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Delivering rust resistant wheat to farmers: a step towards increased food security

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Abstract An important step towards reducing the vulnerability of wheat in Africa and Asia to the Ug99 race of the stem rust pathogen is the substitution of current susceptible varieties with superior resistant varieties. In the 2008–2009 cropping season both seed multiplication and dissemination of Ug99 resistant varieties were initiated in Afghanistan, Bangladesh, Egypt, Ethiopia, Iran, India, Nepal and Pakistan. Ug99 resistant varieties must occupy about 5% of the area sown to wheat in each country to ensure sufficient seed to displace current popular varieties. Because of the underdeveloped seed industry and small farm sizes in most of these countries, various strategies are being applied for rapid multiplication and dissemination of resistant varieties. Approaches being used include pre-release seed multiplication while candidate resistant lines are being tested in national evaluation trials and farmer participatory selection. Resistant varieties are already released in Afghanistan, Bangladesh, Egypt and Pakistan and more varieties are expected to be released in 2010 in these and other countries. Our

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results show that some new Ug99 resistant lines have yield superiority over dominant local varieties. Activities and progress in seed multiplication using existing and new Ug99 resistant varieties are discussed.

Keywords *Puccinia graminis* f. sp. *tritici* · Farmer participation · Seed distribution systems · Stem rust · *Triticum aestivum* · Participatory varietal selection · Ug99

Introduction

Wheat is one of the most important food staples for mankind. It is cultivated on 15.4% of the arable land in the world and in almost all countries, except the humid and high-temperature areas in the tropics and high-latitude environments, where fewer than 90 frost-free days are available for crop growth (Singh and Trethowan 2007). Wheat is the primary source of calories for millions of people worldwide, accounting for around 30% of global grain production and 44% of cereals used as food, of which 18% is traded internationally (FAOSTAT 2009). Globally, approximately 220 mha of land is sown to wheat each year, producing about 600 mt (FAOSTAT 2009), with nearly half of this area and production attributed to developing countries (Singh and Trethowan 2007). In addition, developing countries consume most of the wheat sold on the export market (Aquino et al. 2002), reflecting the huge numbers of consumers in these countries. In some countries, such as those in North Africa, per capita consumption of wheat is as high as 240 kg per annum (FAO 2002). Wheat provides nearly 55% of the carbohydrates and 20% of the food calories consumed globally.

Wheat currently faces a serious threat from stem rust, caused by *Puccinia graminis* f. sp. *tritici*, in particular race Ug99 and its derivatives (Pretorius et al. 2000; BGRI 2009). Ug99 was first identified in Uganda in 1999 and has since spread to other countries in East Africa and to Sudan, Yemen and Iran (Singh et al. 2008; IAEA 2009). Given favorable conditions, it threatens to spread to other wheat-producing regions of Africa and Asia, and potentially the entire world (BGRI 2009). The threat is particularly acute in South Asia, which produces 20% of the world's wheat for a population of 1.4 billion people (Joshi et al. 2009; BGRI 2009).

The threat of Ug99, initially in Kenya and Ethiopia, led to the launch of the global rust initiative (GRI) in 2005, later renamed the Borlaug global rust initiative (BGRI). The foremost objectives of the BGRI are to systematically reduce the world's vulnerability to wheat rusts, facilitate the development of a sustainable international system to contain the threat of wheat rusts, and to continue enhancements in productivity required to withstand future global threats to wheat production (BGRI 2009).

Mitigating the Ug99 threat through growing resistant varieties

It was estimated that poverty in less developed countries is reduced by 0.5–1.0% with every 1% increase in wheat production (World Bank 2005). Gains may come directly from increasing yields or by reducing yield losses through the use of disease resistant cultivars. The best control strategy for most diseases of wheat grown by resource-poor farmers in the developing world, and the most environmentally friendly and profitable strategy for commercial farmers everywhere, is to grow resistant varieties (Singh et al. 2008). It has been suggested that the direct costs of rust resistance in wheat to farmers in developing countries are presently close to zero because this cost is already embedded in the seed (Dubin and Brennan 2009). Currently, the cost of protecting 1 ha of wheat from epidemics through the application of modern chemicals can range from US $10–80/ha. For example, Murray and Brennan (2009) estimated the cost of fungicides for foliar cereal disease control in Australia in 2008 to be approximately US $8/ha, plus the cost of application. Therefore, an aggressive strategy to promote the use of resistant varieties in farmers' fields through large-scale quality seed production is the only viable and effective option for combating rust epidemics because chemical control is not affordable for resource-poor farmers in much of East Africa and South Asia (Joshi et al. 2008; Singh et al. 2008). As a means of addressing the threat of Ug99, Osborn and Bishaw (2009) outlined strategies for fast-tracking the release and rapid seed multiplication of new wheat varieties.

United States agency for international development (USAID) seed multiplication initiative in countries under threat from Ug99

Seed is the major mechanism for delivering agricultural-based technologies to farmers and therefore plays a critical role in realizing the benefits of agricultural research at the farm level. Given there is an essential link between crop improvement and seed supply, ensuring availability and easy access to quality seed should accelerate the delivery, dissemination and adoption of new varieties by farming communities. The promotion of varieties with different resistance genes will enhance genetic diversity in farmers' fields and reduce the risk of pandemics.

Many national programs have initiated collaborations with the International Maize and Wheat Improvement Center (CIMMYT), the International Center for Agricultural Research in the Dry Areas (ICARDA) and BGRI to identify and develop suitable resistant cultivars for use in different wheat regions before Ug99 becomes established. Many varieties and genetic stocks from Bangladesh, Egypt, India, Iran, Nepal, Pakistan and other countries were previously screened against Ug99 and its derivatives in Kenya and Ethiopia and a low frequency of existing varieties and breeding materials were found to carry adequate or high levels of resistance.

To mitigate the threat of Ug99 and other wheat rusts, a seed multiplication project supported by USAID Famine Funds was implemented in Afghanistan, Bangladesh, Egypt, Ethiopia and Nepal. The objective was to have sufficient seed of resistant lines to plant at least 5% of the total wheat areas by 2011. In addition, countries such as Iran, India and Kenya are also engaged in the identification and multiplication of resistant lines. The major activities under this initiative being implemented jointly by the national wheat programs, CIMMYT, ICARDA and BGRI are: (1) identification of suitable Ug99 resistant varieties and their pre- and post-release seed production; and (2) delivery of seed to farmers to ensure its rapid dissemination.

The infrastructures for producing seed and the strengths of the seed sectors in the six different countries are highly variable. Egypt and Pakistan have the strongest seed sectors whereas Nepal and Afghanistan are among the weakest. Consequently, the project was customized to fit the capacity and needs of each country. In countries with strong public and/or private seed sectors, such as Egypt and Pakistan, seed multiplication is through the established seed industry, whereas in Nepal, participatory varietal selection (PVS) is considered to be the best approach to achieve results. The services of emerging small scale seed companies in Nepal are also being used. In Afghanistan, seed is being produced through farmer-based seed production and marketing enterprises supported by FAO. In Ethiopia and Bangladesh, seed multiplication engages the existing public sector institutions, state farms and farmer-based seed production schemes on a regional basis.

Progress in seed production in 2008–2009 under the USAID project and future projections

In 2008–2009, 11 Ug99 resistant wheat genotypes from CIMMYT, Mexico, were deployed for seed production and further evaluation in the above six countries (Table 1). These lines were chosen following selection for resistance in Kenya and assessment in the CIMMYT nursery system. Several lines in this nursery out-yielded the checks by 5–15% in multi-location trials (Singh et al. 2008).

The lines undergoing seed multiplication (Table 1) were also evaluated in multisite national trials. The usual process is that large-scale seed multiplication starts with the release of a cultivar. However, in this project seed multiplication starts much earlier to ensure that at the time of release large quantities of seed will be available for distribution to farmers. This approach carries the risk that some lines will be dropped from the program, even though large seed quantities were produced. Because the highest priority is to replace current Ug99 susceptible varieties as quickly as possible, parallel final stage multi-location testing and seed multiplication will permit earlier large-scale delivery of new varieties to farmers.

The area planted and seed production of Ug99 resistant lines varied across countries in 2008–2009 (Table 2). The total area sown across the six countries was 52.6 ha and produced around 156 t. The maximum area (21 ha) and production (81 t) was in Egypt. In addition to these countries, a large quantity of seed of resistant varieties was produced in Iran (Table 3; 80,000 t), where Ug99 is already present.

Table 1 Seed of Ug99 resistant wheat lines provided from CIMMYT Mexico in November 2008, to six countries for seed multiplication during the 2008–2009 crop cycle

CIMMYT name	Countries and seed quantity (kg)						Total
	Nepal	Bangladesh	Afghanistan	Egypt	Ethiopia	Pakistan	
Danphe#1	100	–	–	–	100	–	200
Picaflor#1	100	100	50	–	–	–	250
Quaiu#1	–	–	50	–	100	300	450
Quaiu#2	100	100	–	–	–	–	200
Pauraque#1	100	100	–	–	100	–	300
Becard#1	100	–	–	–	–	–	100
Munal#1	100	–	50	–	–	300	450
Francolin#1	100	100	–	–	100	–	300
Chonte#1	–	–	50	25	100	300	475
Chewink#1	–	–	–	25	–	–	25
Grackle#1	–	–	–	25	–	–	25
Total	700	400	200	75	500	900	2775

Overall, large amounts of seed of resistant lines were produced by the seven countries.

As in 2008–2009, large-scale seed production was continued in the current 2009–2010 cycle in all six countries (except Pakistan) and in Iran (Tables 4, 5). The area and expected production in the seven countries (Afghanistan, Bangladesh, Ethiopia, Egypt, Nepal, Pakistan and Iran) is 46,899 ha and 117,364 t (Table 5). However, more than 95% of this production is expected to be contributed by Iran. Other countries are expected to produce about 1,150 t of seed (Table 5). With race Ug99 already present in Iran, well organized seed production is underway. However, the expected seed production in the 2010–2011 cycle portrays a much better picture. It is expected to be in the range of 0.27 to >100% (of the potential seed market) even if only 70% of the seed produced is used for planting (Table 5). It is estimated that relative to national wheat areas, the seed produced will be sufficient to cover from 0.27% of the area in Pakistan to greater than 100% in Iran (Table 5). Only about 30% of the seed produced in 2009–2010 in Iran will be required to cover 100% of its cropping area in 2010–2011. Egypt and Bangladesh should reach their projected targets by the end of the 2010–2011 season allowing them to plant 5–8% of their total wheat areas (Table 5). Assuming that 100% of seed produced in 2009–2010 and 2010–2011 will again be used for seed multiplication, the situation will improve further. The current projected seed production figures suggest that all these countries, except Pakistan, will meet production targets by 2011–2012.

Table 2 Areas planted and seed produced of Ug99 resistant advanced lines during the 2008–2009 crop season in six countries

Country	Area planted (ha)	Seed produced (kg)
Nepal	7.5	18,486
Bangladesh	7.0	12,000
Afghanistan	1.98	9,523
Egypt	21.14	81,166
Ethiopia (summer crop)	5.3	17,550
Pakistan	9.0	23,633
Total	52.62	156,808

Nepal

Nepal produces around 1.3 mt of wheat from 700,000 ha, representing approximately 25% of its total cereal production (FAOSTAT 2009). The main seed dissemination strategy is through PVS (Witcombe et al. 2001; Ortiz Ferrara et al. 2007). Seven Ug99 resistant lines obtained from CIMMYT and a resistant line (BL 3063) developed in Nepal were undergoing seed increase in the 2008–2009 cycle

Table 3 Seed production of Ug99 resistant wheat lines and varieties during the 2008–2009 crop season in Iran

Variety	Pedigree	Distributed certified seed (kg)	Area (ha)	Production (kg)
Kavir	Stm/3/Kal//V543/Jit716 = Sorkhtokhm	4,192,000	22,000	45,000,000
Bam	Vee"S"/Nac//1-66-22[a]	2,095,000	12,000	35,000,000
Misr 1	Oasis/SKauz//4*BCN/3/2*Pastor	2,500	15	20,500
520 (2nd EBWYT)	Babax/LR42//Babax*2/3/Vivitsi	2,500	15	20,600
Munal#1	Waxwing*2/Kiritati	150	1	1,000
Parsi	Dove"S"/Buc"S"//2*Darab	1,500	10	15,000
Sivand	Kauz"S"/Azd	1,500	10	15,000
Arg	1-66-22*/Inia	2,500	15	25,000
Total		6,297,650	34,066	80,097,100

[a] T. aest/6/Ti/4/La/3/Fr//Kal/Gb/5/*2 Gb

(Table 1). BL 3063 (GS348/NL746//NL748) is expected to be released for farmer cultivation in 2010.

Seed production was done by the National Wheat Research Station, Bhairahwa, belonging to the National Agricultural Research Council (NARC), and Kalika Seeds, a private company. The total seed produced was 18,486 kg (Table 2), of which 11,986 kg was purchased using USAID-Famine Seed Project funds for further pre-release seed multiplication in the 2009–2010 cycle. Lines undergoing seed increase in 2009–2010 are shown in Table 4. About 57 ha were sown to achieve a target of 115 t of seed. The estimated seed production of resistant lines in 2010–2011 will be sufficient to meet 7.3% of the effective seed market and 2.4% of the total wheat area of Nepal (Table 5).

Bangladesh

Wheat is the second most important cereal crop in the rice-based cropping systems of Bangladesh. The winter is short and mild compared to more traditional wheat-growing countries. The country produces about 0.84 mt of grain from about 400,000 ha (FAOSTAT 2009) and imports 2–3 mt of grain. Four early maturing Ug99 resistant lines (Picaflor#1, Quaiu#2, Pauraque#1 and Francolin#1) with outstanding performance in the Northeast Gangetic Plains of India (Varanasi), a similar production environment to Bangladesh, were provided. In addition, a newly developed variety, BAW 1064, recently named Bari Gom 26, is also under increase. This variety with CIMMYT lines in its pedigree (ICTAL 123/3/RAWAL 87//VEE/HD 2285), possesses adequate resistance to Ug99 and its variants and has superior agronomic performance compared to current varieties. The area under the five lines was about 7 ha and total seed produced was 12,000 kg (Table 2).

A large-scale seed multiplication of these varieties (Bari Gom 26 on 44 ha, Francolin#1 on 15 ha and Quaiu#2 on 0.8 ha) was undertaken in fields of 135 seed producers during 2009–2010 under the supervision of the Wheat Research Centre (WRC), Dinajpur, Bangladesh and CIMMYT. An estimated 115 t of seed is available for planting in 2010–2011. Source seed production (breeder and foundation) of these varieties is also occurring at the WRC Dinajpur Research Station and is expected to produce enough seed for farmers. The projected production of resistant lines in 2010–2011 is 15.8% of the effective seed market of Bangladesh and 5.3% of the total wheat area (Table 5).

Afghanistan

Wheat is the leading staple food in Afghanistan, accounting for 80% of national cereal production. In contrast to the high per capita wheat consumption (180 kg/person/year), average wheat yields are low (2 t/ha) (FAOSTAT 2009). Wheat is produced under both rainfed and irrigated conditions. One-half of all arable land is classified as rainfed (most of it in the

Table 4 Ug99 resistant wheat varieties under seed increase in seven countries during 2009–2010

Name	*Sr* gene	Countries undertaking seed production						
		Nepal	Bangladesh	Afghanistan	Egypt	Ethiopia	Pakistan	Iran
CIMMYT name								
Danphe#1[a]	APR (*Sr2*+)	√				√		
Picaflor#1[b]	APR (*Sr2*+)	√	√	√		√		
Quaiu#1[c]	*Sr2* + *SrTmp*			√		√		
Quaiu#2	*Sr2* + *SrTmp*	√	√	√				
Pauraque#1	APR (*Sr2* +)	√	√					
Becard#1	APR (*Sr2* +)	√						
Munal#1	APR (*Sr2* +)	√		√		√		√
Francolin#1	APR (*Sr2* +)	√	√					
Chonte#1	APR (*Sr2* +)			√		√		
NARS name								
BL 3063[d]	APR	√						
Bari Gom 26[e]	APR		√					
Misr 1[d, f]	*Sr2* + *Sr25*			√	√			√
Misr 2[g]	*Sr25*				√			
Kavir	Unknown							√
Bam	Unknown							√
Parsi[h]	APR (*Sr2*+)							√
Sivand[h]	Unknown							√
Arg[h]	Unknown							√
2nd EBWYT#20[h, i]	APR							√
Morvarid[j]	Unknown							√
V-04178[k, l]	Unknown						√	
Flag 5[m]	Unknown					√		
Expected seed production (t)		115	150	230	360	133	45	116,215

√Variety under seed production, [a] released in Ethiopia in 2010

[b] released in 2009 in Afghanistan as Baghlan 09 and in Ethiopia in 2010

[c] released in 2009 in Afghanistan as Koshan09

[d] projected for release in 2010

[e] released in 2010

[f] released as Muqawim09 in Afghanistan in 2009

[g] projected for release in 2011 in Egypt

[h] released in 2009 in Iran

[i] HPO/TAN//VEE/3/2*PGO/4/MILAN/5/SSERI1

[j] released in Iran in 2010

[k] released in Pakistan in 2010

[l] seven other resistant varieties are under small plot seed multiplication

[m] released in Ethiopia in 2010

north), but 75–80% of all wheat produced in the country comes from irrigated systems located in various regions. Most of the wheat grown in Afghanistan is fall-sown spring wheat, although there are areas where winter/facultative wheats are grown (15–20% of the wheat area).

Table 5 Area sown and expected seed production of Ug99 resistant wheat lines in the 2009–2010 and 20010–2011 crop cycles, and projected seed production as percentage (%) of national seed market and total national area in seven countries in Asia and Africa

Country	Area (ha) 2009–2010	Expected production (t) 2009–2010	Expected production (t) 2010–2011[a]	National annual seed requirement (t)[b]	National potential wheat seed market (t)	Expected seed production 2010–2011 (% of national wheat seed market)	Expected seed production 2010–2011 (% of national wheat area)
Nepal	57	115	2,013	82,000	27,333	7.36	2.45
Afghanistan	115	230	4,025	240,000	73,000	5.51	1.68
Bangladesh	59	150	2,625	50,000	16,667	15.75	5.25
Ethiopia	72	133	2,328	150,000	50,000	4.66	1.55
Egypt	67	360	10,080	122,700	40,900	24.65	8.22
Pakistan	36	110	2,310	846,000	282,000	0.82	0.27
Iran	46,486	116,215	1,045,935	573,000	286,500	365.07	182.54
Total	46,899.6	117,364	1,069,980	2,063,700	776,400		

[a] Based on projected use of 70% of seed for further multiplication in six countries and 30% in Iran, with a seed multiplication ratio of 1:25 for Nepal, Bangladesh, Afghanistan and Ethiopia, 1:30 for Pakistan and Iran, 1:40 for Egypt

[b] Based on 100–120 kg/ha of seed for national wheat area

In 2008–2009, four advanced CIMMYT lines (Chonte#1, Picaflor#1, Quaiu#1 and Munal#1) were multiplied along with two lines from the 2nd Elite Bread Wheat Yield Trial (EBWYT) (entry 14—OASIS/SKAUZ//4*BCN/3/2*PASTOR and entry 27—HPO/TAN//VEE/3/2*PGO/4/MILAN/5/SSERI) on 2 ha of land (Table 2). The four major research stations used for seed production of the advanced CIMMYT lines were Baghlan, Takhar, Nangarhar and Kunduz and the two 2nd EBWYT lines were also multiplied across five sites. The total seed produced was 9,523 kg (Table 2).

Superior lines identified in 2008–2009 were grown on larger seed production areas in the current 2009–2010 season (Table 4). The estimated production is around 230 t which should multiply to 4,025 t in 2010–2011 assuming average yields of 2.5 t/ha under irrigated management (Table 5). The current supply of seed accounts for only 5% of the total annual requirement of about 236,000 t (Kugbei 2007). Farmers in Afghanistan buy up to 31% of seed requirements from formal and informal sources, and the total effective wheat seed market is estimated to be 73,000 t (Kugbei 2007). Therefore, the estimated wheat seed production of Ug99 resistant lines in 2009–2010 amounts to 0.31% of the seed market, but after 2010–2011 it is projected to reach 5.5% (Table 5). However, the seed produced at the end of the 2010–2011 cycle will be sufficient to cover only 1.7% of the total wheat area.

Egypt

Wheat is the main staple food in Egypt. It contributes to more than 30% of the daily caloric intake and per capita annual consumption (180–200 kg) is among the highest in the world. Owing to high population and high demand for wheat products, Egypt is particularly vulnerable to losses caused by wheat rusts. In 1995 a severe stripe rust epidemic caused 14–26% yield losses (El-Daoudi et al. 1996). Ug99 poses a very significant threat to Egypt because of its extremely high dependence on wheat for food and its proximity to Sudan and Yemen.

In 2008–2009, in addition to the germplasm from CIMMYT, Mexico (Table 1), the Agricultural Research Center (ARC) multiplied six promising Ug99 resistant lines selected from the CIMMYT nursery system. Of these, two advanced lines were released as Misr 1 (Oasis/Skauz//4*Bcn/3/2*Pastor) and Misr 2 (Skauz/Bav 92). Around 10 t of Misr 1 and 7 t of Misr 2 were available for export. Of this, 1.5 t of Misr 1 was exported to Afghanistan for seed production. In 2009–2010, resistant varieties were planted on 67.4 ha with a target of 360 t of seed (Table 5). With current progress (Table 5), Egypt is expected to have seed of rust resistant varieties for around 24.7% of its potential seed market and 8.2% of its wheat area by the end of the 2010–2011 cropping cycle.

Ethiopia

Ethiopia is the second largest wheat producer in Sub-Saharan Africa (after South Africa) with an area of 1.5 mha and annual production of about 2.9 mt. In terms of both area and production wheat is the third (after teff and maize) most important crop. Durum and bread wheat are both important. Currently, durum covers about 40% of the national wheat area (Badebo et al. 2009). About 85% of the durum varieties are landraces adapted to specific areas. The country does not produce enough wheat to satisfy national demand and nearly 1 mt are imported annually, mainly on a concessional basis or as food aid.

Among the biotic constraints, the rusts are recognized as the most economically serious problems in Ethiopia. During the past two decades severe stripe rust and stem rust epidemics have occurred and caused significant yield losses (40–60%). Ug99 and its derivatives are a serious threat to national production and a source of inoculum to neighboring countries. Lines for multiplication were identified based on performance in 2008 multi-locational national trials and stem rust tests in Kenya. Eight Ug99 resistant lines were evaluated in 100 m^2 plots during the 2009 off-season at Kulumsa and Debre Zeit. Five lines (Picaflor#1, Quaiu#2, Munal#1, Danphe#1 and Chonte#1) were from CIMMYT whereas three (Flag 3, Flag 5 and Amir 2) were from ICARDA. In the summer of 2009, 5.3 ha were planted using the best seven varieties (Picaflor#1, Quaiu#2, Munal#1, Danphe#1, Chonte#1, Flag 3 and Amir 2) and 17,550 kg of seed was obtained. In 2010, Picaflor#1 and Danphe#1 were officially released as Kakaba and Danda'a, respectively. Flag 5 was released provisionally. Four durum wheat varieties (Hitosa, Denbi, Werer and Tate) released in the last 2 years are under seed multiplication. Off-season (2010) seed multiplication was conducted on 72 ha and 133 t of seed was produced (Table 5). Based on current progress (Table 5), the country is expected to produce seed of rust resistant varieties for around 4.6% of its potential seed market, but only 1.6% of its wheat area, by the end of 2010–2011.

Pakistan

Pakistan grows approximately 8 mha of wheat, and produces over 19 mt of grain (Chatrath et al. 2007). For the past decade the area sown to wheat has been dominated by the variety Inqalab 91 (Joshi et al. 2007), which is susceptible to Ug99. Because of its proximity to Iran, where Ug99 is already present, the need for resistant varieties in farmers' fields is urgent. Three Ug99 resistant CIMMYT lines (Chonte#1, Quaiu#1 and Munal#1) and three previously selected lines (NR 356, NR 358 and NR 360) obtained from Mexico were grown on about 9 ha in 2008–2009 (Table 2). Seed multiplication was carried out by the national program of Pakistan Agriculture Research Council (PARC) and two private seed enterprises; the Jullundar Seed Company and the Ali Akbar Seed Company. A total of 23,633 kg of seed was produced, two thirds by the Jullundar Seed Company.

Due to the potential threat of a new local stem rust race seed production of CIMMYT lines (Chonte#1, Quaiu#1 and Munal#1) was discontinued. The new race was not UG99, and appeared to be very similar to local types. It was virulent for *SrTmp*, the gene present in Quaiu#1, but its virulence on the other two genotypes is currently unexplained. Therefore seven resistant lines including five new selections from CIMMYT (4th EBWYT No. 503, 508, 519, 529 and 530) were used for seed multiplication on about 1 ha for further increase during 2010–2011. Variety V-04178 (SH88/90A-204//MH97) which is resistant to Ug99 as well as the new local race was provisionally released and is under seed multiplication on 35 ha. Overall, the current production estimates indicate that by the end of the 2010–2011 cycle, seed of resistant varieties will be equivalent to around 0.82% of the potential seed market and 0.27% of the wheat area. With an impressive record for releasing improved wheat varieties, as demonstrated by 11 new varieties in the past 2 years, the seed production target may be significantly exceeded.

Seed production and dissemination in other important major countries

Iran

Iran grows around 6.5 mha of wheat producing 14 mt of grain (FAOSTAT 2009). About 2.6 mha or 40% is irrigated; the remainder is rainfed. The main production areas are concentrated in the northwestern region of the country. Durum is grown on about 0.1 and

0.25 mha under irrigated and rainfed conditions, respectively. Rusts are a major problem, although drought was severe for the past 2 years, probably restricting the spread of Ug99.

In the 2008–2009 cropping season, eight Ug99 resistant varieties were multiplied (Table 3). Most of these lines were of CIMMYT origin or developed locally with at least one parent from CIMMYT. Around 80,000 t of seed were produced, enough for planting around 0.75 mha in 2009–2010. This is clearly an impressive achievement. The country is expected to produce >100% of seed requirements for rust resistant varieties (Tables 4, 5). In addition to these, Iran is also currently pursuing seed production of two new resistant varieties released in 2010. The two varieties are: Behrang (Durum: Zhong Zuo/2*Green-3) and Morvarid (Milan/Sha7).

The excess seed production may have beneficial spillover effects for adjoining countries. Iraq grows CIMMYT-derived varieties that were developed in the 1970s. Hence, any excess seed of new improved varieties could have a very significant impact on Iraq's wheat production. New varieties will likely have a yield potential increase of at least 10–15% over the current varieties. These lines are not only resistant to Ug99 but are also resistant to other major wheat diseases that could affect Iraq's wheat production.

India

India is the second largest wheat producer and consumer in the world with production of approximately 80 mt in 2008–2009, or 12% of world production. The dominant variety in South Asia, PBW343, which occupied about 8 mha in India in 2008–2009, is susceptible to Ug99 (Singh et al. 2008). In 2008–2009 this variety was severely affected by *P. striiformis* f. sp. *tritici* race 78S84 which is virulent to *Yr27*. The area covered by Ug99 resistant varieties in 2007 was estimated to be 0.3% (Singh et al. 2008). The discovery that popular variety HUW234, occupying about 2 mha in the eastern Gangetic Plains (EGP), is heterogeneous for resistance to Ug99 (Joshi et al. 2009), and that LOK 1 (a popular cultivar of central India occupying around 3 mha) is also resistant, raises the area of resistant varieties to about 18%.

Indian wheat cultivars with resistance can be accessed on the website (http://www.dwr.in) of the Directorate of Wheat Research, Indian Council of Agricultural Research. Participatory varietal selection has also made significant impacts in some districts in the EGP by changing the varietal spectrum. The area of HUW234 declined from 4–5 mha in the late 1990s to 2 mha at present (Joshi et al. 2009). However, none of the varieties replacing HUW 234 is resistant to Ug99. In addition to introducing resistant material under the All India Coordinated Wheat Improvement Project (AICWIP) network, they were multiplied in farmers' fields following the PVS approach (Joshi et al. 2009). The newly developed Ug99-resistant lines under seed multiplication in 2009–2010 include Picaflor#1, Pauraque#1, Becard#1, Munal#1, Quaiu#2, Francolin#1 and Danphe#1. These lines were grown on about 300 ha under participatory seed production in 2009–2010 with a targeted production of at least 600 t. The official release of some of these lines in the near future is likely and it is therefore predicted that seed production in the next 3 years will generate enough seed to substantially reduce the threat of Ug99 in the EGP.

Conclusion

Stem rust race Ug99 and its derivatives are serious threats to global wheat production in Asia and Africa. If not addressed through effective research, seed production, and distribution of resistant varieties, Ug99 may become another cause of food shortages in many countries. The best strategy to protect wheat from the menace of Ug99 is replacement of susceptible genotypes with new high yielding and resistant varieties. The consultative group centers (CIMMYT and ICARDA) and BGRI, in collaboration with national research centers from countries under threat, have developed high yielding Ug99 resistant varieties that are now being distributed in the most threatened areas. The objective is to have sufficient seed of resistant lines to plant at least 5% of the entire wheat area by 2011. If achieved, this will be a major step towards food security.

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