Middle East, and Asia, and enable dissemination of information products concerning the distribution and nature of stem rust populations and the wheat rust resistance genes of popular varieties (Fig. 2). At the core of GCRMS will be geo-referenced data on the circumstances of stem rust infections collected during field surveys in farmers' fields, including samples of the rust and host plants, and trap nursery data.

GCRMS will be based on the operational model and data flows of FAO's Desert Locust Information System. A dedicated International Focal Point (IFP) will be established at FAO Headquarters in Rome for operating and maintaining the system. National teams drawn from plant protection and research institutes and overseen by a National Focal Point (NFP) in each country will be responsible for undertaking field surveys to collect and record geo-referenced data (using a GPS) onto a standardized form (see last page). Completed forms will be transmitted to GCRMS IFP in Rome. Samples will be sent to advanced research institutes for race analysis, and the results will be passed to Rome.

Field and environmental data will be managed within a geographic information system (GIS) where it will be analyzed by the IFP and archived. The GIS will consist of two geo-referenced components – a centralized database and maps. Separate modules, such as a trajectory model that estimates Ug99 migration and other databases generated by CIMMYT and ICARDA, will be incorporated into the GIS. Substantial progress has been made so far by both international centers. GCRMS will allow the IFP to have an updated global overview of the situation and assist in preparing effective information products that match partner needs.

The elements of success

If the GCRMS is to become a successful and effective information system, three key elements must be considered.

(1) Collaborative databases require identifying and maintaining partnerships

Establishing information networks between countries of varying economic levels and different cultures scattered across several continents does not occur over night. It took more than three decades before FAO's locust monitoring system became operational and reliable. Therefore, interested partners should be identified and provided with the necessary support from the onset so that they can contribute high quality data to the network and the databases. It will be critical that Governments designate a National Focal Point who is well qualified, energetic, and can work effectively with others. The IFP will make regular visits to the countries to provide technical backstopping and on-the-job training to ensure a well-functioning network of data collection, recording, transmission and analysis.

(2) Countries must be willing to their share data

As Ug99 is a transboundary pest, it is important to have a global perspective of its presence as well as its potential threat. This can only be achieved if countries undertake the necessary surveys in the field and share the results with the IFP in Rome. For this to occur, solid working relationships need to be forged between the IFP, the NFP and the field surveyors. If a country is unwilling to share its data, then there will be significant gaps in the global picture, affecting decisions, policies and research at the national, regional and global levels.

(3) Potentially sensitive data must be managed in a responsible manner

There is a risk that some countries may be reluctant to share their data because they feel it may be potentially sensitive information. In order to alleviate such concerns, specific procedures and methodologies can be developed within GCRMS so that raw field data received from the countries will not be redistributed to third parties. Confidentiality arrangements can also be organized as necessary.

Discussion points

During the discussion, it is proposed that the participants indicate what information products

are needed in their countries, who needs them, what formats are required, and how often and by what means should such products be provided by FAO.

Conclusion

Ug99 is a serious threat to global food security, which should not be underestimated. There is a need for a collective fight against the disease but this requires all partners – affected countries or those at risk, national plant protection services and research institutes, researchers, international centers and organizations, and investors – to be actively engaged. There is nothing gained from isolationism and everything to be gained from working together, cooperating and sharing information.

Global Cereal Rust Monitoring Form

Surveyor name: ____

Country/Institution: ____

Date of survey (d/m/y): ________ / ________ / __________________

Location name: ____

Latitude (decimal degrees): **N** ☐☐.☐☐☐☐☐☐

Longitude (decimal degrees): **E** ☐☐☐.☐☐☐☐☐☐

Elevation: _______ meters

Crop ☐ Trial ☐ Weed ☐ Roadside ☐

Crop: **Bread wheat** **Durum wheat** **Barley** **Triticale** **Oats** **Other**

Growth stage: **Tillering** **Flowering** **Maturity**

Field area size: __________ ha Variety: ___________________________

Disease	**Stem Rust**	**Leaf Rust**	**Stripe Rust**	**None**
Intensity (- low + high)	**- +**	**- +**	**- +**	
Severity (%)				

Stem Rust sample collected: **Y N**

Sample ID number: _________

Comment / Observation:

Marker assisted shuttle breeding and gene pyramiding strategies for bringing durable resistance

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The topic deals with four important phenomena, (a) marker assisted selection, (b) shuttle breeding (c) gene pyramiding and (d) durable resistance. These are common principles for enabling the modern tools of biotechnology to get integrated in the conventional plant breeding that strives to render and evolve varieties resistant to diseases.

1. Marker Assisted Selection:

In the last decade and half, plant breeding has adopted modern tools of biotechnology that makes the process more precise than before. The technology is broadly termed as "Marker Assisted Selection". Marker assisted selection is the process of selecting for a desirable expression of a character such as resistance to a disease without actually measuring the expression of either character. The molecular markers are nothing but simple stretches of DNA in an organism located on the same chromosome (which is the site for DNA location in every organism)in a tight linkage with the resistant gene or genes or regions on the chromosome (also refered to as quantitative trait loci or QTLs). These are linked in such a manner that if the markers linked to any particular gene for resistance are observed from the total DNA sample of the plant, then it is assured that in all probability the plant would also be resistant to the disease. Thus, this technology is free of any dependence on environment for selection of a plant. The only limiting feature is the accuracy with which the linkage between molecular markers are mapped as linked with genes for resistance to the disease. For example, every disease will depend for its spread on the climatic conditions desired by the disease causing organism (pathogen), its infection load (either in air, water, soil or seed) and availability of a disease susceptible host plant. If any of the three miss out, then the disease does not occur.

Plant breeders have been working on using a feature of inherited resistance to the disease available in the plant species to make a variety resistant to the disease. Crosses (hybridization) between the resistant donor plant and susceptible variety are effected in order to select for the transfer of the character of resistance into the susceptible variety. This is done by continuous selection for the disease resistant plants in the progeny populations of the crop. But, because of dependence on multiple factors including those which are beyond control associated with

the climatic conditions or due to the lack of inoculum of the pathogen or those strains which are particularly virulent on most varieties (the strains are also known as races which can infect differentially the host resistance in different varieties), it would be impossible to be precise and sure that the selected resistant plant progenies are actually resistant because of the resistant genes in them. It is quite possible that because of the above factors, the disease would not have appeared on most plants and therefore a susceptible plant would behave like a resistant plant.

Marker assisted selection eliminates this ambiguity associated with conventional environment dependent selection for disease resistance. That is because, the molecular markers have the abilty to detect resistance in a plant even when the plant is not challenged by the pathogen or its races.

2. Shuttle Breeding

Shuttle breeding is a technique for growing a crop which involves growing two successive plantings a year- for example, one in the summer season in a location where growing conditions are favorable and the then moving the plants to another location during the winter season to a new location where winter conditions are favorable to plant growth to select for desirable plant type in either or both conditions. This makes the process of plant breeding faster by two fold while it also gives an additional option for selection in two locations and evaluation of one plant and its subsequent progeny for consistency of performance by two alternate generations under diverse environment in an year. The approach immediately evaluates the progeny of a plant selected for fixation of the trait to express for the disease resistance in a diverse location. This especially is extremely useful when one is selecting plants for disease resistance.

Shuttle breeding has been in practice in wheat for leaf, stem and sripe rust resistance between Indian Agricultural Research Institute at New Delhi and its regional stations in the northern Himalayan valley of Lahaul Spiti and Nilgiris hills in the south since last seventy or more years. This concept to enable the advancement of generation coupled with evaluation of the selections against the rust races from extremely diverse regions. This is like testing a motor vehicle in the plains and in the hills for its consistent performance. Late Dr. B. P. Pal who opened several breeding stations for wheat such as Shimla in Himachal Pradesh, Indore in Madhya Pradesh and Wellington in Tami Nadu in the 1930s and visualized the utility of two seasons and two or more locations which have their own climatic diversity and variation in ecology as well as disease spectrum to identify most effective plant progenies which is expected to possess the traits that suit such diverse conditions when selected for best

performance at each location. It was expected that these selections would more likely be stable performers at varying agroecological conditions that described the agricultural variability in a country like India. However, it was principally identified as a useful strategy to quickly and predictably breed for better adapted to diverse conditions by Dr. Norman Borlaug, who dedicated CIMMYT's team of more than 30 wheat scientists In a shuttle breeding project comprising two different experiment stations in Mexico which were used back-to-back to develop new wheats. The two locations used were the Ciudad Obregón station; a dry site situated at sea level in northwest Mexico, and Toluca, a cool highland environment near Mexico City. Since day length, temperatures, diseases, and other conditions differed radically between the two sites, wheat lines that prospered at both were expected to be adapted to diverse growing environments. As an added bonus, by immediately moving the selected seed from one location to the other, it was possible to grow two generations a year, halving the time required for developing a new variety.

3. Gene Pyramiding

The term gene pyramiding in plant breeding is used to signify the activity of building into one variety more than one gene for a character so that the expression of the character is enhanced. It can be generally two or some times four genes put together in a variety. That is, if there are two genes, say for example Sr25 and Sr26, two genes for resistance to stem rust disease in wheat. Evolution-wise, if there is one gene for resistance in a variety that is able to protect the variety against the existing strains or races of the stem rust in a region, over a period of say 4-5 years on an average, the pathogen population throws up new genetic variants by a random process of genetic mutation that may develop the ability to overcome the resistance of the gene. But if both the Sr genes are put together in the same variety, the frequency of variants in the strain which can mutate to affect the resistance by both these genes is very low compared to the frequency if only one resistant gene were to be present. It takes that much longer for the variants of the pathogen to counter more than one gene based pyramided resistance.

Technically, each gene can be distinguished from the other when there are one or more races of the stem rust pathogen which can successfully overcome the genetic resistance of one of the two genes and another set of race/s which can overcome both the genes. But more often than not, there are quite a few Sr genes which do not necessarily have any races which can differentially react with either gene. But this lack of pathogen races which can distinguish among these Sr genes (referred to as differential races), it would be impossible to detect the presence of any of genes in combinations in breeding populations through conventional

means. It is here the role of molecular markers assumes significance because, the molecular markers linked to each of these pyramided genes separately can conveniently help the breeders to pick up different combinations as desired by them in the progeny plants of the crosses between disease susceptible variety and donor lines carrying the disease resistance genes with precision without being dependent on the expression of resistance or screening for resistance.

4. Durable Resistance

In late 1970s, a phenomenon of disease resistance response came to be noted as existing in several plant varieties which seem to show a high level of tolerance to a disease ranging from hypersensitive resistance to low severity to all races of a pathogen, even after the cultivation of the variety for a fairly long period of time in large areas. One such case was noticed by late Dr. Roy Johnson of United Kingdom in wheat against stripe rust in a variety, a feature that he termed as “durable resistance”. The durable resistance as a concept is a relative capacity of a variety that has been in cultivation for a long period, expectedly beyond five years and grown to large areas at a time. The fact in terms of genetics behind this phenomenon is that either there is a quantitative resistance governed by QTLs or by a combination of specific genes, more than one in number.

An integrated approach for marker assisted shuttle breeding and gene pyramiding for durable resistance against Ug99

As explained above, there are several stem rust resistance genes (Sr genes) such as Sr22, Sr25, Sr26, Sr27, Sr32, etc., which have resistance to the Ug99 virulence. What is required is to employ the molecular markers ‘tagged’ as linked to these genes for selection in breeding populations generated by crossing susceptible good variety with different resistance donors known to be carrying these genes. In addition we can use the molecular markers that are typical and contrasting in their expression to those in the donor plants to select most of the desirable features of the variety by employing molecular marker assisted backcross breeding procedures. Among these plants the Ug99 resistant ones selected using the markers can be shuttled across different regions to check for their resistance to stem rust in general and Ug99 in particular, and identify combinations of pyramided lines in the selected stable plants to transfer the durable resistance by retaining the essential high yielding qualities of the original variety. This strategy has been successfully employed against leaf rust in wheat, leaf blight in rice, and is probably one of the most reliable strategies to minimize the threat caused by Ug99.

Quarantine Strategy, Sensitization and Awareness Generation

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The global threat to wheat production from the race Ug99 of *Puccinia graminis tritici,* the dreaded causal agent of stem or black rust, is very imminent and irrefutable. *P. graminis tritici* has historically caused severe losses to wheat production worldwide. Detection and spread of air-borne Ug99 (also known as race TTKS) is of high significance as the most wheat cultivars currently grown in its likely migration path, i.e. East Africa to North Africa, then through Arabian Peninsula and to Middle East and Asia, are highly susceptible to this race and the environment in these areas is conducive to disease development. The entry of Ug99 into SAARC region including India needs to be prevented and it calls for action at the regional level. The quarantine strategy for addressing the threat of this race would involve monitoring through intensive survey and surveillance, rapid, sensitive and robust detection leading to early warning and rapid response and mitigation strategies.

Wheat stem rust as such can be readily detected by visible sporulating lesions on the stems, leaves and awns of infected wheat plants that are easily recognizable by trained wheat workers. The race Ug99 can be detected by planting “trap” plot nursery in the target areas. This nursery includes wheat differential lines having specific combination of rust resistance gene(s). It is, then, imperative to carry out race analysis and genetic diversity at molecular level. Simple Sequence Repeat (SSR) markers which indicate that the Ug99 race cluster is distinct from all known races are available now.

A regular survey and surveillance programme using the spatial, temporal and evolutionary dynamics of wheat rust, conforming to International Standards for Phytosanitary Measures on “Guidelines for Surveillance” of International Plant Protection Convention needs to be initiated for early detection, containment and eradication. Standard Operating Protocols (SOPs) for surveillance must be defined. It is important to monitor the wheat crop effectively ensuring that all wheat growing areas in the region are covered. There is an urgent need to identify potential risk areas where we expect first incursions coming either along the *Puccinia* pathway or through other means. Surveys in off season would indicate if this race survives on other hosts. Geographical Information System (GIS) would certainly prove useful for pathogen tracking and surveillance.

At national level, there is a need to strengthen rust pathology capabilities with special reference to molecular diagnostics and to establish a national referral rust diagnostic laboratory which would facilitate early detection, containment and eradication. Stem rust samples after collection can be sent to such a rust referral laboratory for race verification. SOPs for diagnostics must be defined by national referral rust diagnostic laboratory. Field training would ensure that extension pathologists and field staff are able to recognize the pathogen. We need to strengthen infrastructure facilities and diagnostic capabilities of quarantine personnel at ports of entry.

We need to ensure that we have a system to monitor the occurrence of rust race Ug99 in the region. Researchers and officials in state departments of agriculture need special training on monitoring of Ug99 movement with special reference to its detection. The growers should be advised to spray appropriate fungicides such as Propiconazole and Tilt as soon as the rust pustules are observed on the wheat crop.

Though Ug99 is not seed-borne, the remote possibility of its introduction with plant debris or as seed contaminant during exchange of wheat grain for consumption/ germplasm may not be ignored. Therefore, quarantine processing of imported wheat may ensure that Ug99 is not carried through plant debris. In case of large consignments for consumption, batch testing methodology has to be developed by stipulating appropriate statistical procedures to ensure absence of Ug99.

In India, wheat is allowed to be imported for consumption or research purposes, but not for sowing. During quarantine processing the permissible level of debris, chopped grains etc. in the bulk consignment also needs to be monitored to avoid any remote possibility of Ug99 introduction. Uganda, Ethiopia, Kenya, Yemen and Iran from where Ug99 is reported are wheat importing not exporting countries. However, since Iran is reported to have Ug99 and it has a common border with Pakistan, there is a need to monitor spread of Ug99 to Pakistan and subsequently to other neighboring countries like India.

The threat of Ug99 to our agriculture should be explained to general public, especially among farmers in wheat growing areas. The farmers should also be encouraged to grow varieties with *Sr25* and *Sr26* genes which have shown resistance to race Ug99. Apart from farmers, awareness generation workshops have to be organized for officials of quarantine/ customs, state departments of agriculture, agricultural universities etc. Bulletins on Ug99 and its consequences may be printed in local languages and distributed to farmers directly or through intensive extension machinery. Audio-visual means such as radio/ television may also be used to increase the public awareness. For sensitization of the producers, researchers and policymakers in SAARC region, international communication is crucial. We should be

willing to communicate timely and exchange data within the region if we detect a new virulence or any unexpected reaction.

SAARC countries need a network on survey and surveillance of Ug99 in the region and should develop a common strategy to contain and eradicate Ug99. This calls for establishing an early warning system and Regional Rapid Response Strategy for eradication of the inoculum, if introduced. Finally, the sharing of information and timely communication, collaborative research in areas of epidemiology with emphasis on aerobiology of spores, detection methodology as well as harmonization of quarantine regulations is crucial in mitigating the threat and insulating the region from devastation.

Training, human resource development and setting up regional laboratories for detection of variance

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Training is an integral part of ICARDA and CIMMYT thematic research areas to ensure effective utilization of advances in agricultural sciences and technology. Human resource development programs support and strengthen the national agricultural programs through the provision of training opportunities that meet the needs of a wide range of collaborating research institutions and national priorities. This includes formal and informal training education through specific hand-on practical short courses at headquarter to provide proper practices in the specialized plant breeding fields; but also to foster collaboration, exchange ideas and experiences among of National Agricultural Research Systems (NARS) as well as with ICARDA, CIMMYT, and Advance Research Institution (ARI) scientists'.

ICARDA, CIMMYT, and other advanced research Institutions (ARI) conduct regular training course on various topics to address NARS particularly in Central, West Asia North Africa and the Caucasus (CWANA), South Asia, and Latin America that includes 36 countries that are major wheat producing or where wheat has an important role in the countries economies (Table 1). Within CWANA a number of countries (Afghanistan, Iraq, Eritrea, Ethiopia, Algeria, .) are still lagging in having well trained research support staff able to effectively contribute to national research programs; hence the few trained scientists are attempting to cover a wide range of research fields.

ICARDA and CIMMYT run regular training courses at headquarters and within host countries as national or regional training course. Advance Research Institutions such as University of Minnesota, in collaboration with CIMMYT, hosts Borlaug fellowship training program. Plant Breeding Institute (PBI), Sydney University organizes special training course for participants from developing countries. CRAWFORD Found (Australia) supported and conducted training courser in CWANA region. Other ARI's (Australia, Canada, Denmark, Iran, Morocco, US) have regular and occasional training course and or are associated with graduate training programs. The regular courses cover areas in 1) Wheat improvement courses with focus on breeding for durable resistance, 2) short term courses on breeding, pathology, quality, agronomy, biometrics, GIS, and information technology; 3) Coordinated program for visiting scientists with focus on disease management and breeding for disease resistance; short term events such as traveling seminars/workshops, and in country training courses. Table 2 shows examples of the various courses offered at ICARDA and CIMMYT in 2007; course so

far offered in 2008 during this year. With emphasis on Ug99, breeding for durable resistance, same trend for 2008 course with more emphasis on breeding for durable resistance and on monitoring of ug99.

Human resource development

Different training models are offered to NARS scientists according to levels of education and as requested by NARS programs. Long term training course are organized during full cycle of crop season to allow training of research support staff on various fields (breeding, pathology, agronomy, seed production, plant protection) for duration of 6 to 12 months. This type of long to mid- term training have been very popular among NARS and has allowed the training of large numbers of research support staff some of which were able to continue higher education and become leaders of major important research centers. This basic applied training on wheat breeding, agronomy, pathology, physiology, and other disciplines including language training has provided sound technical background for those that were able to enlist on graduate research programs. The main limitation for this kind of training is that not only those who master the English language were able to attend but also it has become very limited in time and number of participants for obvious funding limitations. To overcome this limitation selected individual training courses are offered to limited number of NARS and have allowed continuation of applied field training. Group training for short duration have been organized on various topics primarily on breeding, biotechnology, information technology, plant protection and GIS (Table 2). These courses have been organized at regional levels hosted by a NARS country or at a country level for specific group of trainees. Field training course are also organized at regional levels as well as at head quarters. Target groups were junior scientists (BSc. MSc degree holders). These courses were often supported by special funds such as JICA, Arab Fund, FAO and others. Degree training course are also organized for graduated student registered at various universities and conducting their research at Centers' laboratories and experimental fields. This training has been very valuable in CWANA particularly for countries were research facilities were not adequate for advanced research in the filed of genetics, biotechnology, plant protection, and breeding. Over the past 4 years (2004-2008) 14 MSc and 28 PhD students conducted their research at ICARDA. NARS scientist, particularly PhD holders, often spend time at research centers as visiting scientists and work with their counter parts on various research topics that often lead to publication on refereed journals and development of collaborative research projects.

Communication

The communication language plays an important role in the success or failure of a training program. Often trainers are confronted by different levels of understanding of the language. For training of technical support staff, ICARDA has been trying to organize short term

regional courses delivered in the common language practiced at a given region. Arabic is the popular language in the Middle East and parts of west Asia were over ten countries could participate in such training; where as Spanish would be the most appropriate language for Latin American countries; compared to English were mainly seven countries mostly in East Africa and South Asia could benefits of such group training; hence the target groups for training courses are of major importance to the success of the training program. English language is the most appropriate language when addressing NARS scientists that are MSc. and PhD holders compared to French were only 14% of NARS could communicate. Intensive English language training courses have been organized for CAC region where Russian is the main language.

Research facilities

The success of a training course in any research field will depend on the research facilities available to NARS to be able to use the information learned and apply the technology. As shown in table 3, most of the countries have adequate biotechnology laboratory facilities; hence training junior scientists to properly run these laboratories, would be of major importance to NARS. Training in plant breeding will be relevant to countries were experimental stations have proper facilities' for field experimentation; hence planned in country training courses are often run in collaboration with NARS to accommodate larger number of participants. Upgrading research facilities will effectively contribute to national research programs in fulfilling their responsibilities towards the advancement of science.

Considering the serious threat of Ug99 to wheat production globally and the serious implications to world food security, a Global Rust Initiative was established by the Nobel Prize Winner Dr Norman Borlaug with CIMMYT and ICARDA as the implementing organizations. As of the onset of GRI in 2005, ICARDA and CIMMYT launched intensive mid and short term training course on breeding for disease resistance with emphasis on durable resistance; screening wheat breeding lines at Ug99 hot spots in Kenya (Njoro) and Ethiopia (Kulumsa, Debra Zeit); epidemiology of wheat rust with emphases on surveillance and pathotyping of stem rust for at risk countries. The objective of the emergency actions in CWANA lead by ICARDA and CIMMYT and supported by Cornell Project, FAO, USAID, Agriculture Canada, ICAR, Arab Fund, IFAD, aims to 1) Support to national programs for the development of effective and sustainable surveillance systems through advocacy, coordination and policy support; 2) enhance efforts in breeding for durable resistance; 3) rapid seed dissemination, 3) Assist NARS in running impact studies on the threat of Ug99

Table 1: Wheat producing countries in Africa, Asia, and Latin America

Regions	No. of Countries	Wheat producing countries
North Africa	4	Morocco, Algeria, Tunisia, Libya
Nile Valley & Red Sea (Including East. Africa & Arabian .Peninsula)	7	Egypt, Sudan, Ethiopia, Yemen, Eritrea, S. Arabia, Oman
West Asia	8	Syria, Jordan, Lebanon, Turkey, Iran, Iraq, Pakistan, Afghanistan
Central Asia and Caucasus	8	Armenia, Georgia, Azerbaijan, Turkmenistan, Tajikistan, Uzbekistan, Kyrgyzstan, Kazakhstan
South Asia	4	India, China, Nepal, Bangladesh
Latin America	5	Argentina, Brazil, Chili, Mexico, Uruguay
	36	

Table 2: Example of training courses offered in 2007 by ICARDA and CIMMYT

Courses offered	Number of participants/ beneficiary countries	Period
Cereal Crop Improvement	19P/ Afghanistan, Egypt, Eritrea, Ethiopia, Lebanon, Morocco, Sudan, Syria, Yemen	Aleppo, Syria April22- May 3, 07
Variety Management and quality Assurance	11P/ Iraq, Jordan, Palestine, Pakistan, Oman, Syria, Yemen	Aleppo, Syria May 6-17, 07
Gene Bank Management for Germplasm Collection	8P/ Egypt, Iraq, Qatar, Pakistan, Syria, Tajikistan, Tunisia	Aleppo, Syria May6-10, 07
Integrated Management of cereal diseases and Insect Pests in CWANA	12P/ Egypt, Ethiopia, Libya, Palestine, Sudan, Tunisia, Yemen	Aleppo, Syria April 22-May 3, 07
Cropping System and Integrated Pest Management	12P/Afghanistan, Syria	Aleppo, Syria May 13-24, 07
Advanced Design and Analysis of Experiments	13P/Eritrea, Lebanon, Jordan, Iraq, Palestine, Syria, Sudan	Aleppo, Syria, August 5-16,07
Workshop on wheat improvement and selection	22/P Iran	Dezful, Iran April 11-21, 07
Wheat Improvement and Disease Resistance	22 P/ Algeria, Mali, Morocco, Tunisia	Tunis, Tunisia April 22- May 3, 07
Wheat Improvement and Seed Production	30P/ Egypt, Ethiopia, India, Malawi, Nigeria, Sudan, Turkey, Tanzania, Uganda, Yemen, Zimbabwe	Kulumsa, Ethiopia Sept. 24-Oct.5, 07
Theoretical and Practical Aspects of wheat quality Improvement	16P/ Ethiopia	Bahir Dar, Ethiopia July 16-30, 07
Improvement of farmer-based Seed Production Scheme and Revitalizing Informal Seed Supply	27P/ Ethiopia	February 12-15,07
Design Analysis of Field Experiments	21P/ Algeria	Alger, Algeria Feb. 25-March 8,07
Seed Marketing and promotion	15 P/ Afghanistan, Azerbaijan, Iran, Kazakhstan, Kyrgyzstan, Pakistan, Tajikistan, Turkey, Uzbekistan	Istanbul, Turkey June 25-29, 07
International Winter Wheat Improvement Traveling seminar	24P/ Kazakhstan	Kazakhstan, July 8-13, 08
Coordinated Program for visiting scientists: Rust Management and wheat breeding for durable resistance	5P/ Kenya (2), Nepal (2), India (1)	CIMMYT, Mexico 3weeks-2 months
Individual visiting scientists	10P/ Israel, China, Korea (2), Tunisia, Syria, Kazakhstan, Sth.Africa (2), Japan,	CIMMYT, Mexico 2weeks-3Months
ICARDA Individual Training courses; Breeding, Biotechnology, Pathology	7/ Ethiopia (2), Qatar, Sudan, Syria (2), Tunisia, Yemen	ICARDA, Syria 2 weeks-1 Month

Tale 3: Assessment of NARS Current Research facilities

Country	Research facilities in wheat I research				
(Wheat producing)	Pathology			Breeding facilities	
	Research	R.Analysis	Biotec.Labs	Exp.Stn	On Farm Testing
Morocco	3	3	4	4	3
Algeria	2	0	3	4	3
Tunisia	3	0	4	4	3
Egypt	3	2	4	4	4
Sudan	1	0	2	3	2
Yemen	1	0	2	3	2
Ethiopia	3	2	3	4	3
S. Arabia	3	0	4	2	2
Iran	4	3	4	4	4
Syria	3	0	3	4	4
Turkey	3	1	3	4	4
Pakistan	3	2	3	4	3
Kazakhstan	2	1	3	3	1
Turkmenistan, Kyrgyzstan, Tajikistan	1	0	1	2	1
Armenia, Azerbaijan	2	0	2	3	2
Georgia, Uzbekistan	3	2	2	3	2
Argentina	4	5	4	4	4
Brazil	5	5	4	5	5
Mexico	3	2	2	4	3
Nepal	2	0	-	-	-
Bangladesh	2	0	-	-	-
China	4	2	4	5	3
India	4	3	4	4	4
Uruguay	5	5	4	5	4

Assessment of Research Facilities (0-5): O=Unexciting facilities; 5= Highly established and functional facilities

Contingency plans for wheat rusts: Preparedness and early response

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Introduction

Wheat rusts are probably the most important biotic constraints to wheat production globally. The use of resistant varieties is the most economic and reliable control measures against all wheat rusts. However, the rusts have a great potential to overcome wheat resistant genes and whenever environmental conditions are favourable, they could cause devastating epidemics. Wheat rusts are transboundary diseases carried by wind for short and long distances, and hence cannot be excluded through quarantine measures. The emergence of virulent strain in one country would sooner or later move into other countries devastating previously resistant wheat varieties.

Recognizing that rust epidemics are a recurrent threat to wheat production and yield, governments need to develop contingency plans that would help them improve their national preparedness and rapid response in cases of rust disease outbreaks. Since such rust outbreaks can very rapidly become a global problem, coordinated regional and global efforts would also be needed.

What is Contingency Planning

There are many interpretations of what are contingency plans, depending on the context in which they are developed and applied. Contingency planning is a management tool used to prepare for potential crises, emergencies and disasters by making sure that clear, adequate and appropriate arrangements are in place to allow a timely, effective and appropriate response once the emergency occurs. The response should minimize the potentially adverse impact likely to arise from an emergency caused, for example, by a crop or animal pest or disease.

Contingency planning is most effective when it is a participatory process that includes all those who will be required to work together before the emergency occurs (i.e. the preparedness phase) and most importantly at its onset. Consequently, multidisciplinary / multi-institutional teams covering all concerned national stakeholders and sectors must be involved in the development of contingency plans. In the case of plant diseases, these usually include the plant protection units, agricultural research, breeding and seed sectors (public and private systems), extension services and farmer organizations, as well as other public and private sector institutions involved in the management of the crops.

Contingency planning also includes the identification of organizational roles of various stakeholders, responsibilities, legal framework, control policies, structures and systems that

would need to be established or strengthened during the preparatory phase of a disease threat as well as when the disease outbreak occurs.

A good contingency plan should consist of information such as guidelines and checklists, committees responsible for the respective activities and their structure, funding sources, existing control or eradication resources, critical needs assessment, coordination arrangements, contact persons and details of the various sectors and institutions involved, draft contracts, etc. Accordingly, a national contingency plan acts as a general manual for use by all authorities involved in the plant pest emergency in the affected country.

A contingency plan should be regularly reviewed and updated to reflect administrative and legislative changes, policy developments, scientific advances and comments from stakeholders and operational partners, and incorporate lessons identified from previous disease outbreaks.

Wheat rust contingency planning

Contingency planning for plant diseases, as in the case of wheat stem rusts, are commonly comprised of two phases:

1. Pre-emergency – preparations before the emergency occurs. This consists of the actions that a country is taking in order to prevent the disease as well as and the steps that can be taken in advance to prepare for responding to the emergency in case prevention fails. In the case of wheat rusts, emergency preparedness and prevention are the most important strategies of a contingency plan. See Table 1.
2. Emergency response – once the emergency commences. This consists of action plans to respond to the emergency and contain it. In the case of wheat rusts, it would be controlling the disease outbreak. See Table 2.

This paper is an initial attempt to provide guidelines to national authorities in their efforts to develop contingency plans for wheat rusts, with emphasis on Ug99. It is based on the principles of contingency planning and on the preparedness/preventive and response actions recommended by various developing countries for similar plant diseases, while taking into consideration the present situation of most countries that are affected or at direct risk of Ug99 and similar wheat rusts.

The two tables below reflect in a matrix form, checklists for the preparedness and preventive actions as well as response actions needed in national contingency plans for wheat stem rusts. They indicate the institutions or groups that should be involved in each suggested action. The tables are by no means inclusive and are meant as guidance for discussion.

The following specific items are common to all major activities. They have been excluded from the tables for visibility purposes, but are an integral part of the contingency plan checklists:

- Assess available human, infrastructural capacities, equipment and material

- Identify the capacity building needed
- Identify sources of funding and relevant national and international institutions for capacity building
- Assess the national regulatory framework and modification needed for improvement
- Prepare inventories of available material, equipment and pesticides, etc and assess the corresponding needs
- Identify sources for obtaining needed material and equipment and the sources of funding
- Identify in each activity the organizations involved, roles, responsibilities, management structure and information flow systems
- Prepare for each activity contact information of the involved organizations and individuals

Table 1: Check list to be used in the preparation of Contingency Plans for Ug99 and other wheat rusts –
<u>Preparedness and Preventive Actions</u>

Activity	Groups involved in the action							
	Field survey team	Trap nursery team	Race analysis staff	Breeders	Seed sector stakeholders	Policy makers*	Extension agents	Farmers
National surveillance and monitoring system in place								
Establish national survey team; agree on the National Focal Point (NFP)	+					+	+	+
Provide GPS and related training	+							
Provide needed transportation means, computers and software	+							
Agree on national institution responsible for race analysis (when applicable)			+			+		
Agree on alternative regional or international institution responsible for race analysis **			+			+		
Provide needed capacity building and infrastructure			+					
Agree on locations of trap nurseries and institution responsible		+						
Provide needed training and sources for differential varieties**		+						
Ensure national information sharing mechanism through the NFP	+	+	+					
Ensure international information sharing mechanism through the NFP and IFP ***	+	+	+			+		
Improve the variety development and registration system *(details in other presentation)*								
Screen national varieties and breeding material for susceptibility to threatening races (incl. Ug99)**		+	+	+				
Improve legal, administrative and managerial functioning of registration and release systems				+	+	+		
Establish multi-location adaptation and disease resistance trials and provide needed capacity building				+	+		+	+
Improve national variety registration database (including rust reactions)				+	+	+		
Enhance national system for quick seed multiplication and distribution *(details in other presentation)*								
Improve legal, administrative and managerial mechanisms to cope with emergency seed multiplication					+	+	+	
Establish mechanisms for exchange of resistant genetic material and seeds available internationally **				+	+	+		
Provide needed capacity building for production of quality seeds and quick multiplication					+		+	+
Provide needed equipment and material for increased seed multiplication capacity					+	+	+	+
Develop a strategy for the quick efficient distribution of seeds to farmers					+	+	+	+

* Policy makers from different institutions including plant protection, agricultural research, extension services, farmer organizations and others as needed

** In cooperation with international institutions

*** FAO is presently establishing a global wheat rust early warning system that is being based on its long established early warning system for the Desert Locust. An International Focal Point for the early warning system is in contact with the NFP to obtain field survey data

Table 2: Check list to be used in the preparation of Contingency Plans for Ug99 and other wheat rusts – <u>Response Actions</u>

Activity	Groups involved in the action							
	Field survey team	**Trap nursery team**	**Race analysis staff**	**Breeders**	**Seed sector stakeholders**	**Policy makers***	**Extension agents**	**Farmers**
Eradication of "Green bridges" of alternate and volunteer plants carrying rust populations (wild grasses, barley or wheat grown out of season or in abandoned fields)								
Establish mechanisms to define and locate green bridges and alternate hosts	+	+				+	+	+
Establish national eradication teams	+					+	+	+
Establish inventory of herbicides, machinery and tools for eradication						+	+	
Prohibition of planting and elimination of highly susceptible varieties								
Establish mechanisms to locate areas planted with highly susceptible varieties	+					+	+	+
Establish agreed lists of highly susceptible varieties	+			+	+	+	+	+
Establish national eradication teams	+					+	+	+
Establish mechanisms for quick information dissemination to farmers						+	+	+
Establish mechanisms for farmers' compensation in case of crop elimination				+	+	+	+	+
Targeted fungicidal application in hot spots of rust infections								
Assess national fungicide registration regulations, wheat rust fungicides registered and mechanisms for new registrations if needed						+	+	
Establish inventory of available rust fungicides (quantities, location, validity, etc) and application equipment at the national and district levels						+	+	
Train extension agents and farmers on spot application when needed							+	+
Inoculum reduction through field and landscape management (strip planting, varietal mixtures or multi-lines, varieties of different resistance profiles, early maturing or shorter duration varieties, changing planting dates)								
Assess implementable field and landscape management techniques	+	+	+	+	+	+	+	+
Establish mechanisms for information dissemination to and adoption by farmers				+	+	+	+	+

* Policy makers from different institutions including plant protection, agricultural research, extension services, farmer organizations and others as needed

** In cooperation with international institutions

*** FAO is presently establishing a global wheat rust early warning system that is being based on its long established early warning system for the Desert Locust. An International Focal Point for the early warning system is in contact with the NFP to obtain field survey data

Origin, evolution, distribution and virulence of Ug99 and the global stem rust monitoring system

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From observations of stem rust on bread wheat entries in Ugandan wheat nurseries, in particular those assumed to carry the 1BL.1RS chromosome translocation, virulence for the *Sr31* resistance gene was suspected. Samples of *Puccinia graminis* f. sp. *tritici*, collected at the Kalyengere Research Station in Uganda, were then sent to South Africa in 1999. The Ugandan rust collection was cultured and increased on a wheat genotype known to carry *Sr31*. Establishment of pure cultures and race analysis on a differential wheat series carrying known *Sr* genes, confirmed virulence for *Sr31*. The original isolate, named Pgt-Ug99 and later abbreviated to Ug99, was reported avirulent on *Sr21, -22, -24, -25, -26, -27, -29, -32, -33, -34, -35, -36, -39, -40, -42*, and *-43, Agi*, and *Em* and virulent to *Sr5, -6, -7b, -8a, -8b, -9b, -9e, -9g, -11, -15, -17, -30, -31*, and *-38* (Pretorius et al., 2000). Ug99 is avirulent to Einkorn but subsequent tests have shown virulence for *Sr21* in some genetic backgrounds (Jin et al., 2007).

Although confirmation of *Sr31* virulence was obtained in 1999, it is possible that the race was present in Kenya as early as 1993 (Singh et al., 2006). In the years following its first description, Ug99 was detected in Eastern Kenya in 2001 and in Ethiopia in 2003 and 2005 (Singh et al., 2006). Ug99 is now well established in Eastern Africa with additional reports of its occurrence in Sudan, Yemen and Iran (Singh et al., 2008; www.globalrust.org).

The step-wise migration of Ug99 towards North Africa, Middle East and Asia is not the only cause for concern. In Kenya, Ug99 obtained virulence for *Sr24* and *Sr36* in 2006 and 2007, respectively (Jin et al., 2008a; Jin unpublished data). Both resistance genes have been used widely in global wheat breeding and virulence towards them further reduces the pool of genetic diversity needed to combat this race.

A stem rust race detected in South Africa in 2000, named 2SA88 by the ARC-Small Grain Institute at Bethlehem (Boshoff *et al*., 2002), may provide some background to the origin of Ug99. Phenotypically, 2SA88 is similar to Ug99 except for avirulence to *Sr31*. In addition, virulence for *Sr8b* and *Sr38* was not known in South Africa until the detection of 2SA88, suggesting a foreign introduction. In 2007 a variant of 2SA88, virulent on *Sr24*,

was collected from spring wheat in the Western Cape, South Africa. Considering the similarities in virulence profiles between Ug99 and 2SA88, the question was raised whether 2SA88 adapted locally or whether it was an exotic introduction. To test the hypothesis that 2SA88 and Ug99 are related, a selection of South African stem rust isolates maintained at the University of the Free State was compared with Ug99 using SSR and AFLP markers. Both the SSR and AFLP analyses, as well as a combined data set, showed that Ug99, UVPgt55 (an isolate of 2SA88) and UVPgt59 (+*Sr24*) were related (Visser et al., in press). Furthermore, the Ug99 cluster differed significantly from the other South African races. This study provided strong evidence that 2SA88 did not originate in South Africa. If the premise that virulence is more often gained than lost is accepted, in this case specifically for *Sr31*, 2SA88 could be the progenitor of Ug99.

Using the North American system for describing stem rust, five races, viz. TTKSF, TTKSK, TTKSP, TTKST and TTTSK, have been detected (Jin et al., 2008b). It is clear that continued monitoring of the Ug99 race cluster is necessary to keep abreast of distribution patterns and new variants.

Monitoring cereal rust pathogens in the global context

Rust surveillance has been an important underpinning component of rust control for more than 50 years in many countries. Considerable value is gained from simply knowing whether or not rust is present in a region, and if present, the distribution and degree of severity within that region. Since Stakman and Piemeisel (1917) demonstrated the existence of races (strains, pathotypes) in the stem rust pathogen in the early 1900s, surveillance in many countries have involved the identification and characterisation of rust races. These surveys have provided important information on rust race distribution, which can be used as an early warning scheme to alert growers and policy makers of the occurrence of new dangerous races.

While many countries have conducted rust surveillance programs and undertaken race analysis, few attempts have been made to co-ordinate these activities at the international level. A number of constraints have made such efforts difficult, including a lack of resources (both infrastructure and personnel), differences in the differential genotypes used, and differences in race nomenclature. A resolution was passed at the 1st International Congress of Plant Pathology in London in 1968 that regional differences in virulence should be conducted in several plant pathogens that included the wheat stem rust pathogen (*Puccinia graminis* f. sp. *tritici*) and the wheat stripe rust pathogen (*P. striformis* f. sp. *tritici*). This led to an international survey of virulence genes in *P.*

graminis f. sp. *tritici* by Professor Irvine Watson and Dr Harold Luig at the University of Sydney. The results of this survey were published in 1983 in a book that contains an excellent historical overview of global stem rust variability (Luig 1983).

Notwithstanding the difficulties inherent in global rust surveillance, the knowledge gathered to date on variation within the Ug99 lineage and distribution of members on this lineage is an excellent example of an exceptional international collaboration on rust surveillance. Information gleaned from surveillance, trap plots, race analysis, DNA fingerprinting and GIS has in a relatively short period of time already clearly defined the importance of Ug99 by demonstrating the vulnerability of a great deal of global wheat germplasm. The detection and detailed characterisation of several mutational derivatives with virulence for two important resistance genes (*Sr24* and *Sr36*) has provided further important information for resistance breeding and control strategies.

The importance of Ug99 and its migration to date, along with other cereal rust threats, have elevated the importance of establishing a global cereal rust monitoring system. An objective of the recently established "Durable Rust Resistance in Wheat Project" is "Tracking of Cereal Rust Pathogens", the goal of which is to "to create a system that can report the distribution and nature of stem rust" (the Global Cereal Rust Monitoring System"; GCRMS). This is to be achieved by ddeveloping an information platform that will underpin GCRMS and developing national capacity to undertake effective pathogen tracking and monitoring. Once established, the GCRMS will facilitate the collection of data on race/virulence distribution and host resistance genes in deployed cultivars, by linking either country specific or regional rust survey efforts. A key to the success of this initiative will be to link the considerable knowledge base that currently exists in several countries that have been engaged in long term rust surveillance, such as India, the USA, Canada and Australia.

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