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Ug99 race of stem rust pathogen: Challenges and current status of research to sustain wheat production in India

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Introduction

Stem or black rust, caused by *Puccinia graminis* Pers.f.sp*. tritici* Errikss.&Henn. is infamous for causing severe losses to wheat (*Triticum aestivum* L. and *T. turgidum* var*. durum*) production. The causal organism of stem rust was named *Puccinia graminis* in 1797 by Persoon and the first detailed reports about this pathogen were given independently by Italian scientists Fontana and Tozzetti [1, 2]. Stakman and Piemeisel [3] showed that stem rust pathogen had various forms or races. Many devastating epidemics of wheat are reported to have occurred around the globe by this pathogen. Notable among these were the epidemics of North America in 1904 and 1916. A series of stem rust epidemics in the middle of 20th century led to the initiation of the International Spring Wheat Rust Nursery Program in 1950 by B.B. Bayles and R.A. Rodenhiser of USDA-ARS (United States Department of Agriculture - Agricultural Research Service). Subsequently, this nursery became the foundation of numerous other international nurseries and led to global cooperation to achieve resistance to diseases and pests of several crops.

In the post Green Revolution period, a major proportion of the Indian wheat germplasm remained resistant to stem rust mainly due to the presence of resistance gene *Sr31*, located on rye translocation 1BL.1RS. Other important stem rust resistance genes that gave substantial protection were *Sr24* and *Sr2.* There are several genes such as *Sr26*, *Sr36* and *Sr38* that remained effective against Indian stem rust races. Except *Sr24* and *Sr31*, neither alien gene has been deployed in India. Translocations carrying these genes, except that with *Sr26*, also carried additional genes that conferred resistance to some other important diseases such as leaf rust, stripe rust and powdery mildew. These genes give high level of resistance in several wheat cultivars of India and the neighbouring countries of South Asia [4]. Consequently, stem rust disease did not appear as a threat and was often not considered important in wheat breeding causing a considerable decline in the wheat research on this disease.

Emergence of race Ug99 and the threat it poses

Around ten years ago, a new race of stem rust, called Ug99, was detected in Uganda [4, 5]. It was named as TTKS, based on the naming system of North American rust workers [6] and more recently as TTKSK with the addition of a fifth set of differentials [7]. However, the race is popular as Ug99 because of its detection in Uganda in the year 1999. This is the only stem rust race that carries a broad virulence against many of the stem rust resistance genes including *Sr31* and is called a Super Race by many workers. The emergence of Ug99 is considered a highly significant event having far reaching consequences not only for India but also for global wheat production due to susceptibility of majority of wheat cultivars against Ug99. It has been estimated that the area under risk of Ug99 amounts to around 50 million ha of wheat grown globally i.e., about 25% of the world's wheat area [4]. Almost entire wheat area of India is expected to be prone to this virulent race. The race is expected to move in next three years to South Asia where wheat is an important cereal for a large population. Germplasm with resistance to Ug99 is

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available [4, 8], but for many parts of the world including India, genetic stocks of this type are not present in popular varieties grown at farmer's fields.

Wheat is the predominant crop, with an estimated 19% of global production (c.117 million tonnes) occurring in the potential Ug99 migration path, and an estimated 1 billion people living within these wheat production areas [8]. The most dominant varieties of India and Pakistan are the "mega-cultivars" 'PBW343' and 'Inqualab 91' that are currently grown in around 7 and 6 million hectares, respectively [9, 10]. Both of them have proved highly susceptible to Ug99. Only 0.3% of a total reported area of over 44 million ha planted to known cultivars in the epidemiologic zone of Ug99 were rated as being moderately resistant [5, 8]. The overall conditions in the migration path of Ug99 are considered highly favourable for outbreak of an epidemic. The favourable environmental conditions in the Indo-Gangetic plains of India, coupled with the extensive coverage of susceptible wheat varieties is a grave cause of concern if Ug99 does spread unchecked. If an epidemic from Ug99 does occur in South Asia, a huge population of wheat farming families would be seriously affected and there would be significant implications for rural and national economic growth rates. The grim situation caused by Ug99 demands for accurate monitoring and early warning to directly support the efforts of wheat researchers and national policy makers working to prevent the spread of the disease.

The Global Rust Initiative (GRI)

The quick migration of Ug99 to Kenya and Ethiopia led to the launch of the Global Rust Initiative (GRI) on September 9, 2005 in Nairobi, Kenya to raise the awareness from the risk posed by Ug99 race [5, 11]. Significant efforts are currently underway to generate human and financial resources to implement a global control strategy. The recommendations relevant to wheat improvement community include: tracking the migration of Ug99 and its further evolution, establishment of a warning system, identification of resistance in global wheat germplasm by testing in Kenya and Ethiopia, implementation of a breeding strategy to incorporate diverse genetic resistance into key germplasm before the race migrates to those areas, and enhancement of human resources and structural capacities. India is a strong partner of GRI, contributes financially, and is actively participating in the germplasm testing in Kenya and Ethiopia along with that from CIMMYT, ICARDA and various other countries. The success of GRI lies in a timely replacement of stem rust susceptible cultivars with resistant ones with equal or better yield potential and other necessary characteristics.

Migration of Ug99 to newer environments

Wheat rust pathogens are wind borne pathogens capable of causing explosive epidemics. They produce millions of urediniospores that are transmitted onto the same or new host plants. Being wind borne, predicted patterns of its movement are quite uncertain. Although, most of the spores are deposited close to the source [12], long-distance dispersal [LDD] is also well documented. LDD can occur with planting material, germplasm exchange or in the seed and grain trade. The occurrence of *Puccinia antirrihini* in the suburbs of Sydney, Australia was probably due to contaminated seed lots of *Antirrihimum* spp. Shipped from the Netherlands [13]. A major mode of dispersal for wheat rusts is step-wise range expansion. This typically occurs over shorter distances, within country or region, and has a much higher probability than the other possible modes of dispersal. A recent example of this type of dispersal mechanism includes the spread of stripe rust by a *Yr9* virulent race of *P. striiformis* that evolved in Eastern Africa. This race migrated to South Asia through the Middle East and West Asia in a step-wise manner over about 10 years (Fig. 1), and caused severe epidemics in its path [14]. It was first detected in North-West region of India during 1996 [15].

Rusts of different crops can also migrate to long distance through unassisted dispersal mechanisms under natural airborne conditions. Several types of long-distance dispersal have been described [16, 17]. LDD plant pathogens are 'r-strategists' as their life history strategies tend to involve large colonization rates, both spatially and temporally. Gene flow through LDD permits the pathogen populations to adapt regional environmental changes by appropriate recombination of the fitness genes. Some of the important examples include the introduction of sugarcane rust into the Americas from Cameroon in 1978 and a wheat stem rust introduction into Australia from southern Africa in 1969 [8]. More recently, the arrival of Asian soybean rust into the USA in 2004 from northern South America /Caribbean was most likely carried by hurricane Ivan [18]. At present, assisted long-distance dispersal is also believed to occur by travelers clothing or infected plant material. There is strong evidence to support an accidental introduction of wheat yellow rust into Australia in 1979, probably on travelers clothing, from Europe [19]. It has been suggested that it is unrealistic to rule out any of previously described dispersal mechanisms [8].

However, chances of step wise movement following *Yr9* track (Fig. 1) are the highest.

Current distribution of Ug99

Following its detection in 1999, investigations in neighbouring countries in East Africa revealed that the same race may have migrated to sites in the Rift Valley province of central Kenya by the same year with subsequent advancement to sites in Eastern Kenya by 2001. In 2003, race Ug99 was detected in Ethiopia and in 2005 it was further reported from at least six dispersed site locations. Recent evidences [5, 20] suggest that Ug99 has crossed the red sea and is now infecting wheat in Yemen and Sudan [4] and preliminary results also indicate its presence in Iran.

Expected migration path of Ug99

So far Ug99 has exhibited a gradual step-wise range expansion, following the predominant west-east air flows. In addition, there is documented evidence connecting East Africa with West and South Asia as a single epidemiologic zone for migration of rust races of East African origin [14]. Taking this as the basis, an international group of experts forecasted in the year 2005 that within few years Ug99 shall reach across the Saudi Arabian peninsula and into the Middle East, South Asia, and eventually, East Asia and the Americas [18]. Recent evidences indicated that the forecast may come true.

GIS tools being used for determining likely movement of Ug99 suggest the notion of two potential air-borne migration routes for Ug99 to south Asia [8, 21]. The first route matches the route described by Singh *et al*. [14] for the *Yr9*-virulent race of *P. striiformis* and is considered the most likely option (Fig. 1). The second route that connects East Africa directly with southern Pakistan/western India, has no known precedence and is highly speculative and of much low probability. So far, the movement of Ug99 has followed the first route and

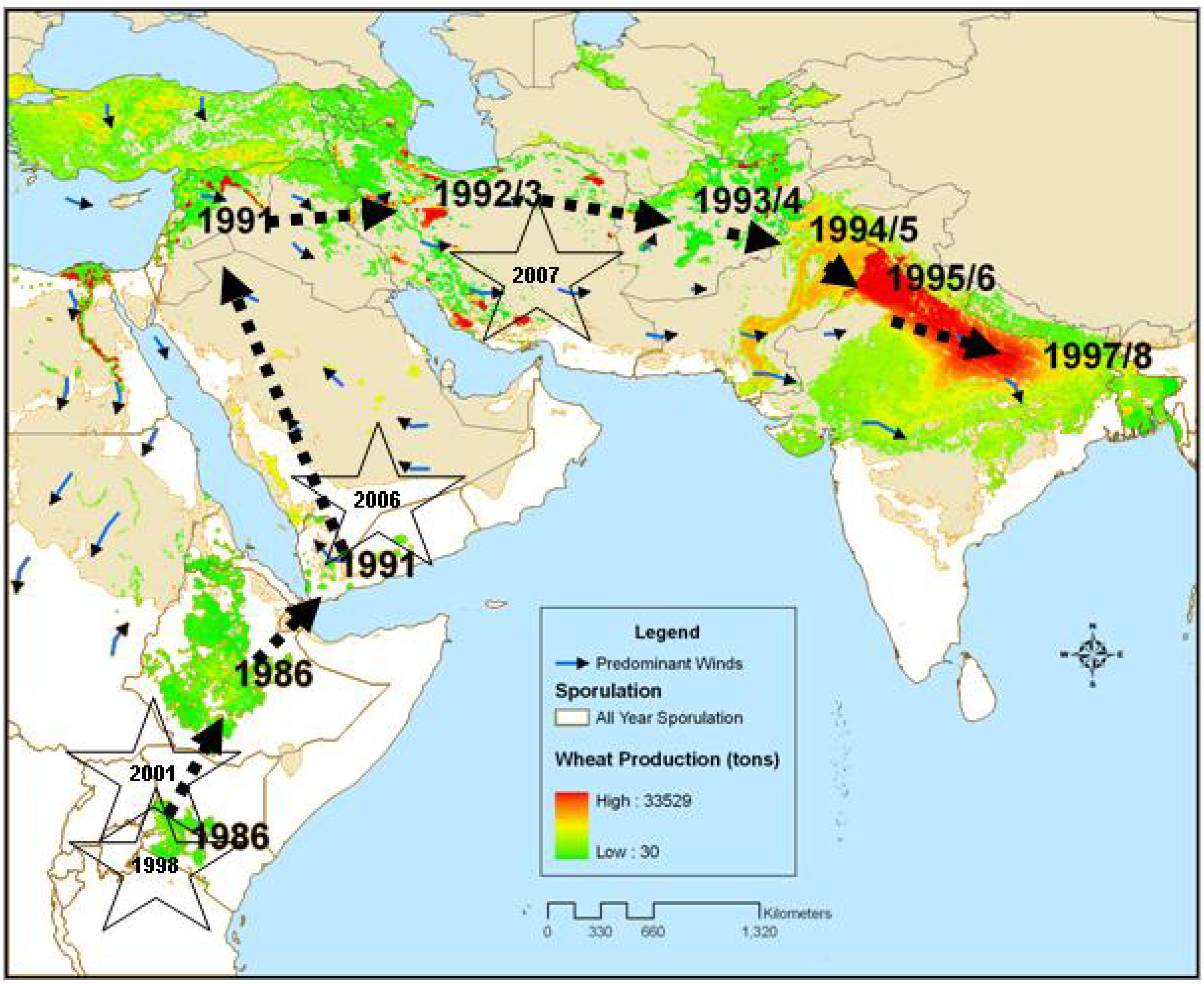

Fig. 1. Historic migration of *Yr9* virulent race of stripe rust from Africa to South Asia and yearly distribution of the stem rust pathogen race *Ug99*. Dotted arrows indicate movement of *Yr9* while star represents *Ug99*

as mentioned above has reported to cross the Arabian Gulf in the 2006 crop season [8]. It is noteworthy that the *Yr9* virulent stripe rust race took five years to achieve this crossing. Once the pathogen spore has entered the Arabian Peninsula, it would get suitable over-wintering conditions. In this geography, the year-round conditions are highly suitable for pathogen sporulation - the average temperature range is 5-40°C [4] in combination with high relative humidity (>60% round the year). During November to February, when there is main wheat season, prevailing airflows are expected to carry spores up the Arabian peninsula only to encounter a west-east airflow around the Mediterranean basin, that would move spores through the wheat belt of the Middle East and into the bread baskets of South Asia [8].

Epidemiology of stem rust in Indian Subcontinent

It is worthwhile explaining the epidemiology of wheat rusts especially the stem rust. Wheat rusts have remained dominant pathogens of the wheat crop in India. Mehta [22], a pioneer Indian wheat rust epidemiologist, worked out the dissemination of wheat rusts. He established that *Barberis* spp. occurring in the hills of India do not have any role to play in the annual recurrence of rusts in India. He regarded central Nepal and Nilgiris as the most dangerous foci of infection for stem rust. Early appearance of stem rust was also recorded in Dharwad (Karnatka) in South of the country. Dissemination of stem rust, according to him occurred mainly from these sources. Gokhale and Patel [23] corroborated these findings while systematically mapping the movement of black rust from South to the North from Dharwad to Gujarat. This seemed true for the entire country. Later, no additional information was added to these findings till the work on mobile survey data was documented. Based on time of appearance of stem rust in different parts of the country [24] it was elaborated that stem rust gets established in normal sown crop either in the neighbouring plains of Nilgiris or central India depending on the mode of transportation of inoculum. Earlier, Nagarajan [25] described that the urediospores of *P. graminis tritici* survive all through the year in the Nilgiri hills of South India. From here the urediospores dispersion to central and North India occurs during November under the influence of tropical cyclones. The defined dispersal route from South to North is called the "*Puccinia* Path" of India. Unlike "Path America", the spread from the Nilgiris to neighbouring states, which have the favourable weather conditions for development of stem rust, is an independent event and there is no feed back of inoculum to the Nilgiris. However, studies conducted on disease gradient in North India indicated that the low temperature not being congenial for stem rust development, was responsible for development consequently poor occurrence and spread of stem rust [26]. It was intriguing to us as a wide range of environmental conditions exist within this zone of the country, which is likely to favour the development of stem rust. For example, temperature would be low in Amritsar of Punjab but would certainly be high for South Haryana, and South and East of Rajasthan. According to Joshi [24], the instances of late appearance of stem rust in the North was considered insignificant as it would not lead to any yield loss.

The authors would like to share some of the observations listed below to corroborate their viewpoints. The introduction of photo-insensitive, semi-dwarf and high yielding varieties during green revolution in India also brought with them the resistance to stem rust. In recent years, the reports of stem rust occurrences are rare. Therefore, it is the resistance against stem rust which has led to gradual decrease in inoculum of stem rust. Interestingly, these days even the hot spot areas of stem rust do not get any infection on the susceptible cultivars as a majority of the area is under resistant cultivars. The adjoining country Bangladesh, though has very favourable weather conditions for stem rust, has also not reported its significant incidence due to the cultivation of resistant cultivars. When Mehta established epidemiology in the 1950s, wheat was largely sown under dry conditions without irrigations and with limited use of fertilizers. The wheat areas in the northwestern

Table 1. Area of wheat in the North West and North Eastern Plains, the two largest zones of India, during the post Green Revolution period 1965-2006

Year	Area (m ha) in the two zones		Area (m ha)
	NWPZ	NEPZ	
1965	4.5	4.7	9.2
1970	4.5	6.9	11.4
1975	4.5	7.8	12.3
1980	7.5	7.7	15.2
1985	9.5	6.7	16.2
1990	9.5	6.6	16.1
1995	9.5	8.1	17.6
2000	9.5	9.3	18.8
2005	9.5	9.0	18.5
2006	9.5	8.9	18.4

Source: Reports/bulletins issued from Indian Council of Agricultural Research over the period 1965-2007.

and northeastern plain zones were also limited (Table 1). The area and productivity of wheat in the 1970s increased dramatically with the introduction of early maturing, rust resistant semi-dwarf wheats (Sonalika and Siete Cerros = Kalyansona "S") and due to irrigation and fertilizer use. Wheat is now grown in much diverse ecology in India and neighbouring countries than in the 1950s or 1960s. The cultivation of stem rust resistant cultivars for the last few decades has removed an important factor in the epidemiology in the region - the removal of susceptible host during the crop season for rust to multiply at exponential rates to cause epidemics, and survive during the off-season at significant levels. This can change within a few years once Ug99 reaches India as it will find susceptible volunteer wheat plants in the plains where water is available for growing summer crops or in the hilly areas.

Emergence of Ug99 in Kenyan highlands illustrated that stem rust pathogen can survive and multiply at low temperatures as well (variation exists among isolates of *Puccinia striiformis* for response to temperature) [27]. The temperature optima for both leaf and stem rusts overlap (11-26 ^{0}C for leaf rust and 15-24^{0}C for stem rust), thereby indicating that these temperatures are likely to favour stem rust as well. Significantly, a healthy looking crop when gets infected few weeks prior to harvesting can lead to heavy losses. Therefore, even though stem rust may appear late in the crop season in the North, it would still be advisable to take measures to meet the challenges posed by Ug99. These findings by earlier workers were very crucial and useful for the wheat rust management in those days. However, the situation has now changed a lot and some of these findings must be revisited in order to strengthen the wheat rust management, especially in view of emergence of Ug99. The regions which have not been affected by stem rust infection be at risk and hence, there is a need to concentrate on developing rust resistant varieties.

Strategies to mitigate the risks of losses from epidemics caused by race Ug99

The best control strategy shall be to identify and deploy resistant wheat genotypes that can prove suitable for the prevalent environments in the countries expected to be affected by Ug99. The performance of wheat genotypes from the four South Asian countries observed during 2006 and 2007 in Kenya revealed that the most of the varieties under test were susceptible to race Ug99 (Table 2). An aggressive strategy to promote resistant cultivars in farmers' fields through large scale quality seed production is the only viable option as resource poor farmers in most of East Africa and South Asia can not afford to use chemical control. Many of the varieties identified as resistant in the year 2005 and 2006 were resistant due to presence of *Sr24* which is linked to *Lr24*. Although, virulence for *Sr24* was reported in India [28], the detection of a new virulent race TTKST at Kenya has demonstrated the limitation of this strategy [4, 7]. Currently, the major attention is being given to identification and promotion of resistant genotypes in Africa, since any reduction in disease pressure in East Africa will also reduce chances of migration beyond the region [4].

Table 2. Performance of wheat cultivars and advanced breeding lines of South Asian nations including India for their field response to Ug99 race of the stem rust pathogen at Njoro, Kenya during 2006 and 2007

Country	Response and frequency			Total
	Resistant[1]	Moderately resistant[2]	Moderately sus. & susceptible[3]	
		Year 2006		
Bangladesh	0	3	81	84
India	16	7	79	102
Nepal	1	1	103	105
Pakistan	0	6	99	105
Total	17	17	362	396
		Year 2007		
Bangladesh	4	5	32	41
India	0	0	0	0
Nepal	0	5	50	55
Pakistan	3	18	84	105
Total	7	28	166	201
Total of two years 2006; 2007	24	45	528	597

[1]Disease severity up to 20% based on modified Cobb Scale (49) and small to intermediate sized uredinia with necrosis or chlorosis (35).
[2]Disease severity between 15-30% disease severities and medium to large uredinia with or without chlorosis and necrosis.
[3]Disease severity between 40-100% disease severity and medium to large uredinia without chlorosis and necrosis.

The effective resistance genes

Various reports [8, 29] indicate the presence of effective genes for resistance from different sources (Table 3). Among the effective genes, *Sr22, Sr24, Sr26, Sr29* and

Table 3. The known *Sr* genes displaying their effectiveness against seedling and/or adult plant resistance to Ug99 race of stem rust pathogen *Puccinia graminis* f. sp. *tritici*.

Sources	No. of genes known	Stem rust resistance (Sr) genes	
		Ineffective	Effective
Triticum aestivum	22	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
Triticum turgidum	9	9d, 9e, 9g, 11, 12, 17	2[2], 13[1,2], 14[1]
Triticum monococcum	3	21	22, 35
Triticum timopheevi	2	-	37
Triticum speltoides	2	-	32, 39
Triticum tauschii	2	-	33[2], 45
Triticum comosum	1	*34*	-
Triticum ventricosum	1	*38*	-
Triticum araraticum	1	-	40
Thinopyrum elongatum	4	-	25, 26, 43
Thinopyrum intermedium	1	-	44
Secale cereale	3	*31*	27[1], 1A.1R
Total	51	-	-

[1]Virulence known in other races; [2]Field resistance not considered satisfactory

SrTmp may have some immediate value. The triticales which often carry *Sr27* or *SrSatu* also proved highly resistant in the field at Njoro. About 10% of the current wheat germplasm tested in Kenya during 2005 showed high to acceptable levels (up to 15% severity) of resistance. A large portion of the highly resistant germplasm from South America, Australia and CIMMYT possess *Sr24*. This gene which is also present in some Indian wheat cultivars [30, 31] varieties has been transferred through *Thinopyrum elongatum* translocation on chromosome 3DL where the leaf rust resistance gene *Lr24* is also present. Since *Sr24* is linked to *Lr24*, resistance against Ug99 can also be introduced using indirect selection for *Lr24*. However, since the virulence to *Sr24* was already known in South Africa and India and a new variant of Ug99 detected in 2006 in Kenya reduces the usefulness of this gene.

Another stem rust resistance gene (*Sr25*) is also present on *Thinopyrum elongatum* translocation together with leaf rust resistance gene *Lr19* on chromosome 7DL. This gene is known to increase the yield potential [32, 33]. However, it was not used widely because it is linked to a gene associated with accumulation of undesirable levels of yellow pigment. A white floured mutant of the translocation, developed by Knott [34], was transferred into some Australian and CIMMYT wheat backgrounds and the mutant devoid of the genes(s) characterizing yellow pigment has been transferred in to commercially grown Indian wheats [31]. The gene *Sr25* conferred high level of resistance only in some genetic backgrounds, especially when the slow rusting adult plant resistance gene *Sr2* was also present, e.g. lines 'Super Seri#1' (yellow flour) and 'Wheatear' (white flour). Till recently, the virulence to *Sr25* was not known, however, a weak virulence has been identified in India during 2008, which needs [Unpublished data] to be confirmed.

A third gene (*Sr26*) of *Agropyron elongatum* (*Thinopyrum elongatum = Lophopyrum elongatum*) origin that was translocated to chromosome 6AL, has been used successfully in Australia and remains effective despite its large scale deployment in 1980s. It is not known to be present in cultivars from India and other countries and the translocation used initially may have yield penalty [35]. Shorter translocations have been developed by I. Dundas in Australia and could be better sources than the available ones [4]. The gene *Sr27* originating from rye (*Secale cereale* L.) has not been used in wheat improvement. Its deployment in Triticale in Australia resulted in a rapid evolution of virulence [36]. This gene has also become ineffective in South Africa and it has been suggested that this gene should be left for triticale improvement in areas where virulence is not known [8]. Till recently, gene *Sr36*, derived from *Triticum timopheevi*, exhibited immunity to the race Ug99 at both seedling and adult plant stages [4]. However, recently the lines carrying this gene displayed susceptibility to stem rust suggesting that Ug99 race has evolved further, which was confirmed later [4].

Genes, *Sr29*, *Sr32, Sr33, Sr35, Sr37, Sr39, Sr40* and *Sr44* have not been tested widely for their effectiveness to other races and are also not being used in breeding. Gene *SrTmp* from 'Triumph' is present in some US wheat cultivars and can be used in breeding. Some of the new high yielding CIMMYT wheats with resistance to Ug99 are likely to carry this gene. An additional unnamed resistance gene located in rye chromosome translocation 1A.1R and different from *Sr31*, is present in some US winter wheats such as TAM200, can also be used [4]. The translocation 1A.1R is also present in a CIMMYT spring wheat line TAM200/ Tui. Both TAM200 and TAM200/Tui also possess *Sr24* gene, and hence, care should be taken while selecting for 1A:1R translocation. Certain hexaploid synthetic wheat derived advanced lines and some lines derived from Chinese cultivars such as Shanghai#7 have also shown high level of resistance. However, the genetic basis of resistance is not known.

Durable resistance against Ug99

It is advisable to introduce durable resistance in current cultivars and recent wheat germplasm as a long term strategy. At present little is known on the genes involved in durable resistance. However, earlier work done by Knott [37] and knowledge on durable resistance to leaf and stripe rusts [38] indicate that such resistance involves multiple minor genes with additive effects. Accumulating such complex resistance in the absence of disease pressure caused by Ug99 race and lack of molecular markers will not be an easy task.

The *Sr2* gene, which is regarded as one of the most important stem rust resistance genes to be deployed in modern wheat disease management, is reported to provide durable resistance to stem rust [38]. The gene *Sr2* was transferred from *Triticum turgidum* L. sp. *dicoccum* Schrank ex. Schübler (cv. Yaroslav) into hexaploid wheat by McFadden [39] producing the variety Hope. Hare and McIntosh [40] determined that stem rust resistance in Hope was largely controlled by a single gene located on the short arm of chromosome 3B. The cultivar Hope was used in Mexico during the 1940s as the donor for developing the stem rust resistant wheat cultivar Yaqui 50 [41]. Since then, the *Sr2* gene has been employed widely by CIMMYT's global wheat improvement program in Mexico and spread to many wheat production regions of the world. The gene has provided durable, broad-spectrum rust resistance effective against all isolates of *P. graminis* worldwide for more than 50 years. On the basis of its past performance, *Sr2* has been described as one of the most important disease resistance genes deployed in modern plant breeding [38]. This gene is present in over 60% of the most recent CIMMYT's spring wheat germplasm including some of the most high-yielding recent genotypes that have high level of resistance to leaf and stripe rusts, and good industrial quality. In India too about 47% of wheat genotypes were identified to possess *Sr2* [42]. *Sr2* is a slow rusting resistance gene and confers only moderate levels of resistance, when present alone [40]. However, in combination with other minor genes, it provides high level of resistance. *Sr2* is associated with chlorophyll loss on ears through brown necrosis and causes pseudo black chaff, *Pbc* [40, 43] which is prominently expressed in favourable environments. Therefore, its presence can be easily detected in breeding programs. Although, disease screening of *Sr2* carrying lines at Kenya has displayed a maximum severity of about 60%, it is considered significantly lower than other susceptible lines that display 100% severity. The gene *Sr2* was detected in several highly resistant old, tall Kenyan cultivars, including Kenya Plume [44], and CIMMYT-bred cultivars Sonalika (a cultivar associated with the Green Revolution in South Asia) and Pavon 76. Both Sonalika and Pavon 76 were resistant during 2004 and 2005 with maximum disease score of 15MR. Because Pavon 76 is susceptible at seedling stage with race Ug99, its resistance as speculated earlier [45] is based on the multiple additive genes where *Sr2* is an important component. US wheat cultivar Chris, which is not known to carry *Sr2* but possesses *Sr7a* [46] also displayed high level of resistance and hence its adult plant resistance may involve interaction of moderately effective gene *Sr7a* and other unknown adult plant resistance genes. High level of resistance in the variety Selkirk may involve interactions of moderately effective genes *Sr2* and *Sr23* (linked to leaf rust resistance gene *Lr16*) and perhaps additional unknown adult plant resistance genes. These observations, although need validation through genetic analyses, indicate that complex resistance to stem rust present in some tall as well as some semidwarf cultivars developed in the 1960s and 1970s continues to remain effective.

Breeding approaches for resistance to Puccinia graminis tritici race Ug99

For any breeding strategy, genetic analyses is necessary to understand the number and type of resistance genes involved in sources contributing the adult plant resistance. Genomic locations of effective genes for resistance having additive effects are also supposed to be determined through molecular analysis. The best breeding approach to incorporate acceptable level of resistance in high yielding background of wheat is believed to be the use of limited or repeated back crossing [47]. Since, most of the genes for resistance are of alien origin and have been tagged with molecular markers [48, 49], these can be helpful in marker assisted selection. Where the alien stem rust resistance genes are linked to leaf rust resistance genes, screening for leaf rust in seedlings or adult plants can also be practiced.

The strategy should also be to use race-specific resistance genes not alone but in combinations [4]. However, it may be difficult to combine more than two translocations in a single genotype as their negative impact on yield and quality parameters can be quite large [8]. If two resistance genes are to be incorporated, a three way cross strategy needs to be followed keeping adapted cultivar as the third parent. It is desirable to use large population size for increasing the chances of transgressive segregants. Molecular markers can be used in segregating generations to select superior segregants for resistance in the background of desired agronomic performance. Limited back crossing can also be followed to restore the characteristics of the recurrent parent.

Research initiative taken by India to meet the threat of Ug99

The Indian wheat programme has already initiated activities in collaboration with CIMMYT, to identify and develop suitable resistant cultivars for rapid deployment in its different wheat zones before *Ug99* arrives. A set of 19 Indian wheat varieties and 3 genetic stocks were screened under natural outbreak of *Ug99* at Njoro (Nakuru), Kenya in the summer nursery 2005. One variety HW 1085 (developed by IARI Regional station, Wellington for South Hill zone) and three genetic stocks, namely, FLW 2, FLW 6 and FLW 8 were found resistant. These three genetic stocks FLW 2 (PBW 343 + *Sr24*), FLW 6 (HP 1633 + *Sr24*) and FLW 8 (HI 1077 + *Sr25*) were developed at DWR Regional Station, Shimla, India. As mentioned earlier, detection of a new variant of Ug99 in 2006 in Kenya reduces the usefulness of the gene *Sr24*. However, it has been still remained effective against Ug99. The alien segment carrying *Sr25*/*Lr19* has been transferred into several Indian wheat cultivars. These newly developed back cross lines also carry the *T. timopheevi* derived resistance to stem rust (*Sr36*) and powdery mildew (*Pm6*). Similarly, the gene *Sr26* has been bred into WH 147 and NI 5439, the popular cultivars of central and peninsular zones, respectively [50]. Both these zones are prone to stem rust infection. The utilization of other effective genes against Ug99 as listed in Table 2 is advocated in wheat breeding programme. Some of these genes such as *Sr13, Sr14* and *Sr37* (moderately effective), and *Sr27* (highly effective) exhibits resistance to wide spectrum of Indian stem rust races [51, 52]. In the year 2006, another set of 102 Indian lines along with lines from other neighbouring countries (Nepal, Pakistan and Bangladesh) were screened at Kenya for resistance. The performance of these lines suggests presence of satisfactorily levels of resistance in Indian lines (Table 4). Some of the released varieties that showed satisfactory level of resistance were GW273, GW322, HD2781, HI1500, MP4010, HI8498, MACS2846, HD4672 (Table 4). The cultivars UP2338 and HUW510 (both may be backcrossed lines [31]) that carry *Sr24,* showed acceptable level of resistance in the year 2005 but lost usefulness next year due to the detection of a virulence on this gene. However, the gene postulation report [53] indicating the presence of *Sr2* in these cultivars, still value their importance. Likewise, based on pedigree details the lines HI 1500, HW 1085 and HD 2781 also seem to carry *Sr24*. Since these lines were not tested in the year 2007 when *Sr24* virulent variant of Ug99 caused an epidemic there, these lines need to be retested for their resistance.

Although the varieties covering major area in India *viz*., PBW 343-7 m ha, HUW 234-2 m ha, Lok 1- 2 m ha [11] are susceptible to Ug99, the varieties found resistant occupy less than 1 m ha i.e., around 3% of the total wheat area of our country. Therefore, there is big challenge to increase good quality seed of these varieties before Ug99 struck our country that is expected to be in next three years. There is urgent need to plan rapid seed multiplication of resistant varieties and their subsequent dissemination in the farmer's fields through national net work. The superiority of some of the *Ug99* resistant lines *viz*., Waxwing/Kiritati has already been established through Elite Bread Wheat Yield Trials (EBWYTs) tested across many locations of South Asia [4] and the best lines have been included in the All India Wheat Coordinated Trial organized by Indian Council of Agricultural Research. Likewise, there is need to promote durum wheat cultivars (HI8498, MACS2846, HD4672) in the central and peninsular zones that showed good to moderate resistance against Ug99. Based on the

Table 4. List of Indian wheat cultivars displaying acceptable level of resistance in testing against *Ug99* race of the stem rust pathogen at Njoro, Kenya during two years of testing (2005-06)

Wheat species	Pedigree	Max. score	Resistance	Year of release	Zone of release	Approx. area covered (m ha)
T. aestivum						
HW 1085	HW 2002A/CPAN 3057	10 MS	Moderately Resistant	1998	Southern Hill	<0.01
GW 273	CPAN 2084/VW 205	30 MSS	Moderately Resistant	1998	Central	<0.1
GW 322	PBW 173/GW 196	20 M	Moderately Resistant	2002	Central & Peninsular	<0.1
HD 2781	BOW/C 306//C 591/HW 2004	10 RMR	Highly Resistant	2002	Peninsular	<0.01
HI 1500	HW 2002*2//STREMPALLI/PNC 5	10 RMR	Highly Resistant	2003	Central	<0.01
MP 4010	Angostura 88	5 R	Highly Resistant	2003	Central	<0.01
T. durum						
HI 8498	CR"S'-GS'S'/A-9-30-1//RAJ 911	10-15 RMR	Resistant	1999	Central	<0.01
MACS 2846	CPAN 6079/ MACS 2340	20 RMR	Resistant	1998	Peninsular	<0.1
HD 4672	BIJAGA RED/PBW 34//ALTAR 84	20 MS	Moderately Resistant	2000	Central	<0.01

studies conducted so far, rust resistance in durum wheat seems to be conditioned by genes different from the known ones, and hence, can provide the much needed diversity in gene deployment, reducing the vulnerability to new virulence(s). It is most likely that *Ug99* might evolve in Iran in view of a functional alternate host. Hence, it will also be useful if Indian wheat material is screened for stem rust resistance in Iran as well.

The opinion held by various plant breeders and the plant pathologists that the new stem rust race *Ug99* is a serious threat to India and the global wheat production. Its emergence suggests that there is no room for complacency in our research efforts directed towards a major food crop like wheat which is already under pressure. If not checked through effective research, *Ug99* may become another cause of food shortage in most of the affected countries including India. Replacement of currently popular susceptible cultivars in these areas with high yielding resistant cultivars is the best strategy to protect wheat from the likely-hood of a menace of *Ug99*. This will require a concerted effort involving scientists, planners, progressive farmers and extension agencies associated with governmental and nongovernmental organizations. Genetic studies also need to be initiated on exploring the diversity for resistance to *Ug99* and its variants among Indian lines, utilizing the international collaboration.

Summary

A highly virulent race of stem rust of wheat caused by *Puccinia graminis* Pers. f.sp. *tritici* Errikss. & Henn. was detected in 1999 in Uganda and may pose a major threat to wheat crop in many countries including India in coming years. This race is commonly known as *Ug99* and designated as TTKSK based on North American system of nomenclature. The race *Ug99* carries virulence to several genes commonly present in global wheat germplasm including *Sr31*, known to be present in several leading spring and winter wheat cultivars and germplasm. Emergence of a new variant TTKST that overcame resistance of *Sr24* gene causing severe stem rust epidemic in Kenya has further aggravated the threat. The occurrence of Ug99 is now widespread in wheat growing areas of Kenya and Ethiopia and has rendered many popular cultivars susceptible. It crossed the red sea to Yemen and migrated to Sudan in 2006, and its presence was confirmed in Iran in 2007. Therefore, development and dissemination of suitable resistant cultivars in a relatively short time before rust migrates to South Asia is of utmost importance for food security. Indian wheat programme in collaboration with CIMMYT and Kenya has identified some wheat cultivars and genetic stocks that are resistant to *Ug99*. However, area coverage to these resistant cultivars must increase to occupy about 3-5% of the total area for enough seed procurement to replace the current popular susceptible cultivars, when *Ug99* reaches Indian Subcontinent. Although, several alien genes can provide resistance, the long-term strategy should focus on achieving durable resistance by rebuilding the *Sr2* complex.

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