Epidemic Spread of Barley Stripe Rust in South America

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ABSTRACT

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Epidemics of barley stripe rust, shown to be caused by *Puccinia striiformis* f. sp. *hordei* race 24 and its variants started in 1975 near Bogotá, Colombia, and affected nearly all commercial barley areas in South America by 1982. The pathogen is theorized to be exotic. Yield losses of 30–70% were estimated in the Andean countries, depending on year and country. European and recently released Andean barley cultivars tested were resistant, whereas North American cultivars were highly susceptible to the pathogen.

Additional key words: *Hordeum*, yellow rust

Barley (*Hordeum vulgare* L.) is an important grain crop in the Andes Mountains of South America (1). Until recently, most of the barley cultivars planted in Ecuador, Peru, and Bolivia were land varieties, as defined by Briggs and Knowles (2), and were known as *criolla* barleys. In Colombia, however, improved cultivars had been grown for about 20 yr. In 1975, barley cultivars near Bogotá, Colombia, were severely infected with stripe (yellow) rust, and preliminary studies indicated that the pathogen was *Puccinia striiformis* f. sp. *hordei* West. race 24 (*P. s. hordei*) (*unpublished*). The disease moved southward in the Andes Mountains during the following years. A review of the literature on barley stripe rust in South and North America showed that *P. s. hordei* had never been confirmed in either area. Similarly, discussions with rust specialists in the United States also indicated that *P. s. hordei* had apparently never been identified in North America (R. F. Line and A. P. Roelfs, *personal communication*). Our field observations and limited greenhouse tests on specimens coming from the Mexican highlands suggest only the presence of the f. sp. *tritici* of stripe rust on barley. Generally, only wheat becomes infected in nurseries in Toluca, Mexico. On the rare occasion that a barley line shows stripe rust, it appears as a low severity coupled with an intermediate reaction, typical of the f. sp. *tritici* infecting barley.

The object of this paper is to present experimental and observational evidence on the identification and exotic nature of the pathogen, epidemiology, virulence changes between 1975 to 1982, the economic impact, and the status of the disease in America. A brief report has been presented (5).

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MATERIALS AND METHODS

Identification of pathogen. Samples of stripe rust-infected barley leaves from Colombia, Ecuador, Peru, Bolivia, Chile, and Argentina from 1975 to 1983 were collected by national cooperators and by us and sent to Wageningen, where the infected leaves were rubbed onto seedlings of Topper barley. After the seedlings were incubated for 24–48 hr in a dew chamber at 10 C with 16 hr of diffuse fluorescent light (about 5,000 lux), they were placed in a greenhouse at 15 ± 2 C and 16 hr of supplemental fluorescent light (about 10,000 lux). Uredospores, collected after about 14 days by tapping the infected leaves, were placed over glycerine for 2–3 days in a refrigerator (2 C) for desiccation. Desiccated uredospores were sealed in glass ampoules and stored in liquid nitrogen until needed.

The differential barley lines (Table 1) plus the highly resistant lines I-5 and Abyssinian 14 were inoculated on the primary leaf with uredospores diluted 1:10 with *Lycopodium* spores as a carrier. Selected cultures were tested on wheat (*Triticum aestivum* L.) cultivars Michigan Amber and Taichung 29, which are susceptible to most races of *P. striiformis* f. sp. *tritici*. Inoculated seedlings were placed in a dew chamber for 24 hr as described previously, then incubated in a growth room with a diurnal cycle of 16 hr of fluorescent and incandescent light (about 25,000 lux) at 18 C and 8 hr of darkness at 12 C. Rust reactions were read on the scale of 0–9 (7) after about 14 days.

The primary source of field information concerning the virulence genes was the Latin American Rust Nursery (ELAR), which was sent out from Quito annually under the auspices of CIMMYT and Instituto de Investigaciones Agropecuarias (INIAP). Field data were obtained each season from the barley stripe rust differentials as well as from other barley cultivars in the ELAR.

Field tests. During 1981, selected barley cultivars sent from Ecuador to the Netherlands were planted in isolated plots in the polders of southern Flevoland as described by Zadoks (15). The cultivars were inoculated with a mixture of races 24 and 23 of *P. s. hordei* collected in the Netherlands. Similarly, these same lines, as components of a barley screening nursery, were planted at Santa Catalina experiment station, INIAP, Quito, Ecuador. The nursery was inoculated with *P. s. hordei* race 24 and its variants bulked from several locations in Ecuador. Rust readings in both countries were taken on adult plants using the modified Cobb scale (4).

Epidemiology. The second author visited Colombia during the initial epidemic in November 1975 at the request of the Colombian government and collected rust cultures from the area. The authors traveled throughout South America on many occasions between 1975 and 1984 observing and collecting samples of stripe rust from barley as well as interviewing national staff about the epidemic.

Yield losses and economic impact. The information cited was obtained from interviews with barley research workers and agriculture ministry officials in the Andean countries.

RESULTS

Identification of pathogen. Samples of isolates sent by Instituto Colombiano Agropecuario (ICA) to the second author in July 1975 were avirulent on the wheats and virulent on the barleys, indicating that they were *P. s. hordei*. The first samples tested appeared to be either race 23 or 24 on the basis of a variable reaction to the differential cultivar Cambrinus (Table 1). However, retesting with the isolates gave a susceptible reaction to Cambrinus. Subsequent samples were virulent on Cambrinus, and in some cases, they were virulent on Varunda. This indicated the presence of race 24 and race 24-Varunda (Table 1).

Between 1975 and 1983, 99 viable collections of stripe rust from cultivated barleys were received in the Netherlands from Colombia, Ecuador, Peru, Bolivia, Chile, and Argentina. All were classified as *P. s. hordei* race 24 or the variants with additional virulence on Varunda or Mazurka (Table 1). The cultures thus appeared to be identical to race 24 and its variants prevalent in Europe.

The adult plant field reactions of selected barley cultivars to stripe rust in the Netherlands and Ecuador are compared in Table 2. These cultivars were obtained from the Ecuadorian or Bolivian breeding programs. The adult plant host responses supported the seedling test results. Slight variations in reaction were probably caused by environment and observer differences in note-taking.

A common wild barley, *H. muticum* Prefl., was widely infected with stripe rust in the Department of Puno, Peru, in 1979. The isolate was identified as *P. s. hordei* race 24, demonstrating that the spread of the rust through the Andes Mountains need not depend only on cultivated barleys. A collection of stripe rust on *H. leporinum* Link., received from Chile in 1981, appeared to be unique because it did not infect any of the normal barley or wheat differentials, thus indicating a different form of the pathogen.

According to greenhouse tests and field observations, some minor changes in virulence patterns have been detected. Variants with compatibility to Varunda and Mazurka have been isolated that are similar to variants found in Europe. Cultivar I-5 became susceptible in the adult plant stage in Ecuador in 1983 and was also reported to be susceptible in Bolivia. Cultivar Bigo, susceptible as a seedling in England for some years and since 1981 in the Netherlands, is still resistant in the Andean countries. There are reports that Emir became susceptible in Bolivia (V. Valasco, *personal communication*), but we have not substantiated this because of nonviability of the spore collections. In Ecuador, the cultivars Dorada, Duchicela, and Teran continue to be resistant, and in Peru and Bolivia, the cultivar Grignon remains intermediate in reaction.

Epidemiology. The first reports of *P. s. hordei* came in 1975 from the savannah area near Bogotá, a principal area for growing malting barleys in Colombia. Two crops of barley were grown annually, which permitted a rapid increase of inoculum on the major commercial cultivars, Mochacá, Surbatá, and Funza (3). The pathogen moved progressively southward between 1975 and 1982 (Fig. 1). By June 1976, a year after the initial reports, *P. s. hordei* foci were found near the Ecuadorian-Colombian border at El Angel, Province of Carchi (H. Orellana, *personal communication*). First reports in southern Colombia (Department of Nariño) were in September 1976 (J. Sierra, *personal communication*). However, there were conflicting opinions about the precise timing of its arrival in Nariño. The rust spread southward rapidly, severely infecting the land varieties of barley in Ecuador and Peru, but encountered two improved cultivars with moderate levels of resistance, Dorada (Ecuador) and Zapata (Peru). The initial reports of stripe rust in Peru were in December 1977 in the south central mountain area of the departments of Junín, Huancavilica, Ayacucho, and Apurimac (8). Higher than normal rainfall occurred in this area in 1977–1978. The rust was not found in the northern departments in 1977, possibly because of the severe drought in that area (8). During 1978, however, *P. s. hordei* was observed in the northern Department of Ancash and in the southern Department of Cusco (8). By May 1978, it was found in the Department of Cochabamba, Bolivia, causing severe damage (V.

Table 1. Selected European barley stripe rust races and their seedling reactions on the barley differentials for *Puccinia striiformis* f. sp. *hordei*

	Host responses to races				
Differentials	23	24	24 Mazurka	24 Varunda	24 Mazurka-Varunda
Topper	S[a]	S	S	S	S
Cambrinus	R	S	S	S	S
Mazurka	R	R	S	R	S
Varunda	R	R	R	S	S
Bigo	R	R	R	R	R
Emir	R	M	M	M	M

[a]S = susceptible, M = intermediate, and R = resistant.

Table 2. Comparison of field reactions to *Puccinia striiformis* f. sp. *hordei* in the Netherlands and Ecuador of barley cultivars from Andean countries in 1981[a]

	Field reaction to stripe rust in nurseries	
Cultivar	Netherlands	Ecuador
Dorada	M[b]	M
Teran	R	R
Clipper	S	S
Convenio	M	MS
Emir	MR	MR
Promesa	MS	MS
IBTA 80	MR	...[c]
K'Ochala	MR	R
San Benito 80	MS	MS
Cebada Criolla	S	S

[a]Netherlands data obtained from nurseries artificially inoculated with races 23 and 24 in southern Flevoland. Ecuador data obtained in Quito from nurseries artificially inoculated with bulk inoculum.

[b]R = resistant, MR = moderately resistant, M = intermediate, MS = moderately susceptible, and S = susceptible.

[c]Although data were not obtained for this line in Ecuador in 1981, it had an intermediate reaction in succeeding years.

Velasco, *personal communication*). Throughout 1978 and 1979, the rust attacked commercial cultivars and land varieties in Bolivia. By mid-1980, it was observed by the first author in barley nurseries in the Bolivian Chaco (Department of Santa Cruz). In November 1980, the rust was reported in irrigated barley nurseries near Ovalle, Chile. The pathogen spread southward into the commercial barley areas of Chile (E. Beratto, *personal communication*). In 1982, the first author observed *P. s. hordei* in barley-breeding nurseries in Bordenave, Argentina, causing severe infection. Thus within 7 yr, *P. s. hordei* race 24 and its variants moved at least 6,000 km and infected almost all major commercial barley areas in South America except in Brazil (Fig. 1). Only two improved cultivars, Dorada and Zapata, showed resistance to the pathogen, as did the French cultivar Grignon, which is planted in Peru and is now cultivated in Bolivia under the name IBTA 80. Samples of the rust from each stage of its migration were tested by the second author and determined to be *P. s. hordei* race 24 or its variants.

Yield losses and economic impact. Precise data on the yield losses and resultant economic impact of *P. s. hordei* have not been obtained in the Andean countries. However, estimates of losses were made based on field surveys in 30 municipalities in Colombia in 1975. About 70% of the barley yield was lost (3), equivalent to about $6 million (U.S.) (*unpublished*). The Ecuadorian Ministry of Agriculture indicated that national barley yields between 1973 and 1976 were 0.88 t/ha (*unpublished*). After arrival of *P. s. hordei*, the yields dropped to 0.62 t/ha until 1980, by which time the resistant cultivar Dorada occupied most of the area and the yields rose to 0.93 t/ha. Dorada had been released in 1971 and fortunately was resistant, thus limiting the impact of the rust in Ecuador to a mean loss of 30%. The national small-grains program in Bolivia conducted fungicide trials on small farms with traditional technology in the Department of Cochabamba (Tiraque) from 1979 to 1981. Estimates of losses with land varieties in these trials varied between 47 and 61% (V. Velasco, *personal communication*). Although the data are sparse and imprecise, there is little doubt of the severe impact of the rust on the barley crop of the Andean countries.

Field response of introduced and local barley germ plasm to *P. s. hordei*. Table 3 shows the field response of some European and Andean germ plasm with high levels of resistance to *P. s. hordei*. These are typical of resistant materials that the Andean barley-breeding programs selected from diverse origins. Field observations indicate that some of the resistance in the Ecuadorian program is of an adult plant type. Since the advent of *P. s. hordei* in South America, it has been obvious that most North American barley cultivars tested in Ecuador were highly susceptible (Table 3).

DISCUSSION

The *P. striiformis* on barley in the Andean countries is indeed the f. sp. *hordei* and not f. sp. *tritici* commonly found there on wheat. Zadoks (14) found f. sp. *hordei* to be very specific. He states that the best evidence for the validity of the f. sp. *hordei* designation comes from field observations in Europe, where barley sections of nurseries are severely infected with f. sp. *hordei* whereas the wheat sections are rustfree. This coincides with the observations in the Andean countries. We postulate that the epidemic was initiated with inoculum originating from outside South America. The epidemiological evidence is consistent with this theory. Before 1975, there were no confirmed reports of f. sp. *hordei* in South America. Samples of stripe rust from barley in Chile, evaluated by the second author before 1975, were always f. sp. *tritici*. We believe that other reports were also due to f. sp. *tritici* infecting barley. The initial focus in Bogotá, Colombia, provided the inoculum that was carried south, we theorize, by prevailing winds. Within 7 yr, the rust spread throughout almost all of the barley areas in South America, with only rarely a cultivated barley noted as resistant, indicative of an exotic pathogen. We know of no reports of *P. s. hordei* in Brazil, presumably because of unfavorable climate.

The pathogen devastated the barley land varieties that date from the time of the Spanish conquest in the Andes. In almost all field and greenhouse observations, the extremely diverse land varieties of Ecuador, Peru, and Bolivia were very susceptible, indicating a lack of coevolution of host and obligate parasite (15).

The evidence points to the conclusion that the f. sp. *hordei* was an exotic pathogen in South America, possibly originating in Europe. The recent introduction of f. sp. *tritici* into Australia was hypothesized to have been caused either by uredospores carried in the undercarriages of airplanes or on contaminated clothing of travelers (13). Either of these methods might have been possible with *P. s. hordei* in South America.

The exotic *P. s. hordei* provided a

Table 3. Adult plant field reactions of some selected barley cultivars to *Puccinia striiformis* f. sp. *hordei* in Quito, Ecuador, in 1982[a]

Cultivar	Country of release	Host reaction
Jupiter	England	0R[b]
Maris Canon	England	0R
Minak	England	5MS
Multum	France	10MS
WW Wing	Sweden	10MS
UNA 80	Peru	0R
Quibenras	Colombia	0R
Teran	Ecuador	TR
K'Ochala	Bolivia	TR
Prato	United States	20S
CM 67	United States	40S
Larker	United States	100S
Morex	United States	80S
Manker	United States	90S
Beacon	United States	100S
Gus	United States	80S
Beecher	United States	30MS
Glenn	United States	80S
Conquest	Canada	100S

[a] Data extracted from diverse breeding nurseries planted in 1982 season. Nurseries inoculated with bulk collections of stripe rust from Ecuador.

[b] Modified Cobb scale (4) and host reaction: S = susceptible, MS = moderately susceptible, R = resistant, and TR = trace resistant.

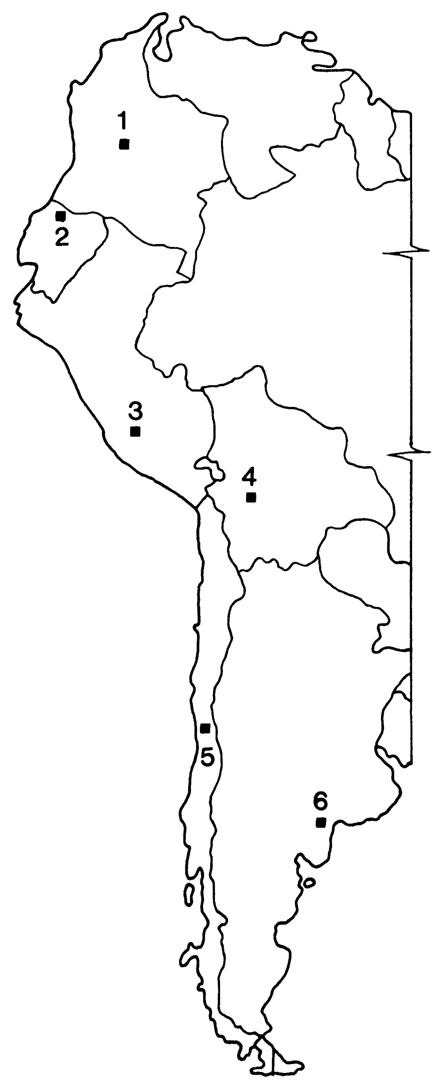

Fig. 1. Migration of *P. striiformis* f. sp. *hordei* in South America. Numbers refer to dates of initial sightings in the indicated countries and squares to the locations. 1 = June 1975, Bogotá, Colombia; 2 = June 1976, El Angel, Ecuador; 3 = December 1977, Junín, Huancavilica, Ayacucho, Apurimac, Peru; 4 = May 1978, Tiraque, Bolivia; 5 = November 1980, Ovalle, Chile; and 6 = November 1982, Bordenave, Argentina.

marker demonstrating that mountains and deserts were not sufficient barriers to prevent continental dispersal of a windborne pathogen. Although we theorize that the rapid, long-range movement within South America was due to wind, some local movement may have been due to transport of plant materials by animals or vehicles.

Changes in virulence were minimal in the Andean countries. Line I-5 has become susceptible, but in general, other variants seem similar to those found in Europe and may have arrived with the original inoculum. Almost all originally resistant cultivars in the Andean countries have remained so, thus showing no significant increase in pathogen virulence. Race 23 was predominant in Europe for decades until race 24 evolved and caused a severe epidemic in 1961 (6); race 24 has now been prevalent for two decades (10,11). Thus it appears that *P. s. hordei* is very stable in Europe, although the 1961 epidemic showed that changes can occur. Little is known about the resistance genes operating in European cultivars, but evidence indicates that there are only a few that are effective (10,11). If the new Andean resistance is genetically narrow, a potentially explosive situation may exist. However, systemic fungicides such as triadimefon have proved effective in the Andean countries and are available (9,12).

The rapid availability of resistant germ plasm from the world barley collection and from Europe has helped the national programs to respond to the menace and has demonstrated the importance of international cooperation. It should be noted, however, that the introduction of exotic germ plasm brings certain risks with respect to other diseases that are normally minor. Indeed, *P. hordei*, the cause of leaf rust, has become an important problem on the new stripe rust-resistant cultivars. The old land varieties apparently were more resistant.

Circumstantial evidence indicates that *P. s. hordei* is not present in North America (Table 3), but it could become a problem if introduced into the wetter, cooler areas where barley is cultivated. Barley stripe rust-resistant germ plasm has been provided to North American cooperators.

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LITERATURE CITED

1. Anonymous. 1984. FAO Monthly Bulletin of Statistics. Vol. 7, No. 10. Food Agric. Organ., Rome.
2. Briggs, F. N., and Knowles, P. F. 1967. Introduction to Plant Breeding. Reinhold Publ. Corp., New York. 426 pp.
3. Buriticá, P., and Miranda, A. 1976. La roya amarilla de la cebada y su control. Programa Nacional de Cereales Menores, Instituto Colombiano Agropecuario, Bogotá, Colombia. 45 pp.
4. Chester, K. S. 1950. Plant disease losses: Their appraisal and interpretation. Plant Dis. Rep. Suppl. 193:189-362.
5. Dubin, H. J., and Stubbs, R. W. 1984. *Puccinia striiformis* f. sp. *hordei*: Cause of barley yellow rust epidemic in South America. (Abstr.) Phytopathology 74:820.
6. Johnson, R. 1968. Genetics of resistance to barley yellow rust. Abstr. 99 in: First International Congress of Plant Pathology, London.
7. McNeal, F. H., Konzak, C. S., Smith, E. P., Tate, W. S., and Russel, T. S. 1971. A more uniform system for recording and processing cereal data. U.S. Dep. Agric. Agric. Res. Serv. Bull. 34-121. 42 pp.
8. Mont, R. M., Romero, M. J., and Gómez, L. 1978. La roya amarilla de la cebada en el Perú. Fitopatología 13:115-118.
9. Orellana, H., Vega, J. G., and Ruíz, E. 1978. La roya amarilla de la cebada, enemigo que amenaza! Bol. Divulg. 97. Inst. Nac. Invest. Agropec., Quito, Ecuador. 8 pp.
10. Röbbelen, G., and Sharp, E. L. 1978. Mode of inheritance, interaction and application of genes conditioning resistance to yellow rust. Verlag Paul Parey, Berlin. 88 pp.
11. Stubbs, R. W. 1985. Stripe rust. Pages 61-101 in: The Cereal Rusts. Vol. 2. Diseases, Distribution, Epidemiology, and Control. A. P. Roelfs and W. R. Bushnell, eds. Academic Press, Orlando, FL. 606 pp.
12. Velasco, V., and Brown, W. M., Jr. 1982. Stripe rust occurrence and control in Bolivia. (Abstr.) Phytopathology 72:975.
13. Watson, I. A., and Butler, F. C. 1984. Wheat rust control in Australia: National conferences and other initiatives and developments. Univ. Sydney, Sydney, Australia. 80 pp.
14. Zadoks, J. C. 1961. Yellow rust on wheat-studies in epidemiology and physiologic specialization. Tijdschr. Plantenziekten 67:69-256.
15. Zadoks, J. C., and Schein, R. D. 1979. Agroecosystems: Man and plant disease. Pages 293-336 in: Epidemiology and Plant Disease Management. Oxford University Press, New York. 427 pp.