Integrated management of major wheat diseases in Brazil: an example for the Southern Cone region of Latin America*

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Abstract Wheat is an important crop in the Southern Cone region of Latin America. Some of the common wheat diseases in this region are Xanthomonas streak, spot blotch, tan spot, and leaf blotch and the rusts. Rice blast on wheat could also be a problem in certain years. Disease management through varietal resistance, cultural practices including appropriate fungicidal spraying schedule, levels of tolerance for field and seed infections and seed treatment criteria, have been integrated and used for several years in Brazil. Emphasis in integrated disease management (IDM) is on reduction in use of fungicides and consequently in the cost of production. Wheat productivity in Brazil has almost doubled during the past 10 years, owing mainly to the IDM approach. The IDM practices used in Brazil for each of the major diseases can also be adopted in other Latin-American countries with similar agroecosystems.

Keywords Integrated management; wheat diseases; Latin America

Introduction

Wheat is an important crop in the Southern Cone region of Latin America which includes Argentina, Bolivia, Brazil, Chile, Paraguay and Uruguay. The annual wheat production in this region is between 15 and 17×10^6 t on a little over 9×10^6 ha. Wheat productivity in this region gradually increased during the past years: in Brazil, for example, the average wheat yield has increased from ~ 1000 kg ha^{-1} to 2000 kg ha^{-1} during the last decade. This significant increase in yield of wheat is mainly due to the integrated disease management (IDM) approach.

Wheat is grown during the winter season in most of the Southern Cone region, i.e. between April and June. During these months the average minimum temperature is $\sim$12.7–17.0°C, the monthly average temperatures are $\sim$21–27°C, and the average relative humidity oscillates between 75 and 85%; wheat production is highly dependent on the variable climatic conditions.

The major wheat diseases in the Southern Cone region are Xanthomonas streak, spot blotch, rusts and tan spot. This paper discusses the IDM procedure adopted for these diseases in Brazil.

Xanthomonas streak

Xanthomonas streak (also called black chaff or bacterial stripe) is caused by *Xanthomonas campestris* pv. *undulosa* (S. J. & R.) Dye. (Xcu). In the field, the pathogen attacks wheat and triticale and very rarely rye and barley. The disease has been increasing gradually since 1982 and has now become one of the important diseases of wheat in the Southern Cone region. Although the disease was already reported to occur in several countries, it was first observed in Brazil in June–July 1979, on wheat cultivars INIA 66 and Mascarenhas in the experimental fields at Palotina in the State of Paraná. The disease exploded in 1982, attacking almost all the wheat cultivars and advanced breeding lines (Mohan and Mehta, 1985). Later, severe outbreaks of the disease were observed in commercial wheat fields in Paraná, São Paulo and Mato Grosso do Sul during the years 1983–1990. In Argentina the reduction of >40% in yield in 1986 was mainly attributed to this disease. Other sporadic outbreaks were also registered in Paraguay and Uruguay between 1984 and 1990.

Usually, the pathogen does not cause seedling losses. Based on the 3 years of field experimentation, Mehta and Bassoi (1992) reported that the disease caused up to 39.7% losses in yield, depending upon the wheat cultivar and the level of bacterial contamination in the seed. As the disease normally becomes severe after the heading stage, when most of the yield components, including the number of grains per spike, are already defined, the reduction in yield is due to the reduction in grain weight.

The disease is being managed at low levels through the integration of different measures, as described below.

Source of primary inoculum

Xanthomonas streak is transmitted through contaminated/infected seed (Schaad and Forster, 1985;

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Mehta, 1990; Mehta and Bassoi, 1992). In some countries oversummering of the pathogen may be possible; however, under Brazilian conditions the pathogen does not survive over a period of 5 months after the wheat harvest, probably because of the summer temperatures during the day of > 34°C during January and February. During 1986–1990 an experiment was conducted to find out whether Xcu oversummers in the infected wheat stubble and serves as a primary source of infection. For this purpose, wheat straw from heavily infected crops of cultivars Caeté and Macuco were collected soon after harvest. One kilo of straw was mixed with the soil of each plot of 1 × 1 m, plots being separated from each other by small concrete walls. Equal numbers of plots were also maintained without adding the straw. The plots were undisturbed until the next wheat season, at which time healthy wheat seeds of cultivars Maringá, BR 23 and IOC 834 were sown in four rows per plot and in five replications. Two border rows of oats per plot were also sown to avoid the interplot interference. Observations for the Xanthomonas streak symptoms were made periodically until the flowering period and the presence of Xcu was confirmed by laboratory tests. First disease symptoms, in the plots seeded with contaminated seeds of cultivars Caeté and Macuco with or without straw, were invariably observed 30–40 days after sowing. In 1989 for example, whereas 5% of the leaf area was infected in plots with Caeté, 65 days after sowing no infection was observed in plots grown with uncontaminated seeds, either with or without straw.

Wheat straw sampled periodically from such plots was analysed in the laboratory for bacterial ooze, macerated with saline water and the suspension was applied to 20-day-old seedlings to verify if Xcu was viable in the infected straw. Results of such studies indicated that the bacteria survive in the straw for only 5 months from the date of incorporation of the straw. Thus, the infected wheat stubble had no role in the epidemiology of the disease and the contaminated seed was the only source of primary infection under Brazilian conditions.

Some seed-assaying techniques are available for routine use. A semi-selective agar medium (XTS-agar) was developed for dilution plating by Schaad and Forster (1985) to determine the amount of bacteria present in the seed lots. Later, Fourest *et al.* (1990) reported the use of a modified XTS-agar by adding 5-bromo-4-chloro-3-indolyl β-D- galactopyrenoside (X-gal) to the medium. According to the authors, X-gal reacts with β-galactoside, turning the normally yellow colonies of Xcu a bluish green. More recently, Bragard, Mehta and Maraite (1992) reported that serodiagnostic assays can also be used to detect the presence of Xcu in the wheat seed lots. A modified seedling injection technique (SIT) was also reported as an alternative to the other existing techniques (Mehta, 1990).

Bragard *et al.* (1992) encountered a large variation in bacterial counts between one replication and the other, using the semi-selective agar media, and discussed some possible reasons for this variation. Some doubts about the routine use of the semi-selective agar media were also raised by Mehta (1990) and Mehta and Bassoi (1992).

Although the quantification of Xcu in the seed is a problematic issue, Schaad and Forster (1985) established a tolerance limit of 1000 colony-forming units (c.f.u.) per gram of seed, for the sprinkler-irrigated areas. According to these authors, > 1000 c.f.u. g^{-1} seed are necessary for the epidemic to develop with sprinkler irrigation at weekly intervals. As there is no other tolerance limit available, this can be tentatively adopted.

In Latin America most of the wheat is not irrigated and hence quantification of bacteria in a particular seed lot would be of little importance, especially during the dry years. In addition, the use of semi-selective agar media is expensive, and an experienced plant pathologist must be available. An alternative is to use the SIT, which is an inexpensive and reliable technique that does not quantify the amount of bacteria present in a particular seed lot but identifies contaminated seed lots. In Brazil, especially in the State of Paraná in 1988 and 1989, large quantities of contaminated seeds of some new cultivars, including Caeté and Candeias, were discarded through the use of this technique and quantification of Xcu on XTS-agar. In this way, selected seed lots of each new commercial cultivar are assayed annually and the disease is being contained.

Seed treatment

If there is a shortage of seed, the contaminated seed lots identified by SIT can be treated with acidified cupric acetate (Forster and Schaad, 1988) or with dry heat treatments (Fourest *et al.*, 1990). However, such treatments are harmful to seeds and cause reduced germination, thereby necessitating an increase in seeding rate per unit area. Mehta and Bassoi (1992) observed that in many countries the cost of seed is relatively high, and that Guazatine Plus (guazatine + imazalil; KenoGard, Sweden) applied as a bactericide has advantages over other seed-treatment methods, being a relatively simple, cheap treatment that yields a good and uniform stand, without any phytotoxic effect. It is also effective in controlling some major seed-transmitted fungal pathogens of wheat. Even when seed treatment is practised, however, the contaminated seed lots should not be used in areas with artificial irrigation.

Tolerance limits in relation to seed source

For the Southern Cone region of Latin America, apart from considerations of quarantine, a zero level of tolerance is not necessary either for seed contamination or for the resultant infection in the crop. Mehta (1990) studied the relationship between the percentage leaf area symptoms observed in the field and the contamination of the corresponding seed lot. Out of a total of 50 wheat cultivars with < 10% leaf area infected at the soft dough stage in the field, seeds of 38 wheat cultivars either had no seedling infection, as indicated by SIT, or yielded < 1000 c.f.u. g^{-1} on XTS-agar. Based on this finding, a tolerance limit of 10% leaf area infected with Xanthomonas streak at the flowering soft dough stage is being employed in seed-multiplication fields, especially in the rainfed areas.

The severity of Xanthomonas streak is variable within a

Table 1. Effect of dry heat treatment on the level of wheat seed contamination by *Xanthomonas campestris* pv. *undulosa* (Xcu)

Heat treatment period (h) at 60°C[a]	Germination (%)[b]	Detection of Xcu[b]	
		Seedling injection technique[c]	Colony-forming units[d] $[(c.f.u.\ g^{-1}) \times 10^2]$
0.0 (check)	86	+ + +	6.0
6.0	84	+ +	0.2
18.0	81	+ +	0.2

[a]Contaminated seed lot of wheat cultivar Candeias, 1988; [b]average of six replications; [c]disease symptoms of wheat seedlings; + + + = severe, + + = moderate; [d]colony-forming units (c.f.u.) on XTS-agar

particular field. Normally, the disease is more severe in the contours (hollows) than in the remainder of the field because in the contours there is a high concentration of organic matter, promoting higher density and vigour of the plants; this consequently creats a more favourable micro-environment for the development of Xanthomonas streak. Thus, a main field showing < 10% leaf area infected should be harvested first for seed; if the level of infection in the contours is > 10%, it should be harvested later and should not be used for seed production.

Varietal resistance

No sources of resistance to Xanthomonas streak have been identified, so no resistant wheat cultivars have been developed. However, under field conditions, visible differences can be observed between different cultivars: cultivars such as Batuira and BR 14 have the least visible symptoms on the foliage; Caeté and Tapejara, although susceptible to foliar infection, are considered tolerant to the disease; highly susceptible cultivars are Alondra, Candeias, Serrano, Panda and Taquari. As a common practice, highly susceptible cultivars are not recommended for areas with artificial irrigation.

Other considerations

Whenever possible, it is advisable to harvest the healthier fields before those infected, because harvesting machines may contaminate the seed (Mehta, 1990). In addition, drying of seeds in the seed-processing unit soon after harvest, is advocated. Seed drying helps to reduce bacterial contamination (*Table 1*). In the authors' experience, even seed with high moisture content (17–20%) harvested after a rainy period from heavily infected fields (50–70% of leaf area infected), reveals few, if any, bacteria when analysed after heat drying. This indicates that the bacteria are easily killed during seed drying at relatively low temperatures (35–40°C) when the seeds have a high moisture content. Further work is necessary to confirm this hypothesis.

Spot blotch

Spot blotch of wheat caused by *Cochliobolus sativus* Ito & Kurib (Anamorph *Bipolaris sorokiniana* Sacc. in Sorok.) was reported in Brazil for the first time in 1945 and later in 1961; it was considered to be one of the major diseases of wheat, especially in the State of Rio Grande do Sul (Gasperi, 1961). The economic importance of the disease in the States of Paraná, São Paulo and Mato Grosso do Sul was recognized in the mid-1970s with the spread of wheat to these States. In July 1975, when these States lost almost all the wheat crop owing to the severe frost (− 5 to − 9°C), large quantities of seeds were imported from Mexico for seeding in 1976. The imported cultivars such as INIA 66, Jupateco 75 and Tanori 71 were highly susceptible to spot blotch, but appropriate control measures were not then available and were not practised until 1979. This resulted in severe epidemics of the disease, year after year, and all the soils became infested with the spot blotch pathogen.

In recent years, spot blotch of wheat has been considered to be one of the most important diseases of wheat in Brazil, as well as in the other Latin American countries (Mehta, 1978). Yield losses have been reported (Hetzler *et al.*, 1991), most of which were attributed to a complex of diseases comprising mainly leaf rust and spot blotch. However, in some years the yield losses caused by spot blotch alone could be quantified: for example, in 1982, losses in yield were determined using the cultivar Anahuac at Palotina, where spot blotch was the predominant disease and butyltriazole and ethirimol were used to eliminate the interference of other, minor, diseases; the yield losses were 31–37%. In 1983, spot blotch alone induced a 79.0–86.5% loss in yield of the highly susceptible cultivar Mitacoré (Hetzler *et al.*, 1991). There was also a drastic reduction in grain quality.

In view of such major losses in yield, emphasis is being given to an IDM approach, which basically includes the components described below.

Varietal resistance

Breeding for resistance to spot blotch has been intensified in recent years through an International Collaborative Research Project (Israel, Germany, CIMMYT and Brazil) funded by the German Government; selection for spot blotch resistance in segregating populations started in the early 1980s and some progress can already be seen. The earlier highly susceptible cultivars such as INIA 66, Jupateco 75, Tanori 71, Mitacoré and Paraguay 214 have been withdrawn from the list of recommended cultivars and new, less susceptible cultivars such as CEP 11, CEP 14, Tapejara, Igapó, Cacatu, Batuira, Piratã and BR 8 have been included. Although accurate data about yield losses induced by spot blotch in the new cultivars are not available, field evaluations during the past 5 years have demonstrated their reduced susceptibility: the average percentage of leaf area infected that was attributable mainly to spot blotch and tan spot during the last 5 years in some new cultivars was lower than that in susceptible ones such as Caeté, Taquari, Maringá, BR 23 and BR 28. The data are the averages of 4–82 experiments per cultivar per year, conducted at eight different locations and covering five distinct wheat zones. As the averages are based on a large number of observations, the apparently smaller differences in disease severity between the cultivars are considered to be significant. The high disease rating in Batuira in 1986 is partly due to the premature senescence of the leaves in this variety. The year 1987 was warm and humid and hence favoured the severity of spot blotch. Most of these cultivars during the same set of experiments also yielded more than the susceptible cultivars. Undoubtedly, the yield potential of each variety also must have contributed in part to the yield differences between the cultivars. It is interesting to note that the average wheat productivity in Paraná during the past 6 years has increased from $\sim 1.0\,t\,ha^{-1}$ to $\sim 2.0\,t\,ha^{-1}$.

Seed infection and seed treatment

Spot blotch is also transmitted through seed. Although efficient fungicides are available to eradicate the pathogen from the infected seeds, decisions related to fungicidal seed treatment of a particular seed lot should depend on certain considerations, as discussed below, and the indiscriminate use of fungicides should be avoided.

A low correlation was found between seed infection as determined by the 'blotter test' and seedling infection (growing-on test) as determined in a glasshouse test of 36 seed lots heavily infected with *B. sorokiniana* (Mehta and Igarashi, 1985a). Results of such studies indicated that ~50% of the seedlings originating from contaminated seed were not infected. Based on these data, a tolerance limit of 20% for seed infection/contamination was established. Thus, out of 20% infected seeds, only ~10% of the seedlings would be infected in the field; moreover, not all the infected seedlings would die, as the degree of infection normally varies considerably. Since, at the present rate, the cost of 10% more seed is more than the cost involved in fungicidal seed treatment, it would be worth treating the seed using the tolerance limit of 20%. In Brazil (Paraná, São Paulo, Mato Grosso do Sul), the criteria used for seed treatment as approved by the Central-South Brazilian Wheat Commission are as follows:

1. No seed treatment should be undertaken if the infection level is <20%, as determined by 'blotter test', and the germination percentage is within the seed standards.
2. Seed lots with <20% infection can be treated only if the germination percentage is low and after seed treatment it reaches the seed standard limit.
3. Seed lots with >20% infection can be treated with fungicide only if the germination percentage is lower than the standard and there is a seed shortage problem.
4. Seed lots could be treated with fungicides irrespective of the level of infection, especially for seeding in new areas or areas where crop rotation is practised. This criterion is based on the belief that the seed treatment would avoid the introduction of additional inoculum into the soil and consequently would minimize the primary source of inoculum.

Such criteria, undoubtedly, have helped to avoid the indiscriminate use of fungicides. The seed quality of the 1975 harvest in Paraná, São Paulo and Mato Grosso do Sul was adequate and no seed treatment was necessary.

Table 2. Survey of area under wheat cultivation, quantity of seed needed and the cost of fungicides for seed treatment in three Brazilian States in 1986[a]

State	Wheat area (ha × 10^3)	Quantity of seed: Needed (bags × 10^3)	Quantity of seed: Treated (bags × 10^3)	Cost of fungicides for seed treatment[b] (US$ × 10^3)
Paraná	1945.0	6808.0	2282.0	5336.0
São Paulo	203.0	711.1	316.0	860.0
Mato Grosso do Sul	409.4	1432.8	345.0	809.0
Total	2557.4	8915.9	2943.0	7005.0

[a]Source, Banco do Brasil (CTRIN); [b]source, fungicide manufacturers. To treat only 33% of the seed quantity needed for the three States, ~US$7.0 × 10^6 were spent without any certainty of its necessity

However, >30% of the seed quantity necessary for 1986 wheat seeding in these States was treated with fungicides without having any data on seed health analysis to justify the seed treatment. Altogether, the cost was US$7.0 × 10^6, which otherwise could have been saved (*Table 2*). Since 1986, very little seed dressing fungicide has been used, mainly because of the official recommendations.

Cultural practices

One way to avoid severe losses due to the foliar diseases in favourable years is to plant more than one cultivar and at different dates but within the recommended sowing period. Late sowing is not recommended, in order to avoid coincidence between the flowering–milk stage and the hot and humid periods during August. Farmers in southern Brazil are gradually adopting this practice. Although the pathogen survives on crop residues, there is no indication nor any report in the literature about the influence of tillage practices and/or crop rotation, on the severity of the foliar phase of this disease (Mehta and Gaudêncio, 1991); this is possibly attributable to the fact that the disease is also windborne.

Chemical control through an appropriate spraying schedule

The success of chemical control depends mainly on an appropriate spraying schedule in Brazil and includes the following aspects (Mehta, Igarashi and Nazareno, 1975; Mehta and Igarashi, 1985b).

1. Fungicides are usually selected on the basis of yield differences between treated and untreated plots. According to a new criterion established for the selection and recommendation of fungicides for foliar diseases, a fungicide that does not maintain the infection level at <50% leaf area infected at growth stage DC (decimal code) 83, is not recommended for a specific disease. Equally important is the amount of fungicide used per hectare. The officially recommended dosage of the systemic fungicides should be strictly followed and

no systemic fungicide should be used in reduced dosage; this would avoid the problem of resistance of pathogens to fungicides. Unfortunately, in Latin America including Brazil, some farmers still use reduced rates of some systemic fungicides.

2. For less susceptible cultivars, only a minor reduction in the rate of infection would suffice, whereas for susceptible cultivars a 30–40-day delay in the start of the epidemic would be required. Contact fungicides are less expensive but are also less effective than systemic fungicides and for this reason they should be used for cultivars that are less susceptible or that require a longer incubation period. Systemic fungicides, on the other hand, should be used on susceptible varieties to obtain reasonably good disease control and to guarantee economic returns.
3. The timing of the first spray application is of primary importance in the spraying schedule. Conventionally, an epidemic starts 45–55 days after sowing under Brazilian and Paraguayan conditions. The first spraying should be done soon after the appearance of the disease symptoms, and not before as a preventive measure. If the disease epidemic does not start until 80 days after sowing, for example, the first spraying should be done then, and not before.
4. A 15–20-day interval between sprayings should be maintained, depending upon the type of fungicide. If an interval of 15–20 days between sprayings is maintained, initiating the spraying at 45–55 days after sowing protects the crop until the soft dough stage ($\sim$ 100 days after sowing). After that, it is not necessary to control leaf diseases, as yield losses are almost negligible.

The spraying schedule outlined above has been used in Brazil for > 10 years and has facilitated the efficient use of fungicides and at the same time has increased cost effectiveness in containing the disease. The availability of only a single group of systemic fungicides for foliar diseases, i.e. the triazoles, is cause for serious concern; new fungicides should be developed to avoid the development of resistance in the pathogen.

Tan spot

Tan spot of wheat, caused by *Pyrenophora tritici repentis* (Died), Drechs. (Anamorph *Drechslera triciti repentis* (Died), Shoemaker) occurs worldwide, including Brazil and Paraguay where severe epidemics have been reported (Mehta and Gaudêncio, 1991). After the introduction of zero-tillage in 1979, tan spot severity increased gradually in the States of Paraná and São Paulo. During the last 4 years it has become as important as spot blotch. Some of the control measures can be integrated and are described below.

Varietal resistance

Cultivars highly resistant to tan spot are not yet available; however, some of the cultivars that offer resistance to spot blotch also offer some resistance to tan spot.

Table 3. Occurrence of perithecia of *Pyrenophora tritici repentis* on wheat stubble in zero-tillage and conventional-tillage cultivation systems in Brazil, 1983–1985

Month and year of observation	Amount of perithecia present[a]	
	Conventional	Zero-tillage
October 1983	*	***
December 1983	*	***
January 1984	*	**
March–June 1984	0	*
August 1984	0	0
September 1984	0	*
October–November 1984	*	**
January–May 1985	0	***

[a]0, perithecia absent; *very few perithecia; **, many perithecia; ***, abundant perithecia (source: Mehta and Gaudêncio, 1991)

Cultural practices

The tan spot pathogen is not seed transmitted; it survives on the wheat stubble under the zero-tillage cultivation system. After 15–20 days, symptoms appear in wheat fields grown under the conventional cultivation system. In this case, the infection is induced by the conidial cycle produced in the adjacent wheat fields under the zero-tillage system; this is mainly because the ascospores do not travel far (Rees and Platz, 1979; Mehta and Gaudêncio, 1991).

In a long-term experiment installed in 1976 at Instituto Agronômico do Paraná (IAPAR), Londrina, to compare the zero-tillage and conventional-tillage systems, periodic observations were made regarding tan spot severity and the survival mechanism of the pathogen. As perithecia were normally present throughout the year on the wheat stubble in the zero-tillage cultivation system, tan spot severity over 3 consecutive years was also always substantially higher in this system of cultivation (*Table 3*). The tan spot pathogen survives over a 1-year period on undisturbed wheat stubble.

In Latin America, wheat is normally sown soon after the harvest of soybeans and the land is not ploughed in the zero-tillage cultivation system. To break the disease cycle a potential compromise between conventional and zero-tillage systems seems desirable. Thus, when the wheat stubble is ploughed under, the stubble inoculum is destroyed and consequently the infection is delayed in the subsequent wheat crop. As burning the wheat stubble did not eliminate the disease (Rees and Platz, 1979), crop rotation or ploughing soon after the soybean harvest in a zero-tillage cultivation system could be beneficial. For rotation, although oats seem to be a good option, for smaller areas, in the authors' opinion peas (*Pisum sativus*) and chickpea (*Cicer arietinum*) could be grown successfully.

If the soil is to be ploughed once a year in the zero-tillage cultivation system, then this should take place after the soybean harvest, and wheat sowing should occur immediately afterwards. In this way, stubble is retained during the rainy season when erosion is a substantial threat and it is incorporated before the wheat crop, to control tan spot. In Pergamino, Argentina, wheat yields were higher with this combined tillage scheme than with either continuous zero-tillage or continuous conventional cultivation (Fernando *et al.*, 1978). Such cultural practices have not yet been fully adopted in the Southern Cone region.

The spraying schedule described for spot blotch is also used to manage tan spot. However, if the necessary cultural practices outlined earlier are not adopted, the first spraying should be done as a preventive measure during the initial crop cycle, i.e. 30–40 days after sowing. This, of course, means that one extra spray would be required and consequently would increase the cost of production; hence a potential integration between cultural practices and fungicidal applications is deemed essential.

Rice blast on wheat

Rice blast on wheat caused by *Pyricularia oryzae* Cav. is a relatively new disease of wheat for Brazil and was reported for the first time in 1985 (Igarashi *et al.*, 1986). The disease is restricted to the hot and humid areas, especially along the river Paranapanema, and was in epidemic proportions in 1986–1987. Comprehensive data on yield losses caused by this disease are not yet available, although yield losses of >50% were observed in some commercial fields. The disease was not reported in any other Latin-American country.

Soon after the second outbreak of the disease, in 1986, integrated disease management measures were recommended. The reduction in severity of this disease after 1987 was attributed to such measures, described below.

Varietal resistance

So far, no resistant wheat cultivar has been identified; however, in some early maturing cultivars such as Anahuac and Batuira, the disease incidence was higher. This is one of the reasons why Brazilian farmers have preferred other cultivars in the recent years, especially in the problem areas.

Cultural practices

The occurrence of rice blast on wheat can be considered to be a typical example of ecological imbalance between the two agro-ecosystems, i.e. wheat and rice, provoked by man.

The rice cultivar CICA 9 from Centro Internacional de Agricultura Tropical (CIAT), Colombia, was immune to the rice blast pathogen and at the same time was high yielding. It was recommended for cultivation in the North of Paraná during the early 1980s and within a few years >90% of the rice area in that region was planted to this cultivar. As a result, in 1985 a new race of *P. oryzae* was observed that was virulent to CICA 9. During 1985–1987, rice in the North of Paraná was sown late, i.e. by the end of December, whereas the recommended sowing dates were between October and 15 November. Coincidentally, during these years some wheat fields near the rice area were seeded very early, i.e. between 20 February and 20 March, whereas the recommended sowing dates were between 20 March and 30 April. Rice was sown very late because of an extended drought period; however, there was no apparent explanation for the early sown of wheat. Thus, when the highly infected rice fields of CICA 9 were being harvested, the early sown wheat was heading or flowering. The conidia of *P. oryzae* were blown by the wind and were deposited on the rachis of the wheat spikes, thereby causing infection.

During the heading and flowering stages the sugar content of rachis is high and for this reason the pathogen was able to become adapted to wheat. In addition, the unusual climatic conditions during 1985–1987 were highly favourable for the blast pathogen: the rains were well distributed during the critical periods for blast development and the average monthly temperatures between May, June and July were higher than normal. Undoubtedly, the first early sown wheat fields served as a focus of infection to other wheat fields sown at normal dates and the disease was able to spread from one field to another because of the continuing favourable weather conditions.

The recommended sowing dates have now been altered wheat sowing in epidemic areas for blast development is recommended only after 10 April; this, too, has improved disease control. In addition, incorporation of stubble soon after wheat harvest is recommended, especially for fields with infected crops; this recommendation has been followed by most farmers.

Chemical control

So far, the use of fungicides has not achieved successful control of the disease.

Rusts

Leaf rust caused by *Puccinia recondita* Rob. ex Desm. f. sp. *tritici* and stem rust caused by *Puccinia graminis* Pers. f. sp. *tritici* Erikss. & Henn. were the important diseases of wheat in Brazil until 1982; heavy yield losses caused by these diseases were reported in several years (Gasperi, 1961; Luzzardi and Pierobom, 1975; Mehta, 1978; Mehta and Igarashi, 1985b). However, no severe epidemics of these diseases have been observed since 1982, the basic reason for this being the integration of control measures such as the release of resistant cultivars, alteration of seeding dates, and fungicidal application using an appropriate spraying schedule.

Varietal resistance

As mentioned earlier, cultivars highly susceptible to rusts, such as Alondra, Jupateco 75 and INIA 66, were replaced in 1980 by resistant or moderately resistant cultivars such as Anahuac, Cocoraque 75, Mitacoré, Tapejara, Caeté, Batuira and Candeias. Because of their high yielding ability and wide adaptation, some of these cultivars were soon adopted by Brazilian farmers. Between the years 1980 and 1988, for example, ~70% of the area under wheat cultivation in Paraná, São Paulo and Mato Grosso do Sul was

Table 4. Percentage area seeded with major wheat cultivars during 1978–1982, in the State of Paraná, Brazil

	Year				
Cultivar	1978	1979	1980	1981	1982
Anahuac	—	0.6	2.8	10.3	24.7
BH 1146	12.2	9.6	9.6	19.7	17.1
Maringá	25.7	34.9	32.5	26.3	15.6
Cocoraque	—	0.4	0.8	4.5	11.4
LA 1549	2.1	4.0	8.7	9.7	10.0
INIA 66	22.1	20.1	23.5	14.1	6.2
Paraguai 281	3.1	3.2	6.3	7.3	3.9
Jupateco 75	12.9	13.7	12.9	2.1	0.0
Tanori 71	18.7	11.6	0.0	—	—
Total	96.8	98.1	97.1	94.0	88.9

Table 5. Percentage area seeded with major wheat cultivars during 1983–1990 in the State of Paraná, Brazil

	Year							
Cultivar	1983	1984	1985	1986	1987	1988	1989	1990
Anahuac	43.6	44.0	47.7	45.5	49.6	44.7	40.9	41.2
Tapejara	0.1	0.6	2.7	7.2	7.1	14.5	25.7	24.8
Maringá	13.5	18.3	15.0	19.5	17.8	13.0	5.2	6.9
CEP 11	—	—	—	—	—	1.1	2.9	4.4
PAT 7392	0.1	0.5	0.9	2.2	3.6	4.9	7.4	3.9
Cocoraque	26.7	26.6	24.6	10.9	6.2	4.3	2.9	1.2
Caeté	—	—	—	—	—	0.2	0.9	2.6
INIA 66	0.1	0.0	—	—	—	—	—	—
BH 1146	4.5	1.9	1.1	0.7	0.2	0.1	0.0	—
LA 1549	1.0	0.0	—	—	—	—	—	—
Paraguay 281	0.4	0.1	0.0	—	—	—	—	—
Total	90.2	92.0	92.0	86.0	84.5	82.8	85.9	85.0

planted to such cultivars and ~45% to Anahuac alone. Anahuac is a moderately resistant cultivar and drastically decreased the amount of inoculum in the region. Simultaneously, other resistant cultivars such as Tapejara, Caeté and Batuira (Rajaram, Singh and Torres, 1988) gained importance gradually: in 1990 the area planted to these cultivars, in the State of Paraná for example, was 30% of the total area under wheat; nevertheless, in 1990 Anahuac was still the most popular variety (*Tables 4* and *5*). No highly susceptible cultivar was recommended or grown after 1982. Cultivars such as Maringá, BH 1146 and Tapejara are susceptible but have the slow-rusting character under field conditions (Mehta and Igarashi, 1979).

There has been no substantial change as regards the occurrence of the predominant races of leaf rust during the 10-year period from 1980 to 1990. Although 3 new races (B10, B2 and B25) have been identified during this period, the prevalence or change in race spectrum have had no effect on the reduction of disease severity.

Sowing dates

A substantial change in the recommendation regarding sowing dates was made in 1980 because of the constant outbreaks of the stem rust epidemics. The previously recommended sowing dates were between 20 March and 15 June.

The late-sown wheat crop (i.e. sown between 20 May and 15 June) starts heading in the beginning of August when the temperature starts rising and becomes more favourable for stem rust. The new sowing dates that have applied since 1980 are between 20 March and 20 May, but 10 April to 10 May is the recommended sowing period. Wheat seeded during this period has already started to ripen by the beginning of August, thus preventing any severe build-up of stem rust.

Chemical control

In addition to the use of resistant cultivars and the avoidance of late sowings, chemical control measures also helped to reduce rust diseases.

The most favourable temperatures for leaf rust development are 18–28°C. These temperatures commonly occur during the wheat season all over Latin America (Stubbs *et al.*, 1986), and such a range of temperatures occurred during the rust-free years (1983–1990) in Brazil. In addition, either the rains were well distributed or there was enough free water on the leaves from dew formation, throughout the wheat cycle during these years. Although concrete data are lacking, rust inoculum was probably present in the air (Mehta, 1978). Thus, the impact of chemical control as one of the potential control measures can be assessed.

Triadimefon was officially released in Brazil in 1976 as the first systemic fungicide for wheat. However, besides being a new fungicide, its use was very much restricted owing to the severe drought in 1977 and 1978. This fungicide was used in 1979–1983; in 1984, another systemic fungicide, propiconazol, was recommended. Because of its great effectiveness in combating several foliar diseases, propiconazol was preferred by farmers and today is one of the most commonly used systemic fungicides in Brazil, as well as in other Latin-American countries.

Apart from the high degree of efficiency of these fungicides, a critical component of the chemical control was the timing of application. As mentioned earlier for spot blotch, most of the farmers adopted the recommended spraying schedule; in particular, the first spray was given in most cases soon after the appearance of the first symptoms of the disease (spot blotch, tan spot and powdery mildew). This first spray was responsible for a reduction in the initial inoculum of rust spores. Normally, the fungicide was applied at intervals of 15–20 days. During the regular wheat disease survey, the first pustules of leaf rust were invariably observed very late, i.e at the end of June or at the end of July, when the second spray was no longer effective and the crop was between the milk and soft dough stages. Later, the rust developed very slowly causing no yield losses. Although stem rust was managed through manipulation of sowing dates, fungicidal applications were also beneficial against this disease.

Conclusions

The severity of some major wheat diseases can be reduced through the adaptation of IDM procedures and, consequently, the cost of production can be minimized. Success in IDM in Brazil has also been attributable to the efficient and constant technical assistance provided to the farmers by the State Government extension services and scientists. Such an integrated approach could also be adopted for other Latin-American countries in which the agroecosystems are very similar. However, more information on the epidemiological aspects is needed for some relatively new diseases such as Xanthomonas streak and rice blast on wheat. At the same time, the effect of different crops and stubble-management practices on the inoculum level of some pathogens needs to be evaluated. Crop rotation, for example, has been found very useful in reducing root-rot infection caused by *Bipolaris sorokiniana* in Southern Brazil (Diehl *et al.*, 1982; Reis and Ambrosi, 1987; Reis, Fernandes and Picinini, 1988; Reis and Santos, 1989). However, the importance of crop rotation as regards the foliar phase of the disease has still to be determined. For further achievements in IDM practices, more integration and collaboration between scientists of different disciplines, extension workers and farmers is highly desirable.

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