Sounding the Alarm on Global Stem Rust

An Assesment of Race Ug99 in Kenya and Ethiopia and the Potential for Impact in Neighboring Regions and Beyond

by the Expert Panel on the Stem Rust Outbreak in Eastern Africa

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Foreword

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Stem rust is a catastrophic disease because of its ability to cause complete annihilation of wheat crops over wide areas. The use of genetic resistance in the major stem rust-prone regions of the world and the organized distribution of resistant germplasm through the International Rust Nursery scheme supported by the USDA and the Rockefeller Foundation, and later replaced by the CIMMYT nursery network, provided ongoing and updated sources of resistant germplasm to the international breeding community. In return, collaborating groups gave feedback on the responses of materials in their respective regions. During the late 1950s and early 1960s, great emphasis was placed on data that came from Kenya, Egypt, and southern Africa. The widespread use of stem rust resistant cultivars such as Red Egyptian, Kenya Farmer, Africa 43 and later, lines like Kenya Page and Africa Mayo, points to the key role of East Africa in the development of genetic resources that led to the global decline of stem rust.

The stem rust threat was a primary reason for the establishment of the Rockefeller Foundation-sponsored program in Mexico, the predecessor of CIMMYT. The semi-dwarf, stem rust resistant, widely adapted spring wheat germplasm generated by this program led to the Green Revolution. Much of the material possessed the historically durable "*Sr2* complex" from Hope and other well-known stem rust resistance genes.

The widespread use of the 1BL.1RS translocation with *Sr31* and its continuing stem rust protection on a worldwide basis has led to complacency throughout the wheat community. The discovery of race Ug99 with virulence for *Sr31* and other important genes in Uganda in 1999, and possibly earlier in Kenya, was a reminder of the pathogen's ability to respond, but little seems to have happened in breeding programs until the emergence of current concerns following the continued incidence and spread of race Ug99 in Eastern Africa.

A major objective of this report is to assess global vulnerability to stem rust if race Ug99continues to spread. Most of the countries and regions responding to a series of questions relating to their specific situations indicated resistance to stem rust was no longer a leading breeding objective. Several noted that routine surveys were detecting increasing incidences of stem rust, associated with ill-advised use of susceptible varieties.

Epidemics occur as a consequence of the use of widely popular very susceptible cultivars. The dynamics of rust epidemics are very much like those of forest or bush fires. The ingredients of fires (and rust epidemics) are fuel (area and distribution of susceptible material, degree of susceptibility), favorable climate conditions (optimum temperatures and moisture), number of ignition points (amount of initial inoculum), air movement, and complacency. Once started, both are difficult to stop. The prospect of a stem rust epidemic in wheat in Africa, Asia and the Americas is real and must be stopped before it causes untold damage and human suffering.

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SUMMARY AND RECOMMENDATIONS

The rusts (*Puccinia* spp.) have been a scourge on humankind since the beginning of historical time. Many epidemics have been recorded over the past 150 years, in the near and far east, Europe, and the Americas. Several devastating rust epidemics have resulted in major famines in Asia and grain losses at a massive scale in North America in 1903 and 1905 and 1950-54.

For several decades the historically enormous problem of wheat stem rust has been "solved" through the use of genetic resistance. In Eastern Africa, that resistance has now been overcome by a new physiological race of the disease designated as Ug99. With the long distance travel of rust spores, in the jet streams and on the clothing of world travelers, it is only a matter of time until Ug99 reaches across the Saudi Arabian peninsula and into the Middle East, South Asia, and eventually, East Asia and the Americas. Plant breeders and pathologists still have time to screen for resistant genotypes, and to get these multiplied and into farmers' fields. However, the current crisis is a wake-up call about the continuing, and potentially devastating, impact that the rust pathogens can have on susceptible cereals, and especially a staple food like wheat.

A "Global Rust Initiative" is being organized by the International Center for Maize and Wheat Improvement (CIMMYT) and the International Center for Agricultural Research in the dry Areas (ICARDA) to help address the immediate problems in East Africa and initiate research activities to prevent a worldwide problem. This assessment (1) reviews the characteristics of the disease and its potential for worldwide devastation, (2) assesses the current situation in Eastern Africa regarding the occurrence of new physiological races, (3) assesses the vulnerability of other geographies to these races, and (4) proposes a strategy for dealing with the threat.

Recommendations

Recommendation #1. Because the stem rust pathogen is airborne and genetically variable, the Panel **recommends** (1) population monitoring by means of trap nurseries and limited sampling for race analysis for the Kenya - Ethiopia region, adjacent areas, and beyond. (2) the establishment of a warning system based on the above data and modelling, using GIS and other appropriate tools.

Recommendation #2. Because diverse sources of resistance would be necessary for all genetic control strategies, the Panel **recommends** that diverse genetic resistance be identified in global wheat germplasm by testing in Kenya and Ethiopia.

Recommendation #3. Because modern cultivars currently grown in Northern Africa and Asia are susceptible to race Ug99, the Panel **recommends** that a breeding strategy be implemented to incorporate diverse genetic resistance to Ug99 into such germplasm before the race migrates to those areas. DNA-marker assisted selection should be utilized where feasible.

Recommendation #4. Because of the likelihood of chemical intervention for control in the short term, the Panel **recommends** that appropriate strategies for use by all producers should be determined.

Recommendation #5. Because the breeding programs will develop elite varieties that need to be maintained, multiplied and distributed especially to small scale farmers, the Panel **recommends** that seed multiplication agencies and community-based organizations be encouraged to produce commercial seed of newly developed stem rust resistant varieties with stipulations that (1) farmers and other stakeholders play a leading role; (2) breeding programs be supported in the maintenance and multiplication of Breeder's and Foundation seed; (3) commercial seed be readily available to farmers; and (4) on-farm demonstrations of elite varieties be conducted.

Recommendation #6: Because of the socioeconomic implications of the stem rust on food security and livelihoods of the wheat producing countries and societies, the Panel **recommends** that ex-ante and ex-post impact assessments be undertaken, taking into account alternative crops and livelihood systems.

Recommendation #7. Because knowledge, skills and hands-on experience on various aspects of stem rust research and management are required by all personnel, including technical support staff, the Panel **recommends** that a training program, including advanced degree training for those associated with the project, in-country practical courses and specialized in-service courses outside the country to strengthen the capacity of national partners, be implemented to augment the current human resource base

Recommendation #8. Because of the need for well equipped laboratory and effective and efficient communication systems to address the threat of wheat stem rust, the Panel **recommends** that facilities for wheat research should be strengthened or established in Ethiopia and Kenya to include (1) renovation of greenhouses and essential field facilities; (2) renovation of pathology laboratories (3) upgrade of irrigation systems; (4) improved communications capacity, especially internet; (5) strengthening of molecular laboratories; and (6) improvement of transport capacity.

Recommendation #9. Because of the need to raise and maintain awareness of the wheat stem rust problem and the need to enhance communication among wheat scientists and other concerned stakeholders, the Panel **recommends** that support be provided to develop, implement and maintain an appropriate communication strategy.

Recommendation #10. Because advanced research institutes in North America, Australia, and elsewhere are in a position to both contribute and benefit from a Global Rust Initiative (GRI) and because much of the necessary research and coordination will be provided by CIMMYT and ICARDA, the Panel **recommends** that (1) appropriate advanced research institutions be engaged in the GRI utilizing their own resources and that (2) CIMMYT and ICARDA receive additional resources from the advanced research institutes and other appropriate donors to coordinate the GRI and meet their respective research responsibilities necessary to avert an epidemic.

CHAPTER 1 – WHEAT STEM RUST

1.1 The disease

The wheat stem rust fungus belongs to the genus *Puccinia*, family Pucciniaceae, order Uredinales, and class Basidiomycetes. The Italians Fontana and Tozzetti independently provided the first unequivocal and detailed reports of wheat stem rust in 1767 (Fontana, 1932; Tozzetti, 1952). The causal fungal organism was named *Puccinia graminis* by Persoon in 1797. Stem rust of wheat caused by *Puccinia graminis* Pers. f. sp. *tritici* Eriks. & E. Henn. is also known as black rust or summer rust due to the abundant production of shiny black teliospores that form in the uredinium at the end of the season or with unfavorable conditions. At one time stem rust was a feared disease in many wheat-growing regions of the world. The fear of stem rust was understandable because an apparently healthy crop during grain filling could be reduced to a black tangle of broken stems and shriveled grain by harvest. A one percent increase in stem rust severity translates approximately to a one percent increase in yield loss.

The widespread use of resistant cultivars worldwide reduced the disease as a significant factor in production. Although changes in pathogen virulence have rendered some resistances ineffective, resistant cultivars have generally been developed ahead of significant damage. The spectacular epidemics that developed in Australia in the 1940s and in the United States in the early-1950s are well known among other occurrences (Luig and Watson, 1972; Roelfs, 1986; Saari and Prescott, 1985). Localized epidemics have continued to occur. Several areas (hotspots) exist worldwide where stem rust has been more severe (Saari and Prescott, 1985) (Table 1). Currently, stem rust is largely under control worldwide except in Eastern Africa (Table 1).

Table 1.1. Current and historical importance of wheat stem rust for various global regions.

Zone	Current	Historical
Africa		
Eastern	Major	Major
Southern	Local	Major
Northern	Local	Major
Asia		
Western	Minor	Major
Central	Minor	Minor
Southern	Minor	Major
Eastern (China)	Minor	Major
America		
North	Minor	Major
South	Local	Major
Europe		
Western	Minor	Major
Eastern	Minor	Major
Australia & New Zealand	Minor	Major

Major = severe losses without the cultivation of resistant varieties; minor = often occurs, but of little significance; local = only occurs in a small part of the region, losses in these areas may be occasionally severe if susceptible cultivars are grown.

1.2 Epidemiology

Stem rust is more important late in the growing period, on late-sown and late maturing cultivars, and at lower altitudes. Spring-sown wheat is particularly vulnerable in the higher latitudes of North America if sources of inoculum are located upwind. Large areas of autumn-sown wheat occur in the southern Great Plains of North America, historically providing inoculum for the northern spring-sown wheat crop. In warm, humid climates, stem rust can be severe due to favorable conditions for disease development. In the Eastern African highlands it survives throughout the year on infected wheat crops and volunteer wheat plants.

Like all cereal rusts the spores of *Puccinia graminis* spread by plant-to-plant contact and by air dispersal. Most spores move only small distances and contribute to local epidemics within the crop. However, a very small proportion of spores get into the atmosphere and are capable of moving long distances to cause new infections. For example, Watson and de Sousa (1983) reported air-borne spread from Southern Africa to Australia.

While stem rust may complete asexual reproduction cycle on barberry (*Berberis vulgaris*) this aspect of its life cycle is no longer considered relevant to wheat production.

Many grasses can be infected as seedlings in the greenhouse or as adult plants when spores are directly injected into the leaf whorl, but they are rust free under field conditions. Barley, triticale, and an occasional rye plant may be infected by wheat stem rust. Wild *Hordeum* spp., such as *H. jubatum* and rarely *H. pusillum*, and *Aegilops cylindrica* are sometimes infected in the United States (Roelfs, 1986); however, it is thought that the inoculum generally comes from wheat to these grasses rather than vice versa in North America. Therefore, inoculum survival in most areas occurs on self-sown (volunteer) wheat, probably barley and possibly grass relatives.

1.3 Virulence

At least 50 numerically catalogued resistance (*Sr*) genes confer resistance to different races of stem rust pathogen. Worldwide, virulence for many of these genes is now common making them useless for crop protection. However, virulence for resistance genes *Sr2, 13, 22, 24, 25, 26, 27, 29, 31, 32, 33, 34, 37, Gt,* and *Wld- 1* is limited or undetected. *Sr13* is ineffective at low temperatures, 18-20°C and virulence occurs in Ethiopia in durum wheat growing areas; *Sr29* and *34* may be ineffective under high inoculum densities. Virulence for *Sr24* exists in South Africa, South America and more recently in India, and for *Sr27* in Australia and South Africa. Virulence for *Sr26* has been undetected despite considerable use of the cultivar Eagle and its derivatives in Australia. Likewise, the wide use of *Sr31* in Kavkaz and similar wheats with the 1BL.1RS translocation did not result in virulence for *Sr31* until 1999 when virulence was detected in Uganda (Pretorius et al. 2000) in a race known as Ug99. This race is now widespread in the eastern African highlands.

1.4 Race Ug99

When tested on wheat seedlings with many of the named resistance genes Ug99 fits the designation TTKS based on the naming system of North American rust workers. As far as can be ascertained the effective resistance genes are *Sr7a, 13, 22, 24, 25, 26, 27, 28, 29, 32, 33, 35, 36, 37, 39, 40* and *44*; and the ineffective resistance genes are *Sr5, 6, 7b, 8a, 8b, 9a, 9b, 9d, 9e, 9g, 11, 15, 17, 21, 30* and *38*. Among the effective genes, *Sr13, 22, 24, 26, 29* and *36* may have some immediate value; the others are either in need of further research, not adequately effective, or have lacked durability. While *Sr36* confers resistance to Ug99, another race in the region caused an epidemic on cultivar Enkoy, which carries *Sr36*, in 1994. Field studies in the region indicate that Hope-derived adult plant resistance is effective and it is clear that future resistance breeding should target its use.

1.5 Evolution of new races and dispersal (migration path)

Occurrence of new races in a geographic/epidemiologic region can be attributed to three phenomena: 1) migration from an outside the region, 2) mutation and selection for a particular virulence, and 3) recombination; both sexual (on barberry) and asexual. The first two of these mechanisms are the most important.

Migration. Airborne spread within an epidemiologic zone is a most common occurrence once a new race has been identified. Urediniospores can move several hundreds, or even thousands, of kilometres. Long distance transport (800 km) may occur annually across the North American Great Plains (Roelfs, 1985), and (2000 km) from Australia to New Zealand (Luig, 1985). Long-distance spread is influenced by latitude and by local and global (predominantly west to east) wind patterns. Generally, spores move west to east due to the winds resulting from the rotation of the earth. Well-documented examples of the long distance spread of cereal rusts in the last half-century were:

1. The occurrence of barley yellow rust in South America and its further spread, including to North America (Dubin and Stubbs, 1986).
2. The introduction of a highly aggressive wheat stripe rust race to California and its northward (Pacific Northwest), southward (Mexico) and eastward spread including its establishment in the Great Plains where stripe rust previously was of no consequence.

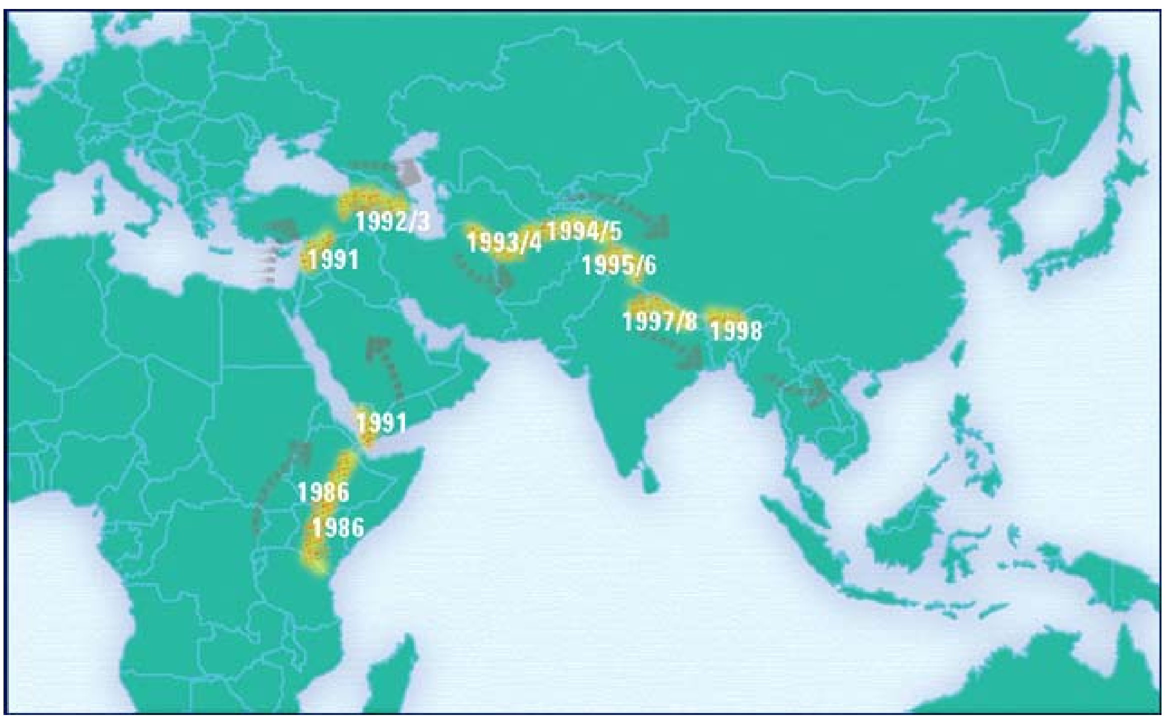

Figure 1. Movement of an *Yr9*-virulent race of *Puccinia striiformis* from the East African highlands to the South Asia

3. The recent introduction and spread of a new wheat stripe rust race in Western Australia and its airborne movement to eastern Australian states.
4. The gradual spread of the *Yr9*-virulent wheat stripe rust from eastern Africa to the South Asia (Fig. 1). This suggests that the entire wheat area in Asia (except China) is a common epidemiologic zone that is connected to Eastern Africa. Therefore, if a new race arises anywhere in this area, given time it could spread throughout the epidemiologic region.

Increased transcontinental travel and human errors have also contributed the movement of races from one area to another. Such introductions of leaf rust and yellow rust in recent years have caused major losses in the new areas. It is now clear that new strains of diseases and pests can move to, and establish at, any location on earth if they have a selective advantage. If the new region is occupied by large area of cultivars susceptible to incoming inoculum, then major epidemics and heavy crop losses may result.

Mutations followed by selection. Mutation is one of the most common mechanisms that lead to the development of new virulence in stem rust fungi. Numerous examples could be cited of the loss of effectiveness of race-specific resistance genes soon after their deployment. Deployment of a resistance gene on a large scale leads to the selection and increase in the frequency of those mutants that have acquired virulence. The increase of such races leads to rust epidemics. With only a few exceptions, the life of a newly deployed, race-specific resistance gene is 3-5 years. As in the case of *Sr31,* the longer a resistance gene remains effective the greater the breeding community depends upon it for continued protection. This may lead to complacency and excessive use arising from the assumption that the original problem had been solved, ultimately resulting in genetic vulnerability.

CHAPTER 2 – KENYA AND ETHIOPIA ASSESSMENT

Eastern Africa has always played a special role in relation to wheat stem rust. For reasons that are not fully understood, but probably related to climate and the continuous cultivation of wheat throughout the year, it has been both a spawning ground for new physiological races of wheat rusts and an important source of resistant germplasm for the entire world. Because the race Ug99 represents a clear and present danger in this region, this section addresses the current situation and the socio-economic impacts in the event of an epidemic.

2.1 Ethiopia

Bread and durum wheats are major cereals in the Ethiopian highlands. Small-scale farmers produce about 95% of the total production. National average yield is 1.4 t/ha (Payne et al., 1996). Rust fungal pathogens are among the major stresses that cause these important yield losses. Major wheat growing areas have seen yellow rust and stem rust epidemics in 1994-1996, 1999, 2004 (Eshetu, 1985; Ayele et al., 2001, Kebede unpublished). Nevertheless, the importance of stem rust has been overlooked in Ethiopia with most attention being paid to yellow rust due its recent importance.

Effect of race Ug99 on wheat production. Although yellow rust has been a constant threat to bread wheat production, stem rust regained its importance when the popular bread wheat cultivar Enkoy became susceptible during 1992/93. No major epidemic of stem rust was reported until 1998 when the high yielding popular cultivar Kubsa (syn. Attila, also released in many other neighboring and Asian countries) became susceptible. In 2001, the cultivar Shinna, released in 1999 for northwestern Ethiopia, became highly susceptible to stem rust in southeastern Ethiopia. A wheat disease survey conducted in 2004/05 (Temesgen, unpublished) showed that 56% of the small scale farmers grew two major bread wheat cultivars, Kubsa and Galama, that are susceptible to stem rust. In addition, wheat cultivation throughout the year (Belg, with a short rainy season and Meher, main season) has contributed to the survival and build-up of stem rust.

Status of bread wheat cultivars grown. The breeding program was established in Ethiopia during the 1950's and a number of cultivars were released. With exposure to large-scale production, resistance to yellow rust and stem rust became ineffective, limiting the duration of cultivation despite wide adaptability and high productivity. These changes in disease response (Table 1) were associated with new races of the pathogens and affected the performance of popular cultivars. Yield trials conducted during 2000-2004 in different areas showed that stem rust has been increasing from year to year. This has resulted in lower than expected yields even at experimental levels. It is predicted that stem rust severity will increase and cause major yield losses in future seasons.

Chemical control of wheat rusts. Chemical intervention is used on an emergency basis when high infections are observed and losses are expected. Large-scale farmers have extensively used fungicides to control rusts. However, small-scale farmers do not use chemicals because of unavailability or high cost in local markets. Consequently, the profitability of fungicide application could not be studied under small-scale production. The large-scale wheat growers in

Arsi and Bale regions spend annually around 0.5 million US dollars to successfully control rusts and maintain high productivity (KARC, unpublished data).

Table 2.1 Cross/pedigree of old and current bread wheat varieties grown in Ethiopia

Variety	Year of release	Cross/pedigree	Reaction to stem rust
Enkoy	1974	(HEBRARD SEL/WIS245XSUP51)X(FR-FNM)^2.A	Susceptible
K6295-4A	1980	ROMANY x GB-GAMENYA	Mod Resistant
ET-13 A2	1981	UQ105 Sel X ENKOY	Susceptible
Pavon 76	1982	VCM/CNO/7C/3/KAL/BB	Mod Resistant
Dashen[1]	1984	VEERY	Mod Susceptible
Mitike	1993	FSYR20.6/87 BOW28//RBC (ET1297)	Mod Susceptible
Wabe	1994	MRL/BUC	Susceptible
Kubsa[1]	1994	ATTILA	Susceptible
Galama	1995	4777(2)//FKN/GB/3/PVN	Susceptible
Tusie	1997	COOK/VEE//DOVE/SERI	Susceptible
Abola	1997	BOW/BUC	Susceptible
Magal	1997	F3.71/TRM//BUC/3/LIRA	Susceptible
Katar	1999	COOK/VEE//DOVE/SERI/3/BIY/COC	Susceptible
Tura	1999	ARO YR SEL. 60/89	Susceptible
Shinna	1999	GOV9AZ//MUS/3/R37/GHL121//KAL/BB/4/ANI	Susceptible
Wetera	2000	MON/VEE//SARA	Susceptible
Hawi	2000	CHIL/PRL	Susceptible
Simba	2000	PRINIA	Susceptible
Dodota	2001	BJY/COC//PRL/BOW	Susceptible
Sirbo	2001	MILAN	Susceptible
KBG-01	2001	(300/SM+501M)/HAR 1709	Mod Resistant
Bobicho	2001	BURRION	Susceptible

[1] These two wheat cultivars, or their sister selections, were released under different names and are widely cultivated in almost all countries of northern Africa and West Asia.

2.2 Kenya

In Kenya, small-scale farmers have increased in number resulting in land sub-division as the population continues to increase. Wheat has expanded to arid and semi-arid areas with unique problems in terms of crop protection. Large-scale farmers contribute about 80% of total wheat production and small-scale wheat farmers produce the remainder. A study in the Nakuru district showed that 78.7% of wheat farmers were small-scale producers. It is expected that the demand for wheat will reach 1 million tons by 2010.

Status of bread wheat cultivars grown. In 1996 severe infection of stem rust was recorded on some commercial wheat cultivars in Mau-Narok and Molo. In 1999 infection was recorded on commercial cultivars, viz. Mbega, Ngamia, Pasa and Duma, in experimental plots at Njoro. In 2000 heavy infection was recorded in experimental plots at Njoro. In 2002, epidemics occurred in farmers' fields at MauNarok and Molo with disease levels ranging between moderately susceptible (cultivar K. Kongoni) and susceptible (cultivar Pasa). In 2003, the disease was recorded in Lanet, MauNarok and Molo at varying degrees; although, the severity was not as high as 2002 but the relative cultivar responses were consistent with those of the previous years.

Although cultivars K. Yombi and K. Chiriku showed some resistance during 2002 and 2003, this was not the case at MauNarok during 2004 (Table 2.2).

Stem rust has spread to other wheat growing regions of Kenya. Although, some cultivars such as Mbuni and K. Kongoni show some resistance, clearly the pathogen has changed, resulting in the susceptibility of several cultivars that were previously resistant.

Table 2.2 Highest reactions of Kenyan cultivars to stem rust at MauNarok, 2002 – 2004

Cultivar	Reaction		Cultivar	Reaction
Chiriku	Susceptible		Kwale	Moderately Susceptible
K.Tembo	Moderately Susceptible		K.Fahari	Moderately Resistant
Heroe	Susceptible		Ngamia	Susceptible
K Nyangumi	Susceptible		K.Yombi	Susceptible
Mbuni	Moderately Susceptible		Pasa	Susceptible
Mbega	Susceptible		Popo	Moderately Resistant
Duma	Susceptible		Njebw1	Susceptible
K. Kongoni	Moderately Susceptible		Njrbw2	Susceptible
K. Paka	Susceptible		Mwamba	Moderately Susceptible
Chozi	Susceptible			

Effect of race Ug99 on wheat production. Yield losses up to 71% were recorded under experimental conditions. If translated to commercial production this level becomes 210,000 tons. The small-scale wheat producers have no purchasing power for fungicides. The large producers are spraying up to three times to contain disease. This is equivalent to US$91/ha plus US$21 for the cost of spraying totaling about US$10 million annually.

2.3 Current and potential economic and social impacts in Sub-Saharan Africa (SSA)

In SSA, especially Ethiopia and Kenya, stem rust is the most widespread and economically important rust disease, and has caused significant losses. As Marasas et al. (2004) observed, the economic importance of rusts follows from the extent to which they may reduce grain yield and stability, their ability to spread rapidly and reach epidemic proportions under favorable conditions, and the pathogens' potential to mutate rapidly to overcome the effectiveness of current resistance genes.

In SSA as in other developing regions, growing resistant cultivars remains the main control method, because most farmers cannot afford to use fungicide on wheat.

Assessment of the economic and social impacts of wheat rusts is not always straight- forward because even when occurrence of the diseases may be recorded, it is seldom accompanied by data on yield losses or the relationship to wheat prices, output levels, or imports (Marasas et al., 2004). Again it is observed that losses of less than 10% are difficult to measure statistically under most circumstances. Disease development must be severe in order to measure losses more accurately and even then it is also difficult to disaggregate rust-occasioned losses from those due to other biotic and abiotic stresses that may occur simultaneously (Marasas et al., 2004).

In making the economic assessment for SSA we have used yield losses that were experienced or are being experienced in Ethiopia and Kenya due to stem rust. For instance, in Ethiopia in 1994 wheat stem rust reduced the yields of variety Enkoy, which was widely grown in the highlands, by 60 to 100% (UNDP, 1994). In Kenya yield losses up to 80% were recorded (KARI, 2005).

Based on the wheat area, yield and production in SSA in 2003 and projected to 2020 (Table 2.1), and the value of losses under various assumptions (Table 2.2), if the wheat production was not reduced by stem rust in 2003, then the estimated gross benefit of the wheat crop was US$ 550 million, using an import parity price of US$212 per ton (SSA is net importer of wheat, which implies that the opportunity cost of its wheat is the import parity price). The projected gross benefit in 2020 would be US$1.1 billion (we have assumed a constant import parity price, although a long-term downward trend in real wheat price, even if fluctuating annually) has been observed (Marasas et al., 2004).

Assuming a 50% yield loss due to stem rust, the gross benefit lost in 2003 was estimated at US$288 million and a gross benefit loss is estimated at US$536 million in 2020. Likewise, an 80% yield loss would result in a gross benefit loss of US$461 million and US$858 million in 2003 and 2020, respectively.

Table 2.1 Wheat area, yield and production in SSA (2003-2020)

	2003	2020	Growth rates (%)
Area (m ha)	1.6	2.2	1.5
Yield (m t/ha)	1.7	2.3	1.4
Production (m t)	2.6	5.1	2.9
Source: CIMMYT, 2004			
Assumptions			
Yield remains the same	1.7	2.3	
Yield declines by 50%	0.85	1.15	
Yield declines by 80%	1.36	1.84	

Table 2.2 Value due to declines in yield in SSA (US$ m*)

Yield remains the same	551	1081
Yield declines by 50%	288	536
Yield declines by 80%	461	858

*Price: US$212/m t.

In developing countries, the social importance of losses like those estimated for SSA depends not only on the absolute magnitude, but also on the role of wheat production in the national economy, the attitude of the particular society towards risk, the time horizon, and other considerations. For some farmers and societies, the true costs of these losses, especially in epidemics, can be great because of the extent to which they rely on the wheat crop. Large crop losses may imply price increases that are passed to consumers, or unforeseen imports purchased at world market prices that may be unfavorable (Marasas et al., 2004). Furthermore, for food (wheat) importing countries like those in SSA a rise in food (wheat) prices leads to a net welfare loss (Levinsohn and McMillan, 2005).

The experience of Ethiopia and Kenya will be used to demonstrate the economic and social impacts that are caused, or can be caused, by wheat stem rust.

Ethiopia

In Ethiopia, many rural households are both producers and consumers of wheat. The per capita consumption of wheat is well over 30 kg/year. Approximately 86% of the population (estimated to be more than 70 million) is rural (CSA, 2001). The poorest regions in Ethiopia also produce the majority of the nation's cereals including wheat. Households tend to earn income from one or two cereals based on cropping systems. They reported their positive sources of incomes as tef (21%), wheat (12%), barley (10%), maize (24%), sorghum (11%) and coffee (12%) (Levinsohn and McMillan, 2005).

Others have observed that rural respondents predominantly describe themselves as subsistence farmers, with 87% reporting that the households' main source of income is subsistence farming (Peacemaker-Arrand, 2004). This author further found that the most widespread source of income among these rural households was from livestock. Only 4.1% rural households support themselves with formal employment, whereas 2.4% rely on "casual labor." Subsistence farming remains the main livelihood of rural Ethiopia.

The most widely consumed cereals in the rural sector are maize (57%), sorghum (40%), tef (33%), wheat (32%), and barley (22%), whereas in the urban sector these are tef (76%), wheat (39%), maize (28%), sorghum (22%) and barley (22%). Households spend a large fraction of their annual income on cereals ranging from 12% to 26% for rural households and 5% to 16% for urban households. Thus, changes in cereal prices can have substantial welfare effects and reduction in these prices is likely to transfer real income from urban to rural households (Levinsohn and McMillan, 2005).

Ethiopia receives more food aid than any other country in the world. All wheat net imports are in the form of food aid. Food aid reached 15% of annual cereal production in 2003 and typically represents 5 to 15% of total annual cereal production (Jayne et al., 2002; WFP, 2004).

Based on the wheat area, yield and production in Ethiopia in 2003 and projected to 2020 (Table 2.3), the value of losses made under various assumptions is projected (Table 2.4). If the wheat yield was not affected by stem rust in 2003, then the estimated gross benefit of wheat production was US$328 million, using an import parity price of US$234 per ton. The projected gross benefit in 2020 is US$1 billion. Assuming a 50% yield loss due to stem rust, the gross benefit lost in 2003 was estimated at US$164 million and a gross benefit loss is estimated at US$440 million in 2020. An 80% yield loss would result in a gross benefit loss of US$262 million and US$708 million in 2003 and 2020, respectively.

The impact on production due to losses in yield will lead to changes in prices of wheat. As observed above, these changes can have substantial welfare effects depending on whether a household is a net buyer or a net seller of wheat. Households that are net buyers of wheat will be hurt by a price increase, whereas households that are net sellers of wheat would see their welfare increase with wheat prices. Thus the 12% of households that received income from wheat will gain from an increase in the price of wheat. However, it has been shown that countries that are net food (wheat) importers, a rise in food (wheat) prices leads to a net welfare loss for the society (Levinsohn and McMillan, 2005).

Table 2.3 Wheat area, yield and production in Ethiopia (2003-2020)			
	2003	2020	Growth rates (%)
Area (m ha)	1.0	1.5	1.5
Yield (m t/ha)	1.4	2.5	1.8
Production (m t)	1.4	4.5	3.2
Sources: FAOSTAT and CIMMYT, 2004			
Assumptions			
Yield remains the same	1.4	2.5	
Yield declines by 50%	0.7	1.3	
Yield declines by 80%	1.1	2.2	

Table 2.4 Value due to declines in yield in Ethiopia (US$ m*)		
Decline in yield	2003	2020
Yield remains the same	328	1048
Yield declines by 50%	164	442
Yield declines by 80%	262	708

***Price: US$234/m t.

Kenya

About 80% of Kenya's population (estimated at over 30 million) lives in rural areas and largely derive their livelihoods from agriculture. Fifty six percent of the Kenyan people live below the poverty line[1]; over 80% of these are in the rural areas. Among the poor households, subsistence farmers and pastoralists account for over 50% of the poor (GOK, 2004).

Among cereals, wheat ranks second to maize and contributes significantly to food security. The per capita wheat consumption is over 27 kg/year. Both small-scale and large-scale farmers produce wheat. Although production is highly mechanized the large-scale farmers are more mechanized than the small-scale farmers who cultivate 2-3 hectares both for subsistence and commercial purposes. In general, these farmers produce over 70% of the nation's maize, 20% of wheat and 80% of milk (GOK, 2004). These three enterprises are the main sources of income for small-scale wheat farmers. Although some of these wheat farmers consume some of their wheat, they are in general net sellers of wheat. In some wheat growing districts, a sizable share of household income is from off-farm activities. However, agriculture is the main means of livelihood for these farmers.

Large-scale farming is practiced on farms averaging about 50 hectares. They produce 80% of wheat, 30% of maize, 20% of milk (GOK, 2004). All the wheat is produced for commercial purposes and is the main source of income for these farmers.

Based on wheat area, yield and production in Kenya in 2003 and projected to 2020 (Table 2.5), the value of losses is estimated under various assumptions (Table 2.6). If the wheat yield was not affected by stem rust in 2003, then the estimated gross benefit of wheat production was US$47

[1] The poverty line is estimated at US$16 and US$35 per month for rural and urban households, respectively, at a current exchange rate of Khs.76.40 to the US$1.

million, using an import parity price of US$212 per ton. The projected gross benefit in 2020 is US$149 million.

Assuming a 50% yield loss due to stem rust, then the gross benefit lost in 2003 was estimated at US$23 million and a gross benefit loss is estimated at US$63 million in 2020. An 80% yield loss would result in a gross benefit loss of US$38 million and US$101 million in 2003 and 2020, respectively.

Large-scale farmers spray their wheat with fungicide to protect it against stem rust. This is costing them about US$10 million annually (KARI, 2005). In the developing world, treatment with fungicide when epidemics occur would not be feasible for many farmers and countries given the constraints to mounting well-coordinated mobilization campaigns (Marasas et al., 2004). Thus, in determining the value of the losses above, we have assumed that both small-scale and large-scale farmers are not spraying their wheat against stem rust.

The situation for small-scale farmers (Table 2.7) alone is that if their wheat yield was not affected by stem rust in 2003, the estimated gross benefit was US$9 million. The projected gross benefit in 2020 is US$30 million.

Assuming a 50% yield loss due to stem rust, then the gross benefit lost in 2003 was estimated at US$4 million and a gross benefit loss is estimated at US$15 million in 2020. An 80% yield loss would result in a gross benefit loss of US$7 million and US$24 million in 2003 and 2020, respectively.

The impact on production due to losses in yield will lead to changes in prices of wheat. The losses are bound to increase commercial imports of wheat, which are already high. During 2002-2004 commercial imports of wheat were 54% (420,000 tons) of domestic demand. Kenyan government imposes a duty of between 25 to 35% (plus 50% suspended duty) on wheat commercial imports to protect domestic wheat producers (Nyangito et al., 2002). When production is high the duty is raised and lowered when production is low. This raises the domestic price of wheat above the import parity price. Both small and large-scale wheat farmers are net sellers of wheat and therefore benefit from increases in price. Large-scale farmers benefit more since they produce 80% of the wheat.

Wheat is an important staple food, particularly for the urban population. Low-income households will tend to spend a larger proportion of their income on wheat than high-income households. Hence, an increase in wheat prices will hurt low-income consumers more than high-income consumers. While increase in price is beneficial to farmers who are net sellers of wheat, it hurts both urban and rural consumers who have to spend more of their income on wheat. Consequently, the policy of taxing wheat imports has the effect of transferring income from poor rural and urban consumers to wheat farmers. This could make society suffer a net welfare loss.

Table 2.5 Wheat area, yield and production in Kenya (2003-2020)

	2003	2020	Growth rate (%)
Area (m ha)	0.13	0.20	1.5
Yield (m t/ha)	1.70	3.06	1.8
Production (m t)	0.22	0.70	3.2

Sources: FAOSTAT and CIMMYT, 2004

Assumptions	2003	2020
Yield remains the same	1.70	3.06
Yield declines by 50%	0.85	1.53
Yield declines by 80%	1.36	2.45

Table 2.6 Value due to declines in yield in Kenya (US$ m)

Decline in yield	**2003**	**2020**
Yield remains the same	47	149
Yield declines by 50%	23	63
Yield declines by 80%	38	101

***** Price: US$212/m t.

Table 2.7 Value due to declines in yield for small-scale farmers in Kenya (US$ m)

Decline in yield	**2003**	**2020**
Yield remains the same	8.5	29.7
Yield declines by 50%	4.2	14.8
Yield declines by 80%	6.8	23.7

CHAPTER 3 – VULNERABILITY OF OTHER GEOGRAPHIC REGIONS

Large stem rust epidemics have not been a feature of global wheat production for many years. The historically stem rust-prone areas of the world used the control of barberry (France and North America) to prevent early infection and resistance to reduce losses. Prolonged use of resistance then led to decline in levels of inoculum both locally and particularly in areas that were considered 'hot-spots' and were sources of wind-blown inoculum to other regions. Once resistance is in place the greatest threats then come from: (1) use of susceptible varieties that enabled inoculum increase, (2) mutations in the pathogen that overcome a resistance gene and the selective increase of the new mutant race on the selective host genotype(s), (3) introduction of different race(s) with the relevant virulence attributes from other regions. Once an outbreak occurs, the magnitude of the problem is related to frequency of use of the "defeated" gene among local cultivars and seasonal conditions that favor rust increase.

Reports from breeders and pathologists around the world, summarized below, indicate that stem rust has been considered to be under control in most regions for many years and pathogen populations have declined to levels that indicate that the disease is no longer a threat. This has led to complacency that, in some cases, has resulted in the increased use of susceptible cultivars and hence an increased vulnerability of the crop. In addition to the natural spread of inoculum by weather patterns, the increasing global movement of people and goods constitute further risk as exemplified by recent introductions of stripe rust to North America, Australia and South Africa.

Another measurement of the decreased interest in stem rust as a threat to wheat is the relatively few research papers that have been published on this disease over the last ten years compared to those published on leaf rust and stripe rust.

3.1 Africa

Eastern Africa. Details of the situation in Kenya and Ethiopia are provided in Chapter 2 and Appendix II. The greatest threat in the region is the potential spread of the race Ug99 to Egypt, Eritrea, Sudan and Yemen as steps to Western Asia and further east.

Southern Africa. Reports were obtained only from South Africa and scientists there had no knowledge of the situation in neighboring countries. While stem rust once was considered a major objective for breeding programs in South Africa, fewer resources were available for race monitoring and research. Spring wheats grown in the winter rainfall areas of Western Cape are generally susceptible and recent localized epidemics of stem rust were controlled by chemicals.

Northern Africa. The countries of greatest risk to stem rust are Egypt and Morocco. Increased stem rust infections were being observed in recent years on certain wheat cultivars and screening nurseries grown in both Egypt and Morocco. Most of the cultivars currently grown in the Nile Valley are susceptible to race Ug99 and it is considered imperative that resistance to that race be developed and deployed. This region could be an important stepping-stone in the spread of the race to Western Asia and further east.

3.2 Asia
For 2004 the FAO estimates that developing countries in Asia harvested 228 million metric tons of wheat from 81 million hectares of land. India and China are the major producers but Turkey, Pakistan and Iran also produce significant quantities. Much of this land is regularly planted to varieties likely to be susceptible to Ug99.

Western Asia including Turkey. A stem rust epidemic in Iran during 1976 caused yield losses as high as 80% in some areas. More recently, stem rust was observed in the Dozen and Gorgan regions adjacent to the Caspian Sea. Saudi Arabia, Iraq, Iran and Afghanistan are all considered vulnerable to stem rust due to favorable environments and widespread cultivation of cultivars susceptible to race Ug99.

Central Asia. For the last several years little stem rust was reported on the international nurseries distributed from the Turkey/CIMMYT/ICARDA facultative/winter wheat breeding program.

South Asia. Historical accounts indicate that widespread stem rust epidemics occurred in India and Pakistan. Since the Green Revolution there has been no report of significant losses to stem rust. Following the identification of Ug99 race, tests in Kenya of the dominant mega-cultivars grown in India (PBW343 which carries gene *Sr31*) and Pakistan (Inquilab 91 which does not carry *Sr31*) indicated that these cultivars were susceptible. Several other important cultivars from the region were also susceptible.

East Asia (China). Stem rust was earlier considered important in north-eastern China, but no recent reports are available. About 60% of cultivars in China carry *Sr31* and studies outside China indicate little evidence of additional resistance genes in Chinese germplasm. However, East Asia is considered to be geographically isolated from South Asia and the likelihood of natural movement of the Ug99 race to China is considered to be low.

3.3 Europe
Stem rust has not been a problem in Europe for many years. However, if Ug99 spreads to North Africa there will be an increased stem rust risk in Southern Europe.

3.4 The Americas
Canada. The last significant losses occurred in Canada in 1955. Stem rust resistance is considered obligatory for release of spring wheats in Canada. Cereal rusts do not over winter in Canada and initial inoculum comes from the south. Canadian wheat lines have been sent to Kenya for assessment of stem rust responses.

United States. In 1996 a 2% loss in production was attributed to stem rust in the soft wheat areas of Illinois, Indiana, Michigan and Wisconsin. This was attributed to the use of susceptible cultivars and an inoculum build-up further south. The situation on the more western Great Plains has been stable over a long period presumably due to the continued use of stem rust resistance. Both 1BL.1RS (Kavkaz) and 1AL.1RS (Amigo) sources of stem rust resistance are used in the USA and breeders in some states have indicated pre-emptive breeding efforts as well as contributing to a USDA: CIMMYT program to screen materials in Kenya in 2005. It is not known if the 1RS gene in Amigo (derived from a different rye source) is the same as *Sr31*.

Mexico. Currently, stem rust is not considered to be an issue in Mexico. However, stem rust resistance is considered essential for release of CIMMYT germplasm in Mexico. All breeding materials of CIMMYT are selected under high stem rust pressure created through artificially created epidemics using the existing Mexican races and international data obtained through CIMMYT's International Nurseries. The greatest threat is considered to be Ug99 race from East Africa.

South America. A stem rust epidemic occurred in Paraguay during the early 1990s on cultivar Itapua 35. More recently there was a build-up of stem rust in northern Argentina due to increased cultivation of Bagutte 10, a susceptible cultivar introduced from France. Increased disease severity is also being observed on international and regional nurseries grown in Bolivia in recent years. Deployment of gene *Sr24* in Brazil during the 1990s soon resulted in the identification of a new race with virulence. Breeders in the Southern Cone region (Brazil, Paraguay, Bolivia, Argentina, Uruguay and Chile) believe there should be a regional resistance strategy, but withdrawal of the CIMMYT coordinator from the region in 2005 could be an impediment to a collaborative approach.

3.5 Australia and New Zealand

The last major stem rust epidemic on wheat occurred in the early 1970s. This led to the establishment of the ongoing Australian Cereal Rust Control Program with responsibilities to monitor variation in the pathogen, to identify, genetically analyze and provide resistant germplasm to breeders, to screen breeding populations for all Australian breeders, and to undertake germplasm enhancement of breeder-nominated lines by backcrossing. Since the 1970s there have been minor outbreaks that resulted in cultivars being withdrawn from recommendation. Although race Ug99 can cause significant losses on some popular cultivars, the *Sr31* virulence is not considered a major threat to Australian wheat industry as the gene was not used in breeding and there is a strong knowledge base that allows virulence information to be applied to risk assessment of the available genetic diversity. Stem rust has not been reported in New Zealand for many years, possibly as a result of control in Australia, which historically, was a source of inoculum.

3.6 Conclusion

The absence of stem rust in rust-prone areas over a long period has led to an assumption that stem rust is part of the past. Clearly the new data shows that such an assumption is no longer—and probably never was—warranted. The occurrence of race Ug99 and its spread in Kenya and then Ethiopia, associated with increased disease levels on previously resistant cultivars, is a timely reminder to largely complacent international community of a potential disaster if there is further spread. Many cultivars grown throughout northern Africa and Asia are closely related to those already affected (Table 2.1) are known to have similar resistances or are susceptible to stem rust.

CHAPTER 4 – STRATEGIES FOR CONTROL

The achievement of resistance to most diseases, including stem rust, requires alliances on several fronts. While the objective may be for a long term solution, this is not always achievable due to the airborne movement of the pathogen, or to new virulent races resulting from mutation, or possibly asexual recombination. Consequently, pathogen populations need to be monitored over time to track further movement of race Ug99 and to ensure that currently effective resistance genes or resistance sources remain effective. The future availability of resistance sources to the farming community will depend on the maintenance of genetic diversity and ability to use effective resistance in instances of resistance failure. As new resistance genes may not be in high yielding genotypes, they must be transferred to adapted germplasm. In order to replace susceptible cultivars as quickly as possible national programs require appropriate infrastructure to enhance seed increase and distribution.

Increasing evidence from leaf rust and stripe rust research indicates that some sources of resistance are more durable than others. Such resistances are usually based on combinations of 3 to 5 genes that individually have small effects but act in an additive manner to provide adequate protection from disease. Longer term research should address the potential of minor genes for the control of wheat stem rust.

4.1 Pathogen monitoring

Monitoring the incidence and likely spread of race Ug99, and its further evolution, should be a high priority in Africa, the Middle East and Asia, especially because (1) the spores of these fungi can move freely over long distances, (2) several currently grown cultivars, with or without gene *Sr31*, are susceptible to this race, and (3) the same cultivars, with different names, are being grown in more than one country. 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 institution such as CIMMYT and ICARDA is important to coordinate such effort. This could alert national programs to a forthcoming problem that could be reaching to their countries. Emergency measures could then be taken much earlier to prevent an epidemic.

Several countries in Africa and Asia do not conduct annual surveys or adequately characterize the avirulence/virulence of the prevalent races. USDA’s Cereal Disease Laboratory at St. Paul, Minnesota has undertaken to provide support to the race characterization. To supplement this further, a stem rust trap nursery will be developed and planted at various sites in Africa and Asia to determine the presence and migration of race Ug99 in the region. Further, there is a critical need to put in place an effective warning system that provides stakeholders and policy-makers with reliable information on the actual and likely spread of the Ug99 rust strain, identifies areas and farming communities at greatest risk and details likely economic and food security impacts.

Recommendation #1. Because the stem rust pathogen is airborne and genetically variable, the Panel **recommends** (1) population monitoring by means of trap nurseries and limited sampling for race analysis for the Kenya - Ethiopia region, adjacent areas, and beyond. (2) the establishment of a warning system based on the above data and modelling, using GIS and other appropriate tools.

4.2 Genetic resistance, diversity and utilization

Enhanced information on the effectiveness of resistance and genetic basis of such resistance in important wheat cultivars. Although several cultivars may be available in a country, only a few tend to occupy large areas. It will be highly desirable to determine which of these cultivars have adequate resistance to stem rust, especially to race Ug99. This can be done by screening them in field trials in Kenya and Ethiopia. The resistant cultivars can be promoted in their respective countries of release. To enhance genetic diversity, further greenhouse tests and genetic analysis both in the greenhouse and field will be necessary. Greenhouse tests should distinguish cultivars that may carry adult plant resistance from those that carry race-specific seedling resistance genes as well as seedling infection types may give clues to which resistance genes are present. Detailed genetic analyses will be necessary to determine the nature of resistance and molecular mapping will help identify resistance genes involved. Available DNA markers linked to several alien resistance genes can also be used to determine their presence.

Testing of new wheat germplasm developed by International Centres, National Programs and Advanced Institutions in Eastern Africa. Several breeding programs at present do not select or evaluate their breeding materials against stem rust or select only with races that are relevant in their respective countries. These do not have virulence for *Sr31* and possibly other resistance genes overcome by Ug99. A network to facilitate testing of germplasm developed by various institutions in Kenya and Ethiopia can identify lines that are resistant to race Ug99. These lines can then be promoted for release or at least can be used in future breeding. They can also be studied further to understand the genetic basis of resistance.

Recommendation #2. Because diverse sources of resistance would be necessary for all genetic control strategies, the Panel **recommends** that diverse genetic resistance be identified in global wheat germplasm by testing in Kenya and Ethiopia.

4.3 Breeding for resistance with emphasis on durable type

Growing resistant cultivars is the best rust control strategy as it is environmentally friendly and has no cost to farmers. Because leading cultivars currently grown in Africa, the Middle East and Asia and a major portion of the current advanced breeding germplasm of CIMMYT and ICARDA are susceptible to Ug99 race, an aggressive breeding strategy needs to be in place to rectify the situation. Known race-specific resistance genes that are effective to race Ug99 are already identified. However, some of these such as *Sr24* and *Sr36* need to be utilized with great caution, as virulences are known to occur in different areas including Africa. That leaves fewer alien resistance genes such as *Sr25* and *Sr26*. Additional less effective resistance genes such as *Sr7a* and *Sr23* can be useful as they may interact to enhance the expression of slow rusting, adult plant resistance genes. Marker-assisted selection may help in combining some of these currently effective genes in an attempt to enhance their longevity.

The best strategy for durable genetic control is to initiate a thorough search for slow rusting, minor resistance genes that have additive effects. Resistance gene *Sr2*, transferred to hexaploid wheat from tetraploid emmer wheat, is a good example of such resistance genes. *Sr2* when present alone confers only intermediate resistance that is often not sufficient under high disease pressure but is believed to interact with other unknown genes, both race-specific and slow rusting, to confer high levels of resistance, commonly known as *Sr2*-complex. Such gene combinations probably contributed to the long term effectiveness of stem rust resistance in CIMMYT germplasm during the green revolution and post green revolution period, until the wide use of 1B.1R translocation. In the presence of *Sr31* it was difficult to maintain combinations of *Sr2* with other minor resistance genes. Some older cultivars such as Kenya Plume and post green revolution cultivars such as Pavon 76 have shown adequate resistance to the race Ug99 in both Kenya and Ethiopia. A targeted breeding strategy that can recover the *Sr2*-complex in modern wheat cultivars should be implemented. Where possible marker assisted selection should be applied.

Recommendation #3. Because modern cultivars currently grown in Northern Africa and Asia are susceptible to race Ug99, the Panel **recommends** that a breeding strategy be implemented to incorporate diverse genetic resistance to Ug99 into such germplasm before the race migrates to those areas. DNA-marker assisted selection should be utilized where feasible.

4.4 Emergency control measures

Stem rust is already being controlled in Kenya and South Africa by using fungicides. However, in other developing countries chemicals have not been used for stem rust control. It may become necessary to develop protocols in case Ug99 migrates to neighboring countries before resistant cultivars occupy a significant area. Chemicals are being used by large scale farms in Ethiopia, but the small scale farmers who produce over 95% of the wheat do not use chemicals. Availability of generic fungicides at low prices and an integrated control strategy may provide short-term control. These fungicides must be assessed in both Kenya and Ethiopia to identify the most effective chemical as well as rates and timing of applications. Some information may be available from South Africa.

Recommendation #4. Because of the likelihood of chemical intervention for control in the short term, the Panel **recommends** that appropriate strategies for use by all producers should be determined.

4.5 Seed multiplication and distribution

Testing and release of a cultivar takes 3-5 years and its adoption by farmers is often slower. Problems associated with seed multiplication and distribution are the most important reason for slow adoption. All efforts including the PVS through farmers' participation will be necessary to promote resistant cultivars to prevent an epidemic. In Ethiopia and Kenya it must be initiated immediately. It will be important to have sufficient quantities of seed of adapted resistant cultivars available should race Ug99 appear in the Nile Valley, especially in Egypt.

Recommendation #5. Because the breeding programs will develop elite varieties that need to be maintained, multiplied and distributed, especially to small scale farmers, the Panel **recommends** that seed multiplication agencies and community-based organizations be encouraged to produce commercial seed of newly developed stem rust resistant varieties with stipulations that (1) farmers and other stakeholders play a leading role; (2) breeding programs be supported in the maintenance and multiplication of Breeder's and Foundation seed; (3)commercial seed should be readily available to farmers; and (4)on-farm demonstrations of elite varieties be conducted.

4.6 Socio-economics

The socioeconomic implications of stem rust on food security and livelihoods in SSA, Ethiopia and Kenya were discussed in Chapter 2. It is clear that stem rust poses a significant threat to food security and livelihoods. However, more detailed work will be required to understand on-farm costs of control measures, alternative options and livelihood strategies of the farm households and the likely economic, social and food security impacts for the respective countries.

Recommendation #6. Because of the socioeconomic implications of the stem rust on food security and livelihoods of the wheat producing countries and societies, the Panel **recommends** that ex-ante and ex-post impact assessments are undertaken taking into account alternative crops and livelihood systems.

4.7 Human resources

The current knowledge base to implement an integrated control of stem rust including disease epidemiology, resistance genetics and breeding is insufficient in most national programs. This is largely due to the rare occurrence of stem rust worldwide and hence little work is currently being done internationally. Targeted training of scientific and technical staff at various levels is essential to ensure sustainable wheat production.

Recommendation #7. Because knowledge, skills and hands-on experience on various aspects of stem rust research and management are required by all personnel including technical support staff, the Panel **recommends** that a training program, including advanced degree training for those associated with the project, in-country practical courses and specialized in-service courses outside the country to strengthen the capacity of national partners, be implemented to augment the current human resource base.

4.8 Infrastructure

The current infrastructure in Ethiopia and Kenya is inadequate to conduct necessary research and its application for the essential activities described in 4.1- 4.5. Improving existing facilities will greatly enhance the efficiency and implementation of control measures.

Recommendation #8. Because of the need for well equipped laboratory and effective and efficient communication systems to address the threat of wheat stem rust, the Panel **recommends** that facilities for wheat research should be strengthened or established in Ethiopia and Kenya to include (1) renovation of greenhouses and essential field facilities; (2) renovation of pathology laboratories (3) upgrade of irrigation systems; (4) improved communications capacity, especially internet; (5) strengthening of molecular laboratories; and (6)improvement of transport capacity.

4.9 Reporting and communication

Current information on wheat rust situation, resistance sources, their availability and any progress on stem rust research will require prompt communication to global wheat community and other stakeholders. This would require a Web based communication strategy, organization of workshops, and publications.

Recommendation #9. Because of the need to raise and maintain awareness of the wheat stem rust problem and the need to enhance communication among wheat scientists and other concerned stakeholders, the Panel **recommends** that support be provided to develop, implement and maintain an appropriate communication strategy.

4.10 Resource for IARCs

Current resources allocated to wheat pathology and resistance breeding are inadequate to meet the current threat posed by the stem rust that needs a concerted new efforts including the facilitation of international germplasm testing, and targeted development of resistant germplasm adapted to different wheat production areas beyond Eastern Africa. Such efforts will best be rewarded if the best partners are engaged. That includes the considerable expertise that resides in advanced research institutes in North America, Australia and in other parts of the world.

Recommendation #10 Because advanced research institutes in North America, Australia, and elsewhere are in a position to both contribute and benefit from a Global Rust Initiative (GRI) and because much of the necessary research and coordination will be provided by CIMMYT and ICARDA, the Panel **recommends** that (1) appropriate advanced research institutions be engaged in the GRI utilizing their own resources and that (2) CIMMYT and ICARDA receive additional resources from the advanced research institutes and other appropriate donors to coordinate the GRI and meet their respective research responsibilities necessary to avert an epidemic.

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