Challenges in controlling leaf rust in the Southern Cone region of South America

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Abstract

Leaf rust (caused by *Puccinia triticina*) continues to be the most important and widespread foliar disease of wheat in the Southern Cone. The *P. triticina* population of the region is extremely dynamic, leading to short-lived resistance in commercial cultivars. Some high yielding materials susceptible to leaf rust have been released and their increasing cultivation relies on fungicide applications to control leaf rust. The most important challenge of breeding programs in the Southern Cone is to incorporate durable leaf rust resistance in high yielding cultivars. These cultivars must also combine resistance to other relevant diseases and meet industrial quality standards demanded by the market. Leaf rust resistance in wheat varieties and lines lies mostly in combinations of seedling resistance genes or combinations of these with adult plant resistance (APR), including *Lr34*. Few recently released cultivars carry APR to leaf rust that might be expected to be durable. Since efforts to introduce slow rusting into high yielding adapted germplasm are increasing in most countries, more cultivars carrying this type of resistance will likely be released. If major genes are used, the introduction of effective genes not present in the regional germplasm will increase the diversity of resistance. Molecular markers are used in breeding in Argentina and are starting to be implemented in Brazil and Uruguay. Increased use of molecular tools could improve genetic progress in breeding programs, allow identification of APR genes present in current regional germplasm, and facilitate identification of new resistance genes.

Key words

Breeding for resistance, durable resistance, *Puccinia triticina*

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Introduction

Leaf rust (caused by *Puccinia triticina*) continues to be the most widespread and most important foliar disease of wheat in the Southern Cone. The general situation of the disease was reviewed previously (Germán et al. 2007, 2009) and is updated here. During 2008 and 2009 leaf rust caused moderate epidemics in all countries, but in 2010 epidemics were more intense in Uruguay and in the main wheat areas of Argentina. In the most favorable areas for leaf rust development (Brazil, Paraguay, Uruguay) leaf rust can cause grain yield losses higher than 50% in severe epidemics if fungicides are not applied (Germán et al. 2007).

The widespread occurrence of wheat leaf rust in the eastern epidemiological zone is explained by the use of susceptible cultivars in a significant proportion of the wheat areas of Argentina, Brazil, Paraguay and Uruguay. In Argentina and Uruguay, over 50% of the wheat area in 2010 was planted with moderately susceptible and susceptible cultivars. In Brazil, over 60% of the wheat varieties were susceptible to the leaf rust races present in 2008 and 2009 and the situation was similar in 2010. In Paraguay, the susceptible Brazilian cultivar CD 104, the most widely grown cultivar in Brazil and Paraguay for many years, is losing area in favor of newer less susceptible varieties. In Chile, spring cultivars have adequate levels of resistance, but winter varieties are predominantly susceptible. The release, mostly by private companies, of high yielding susceptible cultivars is becoming more common. These varieties are being introduced from France, or are derived from French breeding materials, and are being adopted by farmers on substantial wheat areas in Argentina and Uruguay.

This paper will provide updated information about the leaf rust situation in the Southern Cone region, economic importance of the disease, changes in the pathogen population, basis of breeding for resistance, resources for research, and the main challenges in breeding for resistance.

Use of fungicides to control leaf rust: an indication of its economic importance

Farmers continue to grow high yielding susceptible cultivars using fungicides. Although farmers in Argentina and Uruguay are discontinuing to plant highly susceptible cultivars that are difficult to manage even with fungicides (requiring more than one application in Argentina and one to two applications in Uruguay), those in Brazil and Paraguay where the disease situation is more complex, continue to grow susceptible cultivars if chemical use allows achievement of high yields, even when requiring three fungicide applications. In Chile farmers demand almost immunity to leaf rust in new cultivars, the same result as with chemical control, although some old susceptible cultivars are still being used with chemical control.

Fungicides are widely used to control the disease complex present in crops, with leaf rust as the main target due to the high area occupied by susceptible cultivars. There are no official estimates of the use of fungicides in wheat. Estimates from several sources indicate that during 2008 and 2009, fungicides were applied on approximately 25% of the Argentine wheat area. During 2010, triazols and mixtures of triazols and strobilurins were used on over 40% of the 4.3 million ha sown with wheat in Argentina, with an average of 1.2 applications. Double applications were required on highly susceptible cultivars in the central area where the leaf rust epidemic was more severe.

An estimated average of 1.0 to 1.5 applications per ha of mixtures of triazols and strobilurins or triazols alone was used on 0.5 million ha of wheat in Uruguay, with the highest estimate under the moderate to severe leaf rust epidemic of 2010. Under these conditions highly susceptible cultivars required two to three applications for control.

In Brazil (2.3 million ha of wheat during 2008-2010) and Paraguay (0.5 millon ha) most of the wheat area uses chemical control (mixtures of triazols and strobilurins). Depending on the year, farmers in these countries apply fungicides once or twice to control leaf rust and other foliar diseases, but the number of applications can increase to three or four applications in the case of highly susceptible varieties such as CD 104.

In Chile, higher yields (average of 5.7 tonnes/ha during the crop season 2009-2010) make fungicides more widely used since their cost represents a lower proportion of production (100 to 150 kg of wheat per ha). Most winter cultivars require at least one fungicide application to control not only leaf rust but also other diseases, allowing attainment of over 10 tonnes/ha. Leaf rust damage is relatively low since leaf rust infections are normally observed in the flag leaf stage and the development is slow during the cool months of October and November.

Puccinia trtiticina population

The *P. triticina* population in the Southern Cone is extremely dynamic, leading to short-lived resistance in commercial cultivars (Germán et al. 2007). The prevalent races change dramatically over time according to the resistance genes present in the commercial cultivars.

Annual surveys and race analysis of the *P. triticina* population are performed in Argentina, Brazil and Uruguay. Information from Chile and Paraguay is more sporadic. Race nomenclature described by Long and Kolmer (1989) is used, with additional virulences to *Lr10* and/or *Lr20* indicated after the Prt code. The pathogen population has remained relatively stable during 2008-2009, with the same predominant races in Argentina and Uruguay. In order of prevalence during 2009, races with more than 5% frequency in Argentina were MDP, MDT-10,20, MCP-10, MFP, MFP-20, MDP-10,20, MFT-10,20, and in Uruguay, MFP, MFP-10,20, MDP, MFP-20, MDP-10,20 and MFT-10,20. Races MDT-10,20 and MFT-10,20 (Brazilian designation B55) have predominated in Brazil since first identification in the latter in 2005. New races MCT and MJP were identified in Argentina during 2009, TPR-20 in Uruguay during 2008 and MFT in 2009. Cultivars BIOINTA 3004, Don Mario Themix and Don Mario Atlax had increased leaf rust infection in Argentina during 2010. In Uruguay the situation was also stable until 2010 when increased infection was observed on cv. Atlax, due to the presence in high frequency of new races TDT-10,20 and TFT-10,20, which were previously detected in Brazil. The widely grown cultivar INIA Carpintero was resistant until 2009 and also had high leaf rust infection during 2010; races contributing to this change are under study.

Changes in the pathogen population also occurred in Paraguay as evidenced by increased leaf rusting on some commercial cultivars. Initially resistant, cv. IAN 10 has shown leaf rust infections up to 80S since 2009. High infections were also observed on cv. Itapúa 45, Itapúa 55 and Itapúa 65. No new races or associated changes in the rust resistances of cultivars were detected in Brazil since 2008, and leaf rust levels on commercial cultivars in Chile have also been stable in recent years.

The same races occur in the eastern epidemiological zone (Argentina, Brazil, Paraguay and Uruguay). Within this region, generally the pathogen populations present in Argentina and Uruguay are very similar (Ordoñez et al. 2010), probably because of the similarity of cultivars planted in both countries. The same situation of similar cultivars and likely presence of similar *P. triticina* races also occurs in Brazil and Paraguay. However, if races affect a wide range of cultivars, they spread very fast within the entire epidemiological zone. MDT-10,20 and MFT-10,20 were first identified in Brazil in 2005, and then in 2007 in Argentina and Uruguay, indicating that these races probably originated in Brazil and later migrated to the other countries. Similarly, races TDT-10,20 and TFT-10,20 (B57) were detected in Brazil in 2005 and in Uruguay during 2010. Race MDP-10,20 (B58) was first detected in Uruguay and Argentina in 2004 and 2005, respectively, and in Brazil in 2007. This pattern of appearance indicated this race probably originated in Uruguay or Argentina and later migrated to Brazil.

P. tritici isolates from South America (Argentina, Brazil, Chile, Peru and Uruguay), fell into five groups according to their virulence phenotypes and molecular genotypes (Ordoñez et al. 2010). Four of these groups were very similar in SSR genotype to previously characterized North American populations suggesting a common origin of *P. triticina* on both continents. In the fifth group there were three isolates found only in Chile. The use of durum and distinctive bread wheat cultivars in Chile, and its relative isolation from the rest of the region by mountains, results in a different *P. triticina* population, although there are some races in common with the eastern zone.

Race MCD-10,20, prevalent in both South America and North America for several years, was first detected in Mexico and later in USA (1996) and in Uruguay (1999). Different isolates of MCD-10,20 from both continents had similar SSR genotypes (Ordoñez et al. 2010), indicating likely intercontinental migration.

Genetic basis of leaf rust resistance

The presence of *Lr3a, 3ka, 9, 10, 16, 17, 24, 26, 34, 37, 41* (or *Lr39*) and *Lr47* in recent popular Argentinian cultivars was postulated using molecular markers and *P. triticina* races with different virulence phenotypes. In Uruguay, cultivars carrying genes *Lr16, 24, 34, 37* and *39* are being planted, besides others with unknown resistances. Most resistance genes were present in old cultivars and materials grown in the early 2000s. *Lr37* and *Lr39* are present in high yielding French and French-derived cultivars (e.g. Baguette cultivars and Nogal, respectively) which are planted in both countries. *Lr47* was introduced in Argentinian cv. BIOINTA 2004. There is no recent information on the genetic basis of resistance in cultivars from Brazil, Chile and Paraguay.

Resistance in wheat varieties and lines lies mostly in combinations of seedling resistance genes or combinations of these with adult plant resistance (APR). There are a few examples of recently released cultivars which only have APR likely to be of the slow rusting type (e.g. Klein Capricornio released in Argentina, and cv. Canindé 12 and Canindé 13 recently released in Paraguay).

Lr34 was postulated in Argentine cultivars and its presence has been demonstrated in several Uruguayan cultivars. Genetic studies indicate that APR conferred by genes different from *Lr34* is present in some Uruguayan cultivars. The presence of APR becomes evident after the development of races with virulence to the seedling genes present in cultivars. This leads to increased field infections on some cultivars, but with a residual partial resistance expressed as slower rusting relative to susceptible checks. Mapping data from Tc*3/Americano 25e showed that *Lr46* is present in this old line (J. Kolmer pers. comm.) which is in the pedigree of many old cultivars from Uruguay and Argentina. *Lr46* is common in CIMMYT germplasm (Singh et al. 2011) widely used directly or in breeding programs in the region. Kolmer et al. (2007) found two possibly undesignated APR genes in 'Americano 44d', another old Uruguayan land race selection released in 1918. Other uncatalogued APR genes were found in Brazilian cv. 'Frontana' (Singh and Rajaram 1992), 'Toropí' (Barcellos et al. 2000), 'BR35' (Brammer et al. 2004), and Argentinian cv. 'Buck Manantial' (Altieri et al. 2008). APR genes conferring durable resistance different from *Lr34* and *Lr46* are widely distributed in CIMMYT germplasm (Singh et al. 2011), including a slow rusting gene (*LrP*) present in Parula.

Breeding for leaf rust resistance

Breeding for leaf rust resistance is among the most important objectives for public and many private breeding programs in the Southern Cone countries, but has become less important in some programs due to the efficient control of the disease through use of fungicides. The general approach in the public programs is to avoid the release susceptible cultivars. However, some high yielding susceptible lines have been released, mainly by private companies, since there are no protocols preventing such releases. Public and some private breeding programs are trying to incorporate resistance into their germplasm, mainly APR conferred by minor additive genes, although major genes are also being used. Phenotypic selection is possible every year in most places, even without artificial inoculation. Marker assisted selection is being used in some programs to introduce specific resistance genes.

In Argentina, the control of leaf rust using resistant cultivars could be improved. Advanced lines and commercial cultivars from all breeding programs are tested in the seedling stage each year. They are also field tested in inoculated nurseries at several locations. This allows determination of the effectiveness and type of the resistance present in elite germplasm. Introduction of APR is the main objective in the INTA (National Institute of Agricultural Technology, Argentina) breeding program, although combination of APR with seedling resistance may be the best option for areas with high disease pressure. A special project in INTA focuses on introducing slow rusting to leaf rust in adapted germplasm. Selection of sources of resistance is based on phenotype (seedling susceptibility and APR) and other available information. The materials are mainly from CIMMYT and to a lesser extent local germplasm carrying *Lr34* and *Lr46*. Local materials resistant to Ug99 and derived *Pgt* races are also being used in crosses. Besides phenotypic screening, marker assisted selection is being used to pyramid seedling-effective genes *Lr47* and *Lr19* (low in yellow pigment) with other genes present in resistant backgrounds. A molecular marker for *Lr34* is being used to confirm its presence in parental materials and in advanced lines derived from parents that carry this gene. Other breeding programs in Argentina (Klein, Buck, ACA) have released resistant cultivars selected phenotypically. Cultivars from Brazil and Uruguay planted in Argentina are generally resistant to leaf rust.

The number of genotypes with resistance to all races is very limited in Brazil and Paraguay. Most efforts in breeding for resistance are focused on the incorporation of APR in adapted germplasm. Characterized sources of resistance such as Parula (*Lr34,46,P*) and Chapio are being used, along with other sources of APR (regional and introduced germplasm). APR is identified phenotypically, based on field and seedling tests. A diagnostic marker for *Lr34* and markers already developed for the APR of Toropí are under validation and will be used in breeding. BRS 296 (PF 93232//Cook*4/VPM 1), released in 2009, has expressed high levels of APR for over seven years in experimental plots, with a final leaf rust score of 5SMS.

The resistance present in new cultivars released in Paraguay is probably complex since it has been stable for a number of years. Sources of slow rusting resistance from CIMMYT and the Southern Cone are being used heavily by the local breeding program. Field selection is facilitated by the occurrence of high levels of leaf rust infection every year, favored by the use of spreader rows consisting of mixed susceptible materials. The recent release of two varieties of CIMMYT origin carrying APR will further improve leaf rust stabilization in this country.

Chilean spring germplasm, primarily based on CIMMYT sources, generally has good levels of leaf rust resistance. Useful sources of resistance have been identified in winter germplasm; the genetic basis of this resistance is unknown but it has been effective for a long period of time. Segregating progenies of 700-1,000 crosses annually are selected under natural infection enhanced by the use of spreader rows. Several locations are used for selection. Generally the upper threshold of response for release is 20MS. Biotechnological tools were used in Chile for the development of imidazolinone (herbicide) resistant cv. Pantera and Bicentenario, but are not currently used for selection of leaf rust resistance.

In Uruguay elite resistant germplasm and recently released cultivars generally carry seedling resistance to current races. *Lr34* is present in cultivars used in crosses, and a diagnostic molecular marker will be used in the short term to postulate its presence in advanced lines and new parental materials. Germplasm with leaf rust APR derived from selected CIMMYT and regional materials was developed from crosses with adapted susceptible cultivars. The first BC_1F_5 lines with APR were evaluated for yield potential, and some have been included in the crossing block. Lines with good agronomic type and acceptable industrial quality combining resistance to leaf rust and other diseases have been identified.

Projects to identify the basis of durable resistance.

In Argentina, mapping populations derived from Buck Manatial and Sinvalocho gamma are being studied (Altieri et al. 2008; Ingala et al. 2008). A doubled haploid population derived from a Toropi cross is being developed in Brazil (Scagliusi et al. 2010; Wiethölter et al. 2010) to detect genomic regions associated with the durable APR in this cultivar. The histological mechanisms involved in the resistance expressed by Toropí are also being examined.

The basis of expressed APR in a set of Brazilian lines from the EMBRAPA (Brazilian Enterprise for Agricultural Research) wheat breeding program has been under study for several years (Almeida et al. 2010). A core collection of diverse wheat lines will be assessed for leaf rust and other relevant traits for breeding purposes in Brazil. The genomic regions associated with resistance to leaf rust and other characteristics will be identified using association mapping. Association mapping will also be used to study APR to leaf rust as part of a recently approved project in Uruguay.

Trained human resources infrastructure, funding and research coordination

Resources to work in rust pathology and breeding for leaf rust resistance differ among countries in the region.

Work on breeding for leaf rust resistance in Argentina is supported by a rust pathologist and recently a molecular geneticist is working specifically on durable resistance and marker assisted selection. The available infrastructure and specific equipment for rust research is adequate for current projects; however, an increase in the number of researchers and additional infrastructure and funding would accelerate outcomes. Collaboration between the rust pathologist and molecular geneticists in INTA-Argentina is adequate and it is improving with breeders.

Brazil has adequate personnel, infrastructure and equipment as well as teamwork among researchers of different disciplines. Breeding for resistance to rusts has funding, technical support, and infrastructure of national institutions (Conselho Nacional de Desenvolvimento Científico e Tecnológico, Ministerio da Agricultura Pescuaria e Abastecimento, Empresa Brasileira de Pesquisa Agropecuária, Fundação de Amparo à Pesquisa do Rio Grande do Sul, Universidade Federal do Rio Grande do Sul, Universidade Estadual do Centro-Oeste do Paraná, Universidade Federal de Pelotas).

In Chile, a progressive reduction in human resources has occurred as several highly experienced breeders and pathologists have retired and were not replaced. Plant pathologists and breeders currently work in highly integrated manner. The public breeding program has adequate funding as private industry also provides financial and collaborative support. Good laboratory facilities and new greenhouses are available, but specific equipment for rust research is very old (from the early 1980s) and needs to be renewed.

Paraguay has serious deficiencies in researchers, training and infrastructure and needs to more efficiently address breeding for resistance to leaf rust or other diseases.

INIA-Uruguay wheat breeding and rust pathology programs have adequate personnel, infrastructure and equipment. A molecular geneticist recently joined INIA-Uruguay to study genetics and breeding for durable resistance to leaf rust through molecular work as one priority, and this has also improved the collaboration between disciplines.

In most countries breeding for leaf rust resistance is only one aspect of multidisciplinary breeding programs. Specific research for rust resistance provides a good contribution to breeding in general and allows a better integration between disciplines. However, better collaboration in defining sources of resistance, hybridization programs and field selection would be beneficial. In general, breeders require more training to identify and select APR to leaf rust in segregating populations.

A regional testing network and exchange of information is fundamental since most Southern Cone countries are in a single epidemiological zone, with Chile being partially contiguous; some races from the east are also found in that country (Germán et al. 2007). Past experience with regional research projects has been good, and the exchange of information among countries needs to continue. This can be done through regular contacts and regional meetings.

Challenges in controlling leaf rust in South America

Introducing durable resistance into high yielding adapted germplasm with acceptable market quality

The most important challenge for breeding programs in the Southern Cone is to incorporate adequate levels of durable leaf rust resistance into high yielding cultivars. These cultivars must also combine some resistance to other relevant diseases, including foliar and head blights, especially Septoria tritici blotch (caused by *Mycosphaerella graminicola*), tan spot (caused by *Pyrenophora triciti repentis*) and Fusarium head blight (FHB, caused by *Fusarium* spp.) in Argentina, Brazil, Paraguay and Uruguay, stripe rust (caused by *Puccinia striiformis* f. sp. *tritici*) and septoria leaf blotch in Chile, and resistance or tolerance to head blast (caused by *Magnaporthe grisea,* anamorph *Pyricularia grisea*) in Brazil and Paraguay. Besides disease resistance, varieties must meet industrial quality standards demanded by the market.

Table 1 ***Average grain yields with and without fungicides, yield reductions and disease reactions of old widely grown and two new wheat cultivars. Paraguay, 2008, 2009***

	Yield (kg/ha)						
Cultivar	**With fung.**	**Without fung.**	**% yield reduction**	**Leaf rust**	**Fusarium head blight**	**Tan spot**	**Blast**
Old							
CD 104	4672	3505	25.0	S[1]	S	MS	S
Itapúa 40	4628	4307	6.9	MS	MS	MS	MS
New							
Caninde 1	4415	4228	4.2	R	S	MR	R
Itapúa 70	4964	4986	-0.4	MR	MS	MS	MS

Source: Wheat Program, CRIA, Cap. Miranda, Paraguay (unpublished)

[1]R = Resistant, MR = Moderately resistant, MS = Moderately susceptible ,S = Susceptible

Examples of the most important challenges that local breeding programs are facing to control leaf rust, and some achievements are shown in Tables 1-6. In Paraguay, Itapúa 40 and the widely grown Brazilian cultivar CD 104 have similar grain yields compared to new cultivars when leaf rust is chemically controlled (Table 1). However, without fungicides they suffer high yield reductions. Breeding has been successful in combining resistance to leaf rust and other important diseases such as tan spot and head blast, but resistance to FHB is still not adequate. Some recently released cultivars (Canindé 12 and Canindé 13), with APR to leaf rust are susceptible to tan spot.

In Argentina some high yielding leaf rust susceptible cultivars, mostly of French origin, are planted over a large area and require one or more fungicide applications to prevent losses. In southeastern Buenos Aires province, these cultivars have higher grain yields than local resistant cultivars such as ACA 303 (*Lr10,16+*), Klein Capricornio *(Lr34+*, APR) and BIOINTA 2004 (*Lr47,34+*) when fungicides are applied, but this difference is lower when fungicides are not used (Table 2).

In Uruguay, the situation is similar to Argentina, although environmental conditions are more favorable for leaf rust infection and more fungicide applications are usually required to control leaf rust in highly susceptible

Table 2 ***Grain yield with and without fungicides, yield reductions and leaf rust infection. Balcarce, Argentina, 2010***

	Yield (kg/ha)			
Cultivars	**With fung.**	**Without fung.**	**% yield reduction**	**LR response**
French				
Baguette 19	6580	5723	13.0	90S[1]
Baguette 30	6257	5393	13.8	90S
Local				
ACA 303	5307	5350	0.0	5MS
Klein Capricornio	5233	4878	6.7	5MS
BIOINTA 2004	4773	4960	-3.9	0

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[1] Severity: modified Cobb scale (Peterson et al. 1948), R = Resistant, MR = Moderately resistant, MS = Moderately susceptible, S = Susceptible (Stakman et al. 1962)

Table 3 ***Yield with and without fungicides, yield reduction, leaf rust and foliar diseases infection. La Estanzuela, Uruguay, 2010***

	Yield (kg/ha)						
Cultivar	**With fung.**		**Without fung.**		**% yield reduction**	**LR response**	**Foliar spots**
French							
NT 805	8358	a[1]	6745	a[1]	19 **[2]	99S[3]	
Local							
LE 2331 (I. DON ALBERTO)	8170	a	7367	a	10 NS	2MRR	40[4]
LE 2354 (GENESIS 2354)	8131	ab	7101	a	13 NS	3MR	3
LE 2369	7592	b	7194	a	5 NS	5RMR	25

Source: Modified from Castro et al. 2011

[1] Numbers followed by the same letter in the same column are not significantly different

[2] **, highly significant, NS, non significant

[3] Severity: modified Cobb scale (Peterson et al. 1948), R = Resistant, MR = Moderately resistant, MS = Moderately susceptible, S = Susceptible (Stakman et al. 1962)

[4] Percentage leaf area affected by Septoria leaf blotch and tan spot

cultivars. Earlier infections result in high and significant yield losses in susceptible cultivars (Table 3). French derived germplasm, such as NT 805, has higher yield potential in the absence of leaf rust, but usually yields less when fungicides are not applied. Therefore, high yielding leaf rust resistant cultivars are required to reduce the area of susceptible wheats in Argentina and Uruguay.

Most resistant advanced breeding lines in the INIA-Uruguay breeding program have effective seedling resistance (Table 4), which may be overcome by the pathogen in a short period of time. Slow rusting is more difficult to select when these seedling resistant elite lines are used in crosses.

Specific crosses with locally adapted susceptible cultivars and lines have been made to introduce APR to leaf rust in INIA-Uruguay wheat germplasm. BC_1F_5 lines selected from these crosses were yield tested at La Estanzuela during 2010 without chemical control (grey background in Table 5). Some lines had grain yields statistically similar to the best checks (LE 2358 and LE 2346), but had higher yields than other check cultivars in the presence of leaf rust.

Some of the advanced lines developed in Uruguay combine APR to leaf rust and resistance to prevalent diseases (Table 6). Considering the susceptibility to FHB of most CIMMYT sources of APR used in crosses, the moderate resistance to FHB of derived lines such us PARULA/ORL 99192*2 is an important achievement.

Lines listed in Table 6, and others with similar characteristics, as well as new CIMMYT lines which combine APR to leaf rust and resistance to *Pgt* race Ug99 and its derivatives have also been used in recent crossing programs.

Diversity of resistance between countries in the Southern Cone and other countries in South America

A better knowledge of the bases of resistance being used in different breeding programs would be very useful for combining different sources. Few major genes appear to be present in the regional germplasm and resistance appears to depend on different combinations of these genes. For this approach to continue in the future, it will be necessary to know which genes are being combined and to introduce different effective genes in order to maintain diversity within and among the programs to reduce the risk of widespread epidemics. This is seen as an important step forward since races rapidly migrate from one country to another, and between continents in the longer term (Ordoñez et al. 2010).

Table 4 ***Seedling infection types produced on Uruguayan breeding lines to 17*** *P. triticina* ***races***

Line	CHT	KDG-10,20	MCD-10,20	MCR-10	MCT-10	MDP	MDP-10,20	MDR-10,20	MDT-10,20	MFP	MFP-10,20	MFP-20	MFR-10,20	MFT-10,20	MMD-10,20	SPG-10	TDD-10,20
Facultative																	
LE 2359	0[1]	0	0	0;	0	0	0	0	0	0;	0	0	0	0;	2	0	0
LE 2366	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LE 2377	0	0;	0;	0;1=	0;	0;	0;	0	0;	0;	1-;	0	0	0	0;	0	0;
LE 2379	0	;1=	1;	2-;	;1=	1-;	2	;1=	12-	0;	;1-	0;	;1=	2=;	;	0	1;
Spring																	
LE 2354	0;	0;	;1=	;1=	;1=	;1=	;1=	0	0	;1-	0;	;	;1-	;	0;	0;	;1=
LE 2382	0	0;	0;	0;	0;	0;	2-;	,1=	2=;	0;	0	0;	0;	2=;	2=;	0;	;1=
LE 2388	0	0;	,1=	12-	2=;	1-;	1-;	;1=	0;	;1=	0;	;1-	;1=	;1=	;	0	;1=
LE 2390	0	0;	0	0;	0;	2=;	2	0;	2=;	0;	;1=	0;	0;	2-;	0;	0;	0;

[1]Infection type, Stakman et al. (1962), IT 0 to 4 scale, 0 to 2+, low, 3- to 4, high. + and – indicate larger and smaller IT, respectively

Table 5 *Yield and leaf rust infection of INIA breeding lines. La Estanzuela, Uruguay, 2010*

Line	Cross	Yield (kg/ha)		LR response
LE 2358	PI/FUNO*2/5/VLD/4/CO723595/3/TAM200*2//TAM107/ TA2460/6/LE2220	6862	a[1]	0[2]
LE 2346	PEETHREE NR2/2*OS//NWT/3/OS.VONA PYN COMP/4/ PIOPIO/5/LE2221	6766	a	0
F5 09-13158	I.TORCAZA*2//CEP8749/EMBRAPA27	6657	ab	0
F6 09-696	ITIJ/4/TRAP1/YACO/3/KAUZ*2/TRAP//KAUZ	6487	abc	15MSS
LE 2359	ITIJ/LE2266	6459	abc	0
F6 09-10081	IGAR/LE2321	6096	abcd	10MS
F5 09-13139	I.TORCAZA*2//CEP8749/EMBRAPA27	6007	abcd	0
F6 09-599	IGAV/5/CEP85155/3/CEP7780*2//H499.71A/4*JUP/4/BR23	5999	abcd	15MSS
F5 09-13049	I.TIJERETA*2/SUZ6/OPATA	5986	abcd	0
F6 09-10027	IGAR/ALSEN	5935	abcd	0
F5 09-13177	I.GORRION*2/CHAPIO	5895	abcd	30MSS
I. GARZA	ICAB/ITIJ	5856	abcd	10MS
BAGUET.19		5530	bcd	70S
BIOINTA3000		5467	cd	50S
I.TIJERETA	LE2132/ECAL	5196	de	15MSS
BIOINTA3004		4122	e	70S

Source: M. Quincke, INIA wheat breeding program (unpublished)

[1]Numbers followed by the same letter in the same column are not significantly different

[2]Severity: modified Cobb scale (Peterson et al. 1948); reaction: R = Resistant, MR = Moderately resistant, MS = Moderately susceptible, S = Susceptible (Stakman et al. 1962)

Table 6 *BC_1F_5 lines from INIA-Uruguay combining adult plant resistance to leaf rust and resistance to other prevalent diseases*

Line	Cross	Fusarium head blight	Tan spot	Septoria tritici blotch	Stem rust (Kenya)
R09-19126	I.TIJERETA*2/TOROPI	MR[1]			
R09-19008	PARULA/ORL 99192*2	MR			MRMS
R09-19149	PARULA/ORL 99192*2	MR			
R09-19228	LE 2304*2 / PARULA	MRMS			R
R09-19024	LE 2304*2 / PARULA				R
R09-19107	GENARO*3/PARULA//LE 2252	MRMS			R
R08-10690	LE2252*2//GENARO*3/PARULA		MR		R
R09-19200	I.GORRION*2 / CHAPIO	MRMS			
R09-19197	I.GORRION*2 / CHAPIO			R	
R09-19229	LE 2304*2 / TOROPI			R	R
R09-19249	LE 2304*2 // CEP8749/EMBRAPA27	MR			
R09-19173	I.TORCAZA*2 // CEP8749/EMBRAPA27		MR	R	
R09-19189	I.TORCAZA*2 // CEP8749/EMBRAPA27	MR		R	
R08-4898	I.TIJERETA*2 / AMADINA		MR		
R09-19318	I.TIJERETA*2 / AMADINA			R	

R = Resistant, MR = Moderately resistant, MS = Moderately susceptible

Concluding remarks

Many cultivars used in the Southern Cone are leaf rust susceptible or have short-term effective seedling resistances. However, some recently released cultivars carry APR, which is expected to be durable. Since efforts to introduce slow rusting into high yielding adapted germplasm with adequate quality are increasing in most countries, more cultivars carrying this type of resistance are likely to be released. In some of the countries it will be difficult to meet the challenge of releasing cultivars with these characteristics without increasing scientific staff, training, updating and increasing facilities, equipment, and funding. In others, improvements in these aspects will result in faster progress. Increased use of molecular tools could improve genetic progress in breeding programs, allow identification of APR genes present in current regional germplasm, and facilitate identification of new resistance genes.

Fungicides are very valuable for controlling leaf rust and protecting cultivars with specific resistance when virulent races emerge. It may also be relevant to fine-tune the usage of chemicals on genotypes with intermediate levels of disease.

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