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Races of *Puccinia striiformis* f. sp. *hordei*, the pathogen of barley stripe rust in the United States in 2004

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Abstract
Stripe rust of barley, caused by *Puccinia striiformis* f. sp. *hordei* (PSH), occurred mainly in California, Idaho, Oregon, and Washington and caused localized damage to barley crops. Growing cultivars with high-temperature, adult-plant resistance and the cropping system contributed to the low level of stripe rust. Stripe rust samples were collected from the four states and tested under controlled greenhouse conditions on seedlings of a set of 12 barley genotypes used to differentiate races of the fungal pathogen. A total of 15 races were detected, of which three were new. PSH-72, a new race, was virulent on all 12 differential genotypes. The most predominant race was PSH-71 that was virulent on differential genotypes Topper, Emir, Hiproly, Varunda, Abed Binder 12, Trumpf, Mazurk, Bigo, and Bancroft.

Introduction
Puccinia striiformis Westend. f. sp. *hordei* Eriks., the causal agent of barley stripe rust, has established in the United States since it was first reported in southern Texas in 1991 (Marshall and Sutton, 1995; Roelfs et al., 1992). In the early 1990s, the disease occurred in the south central states and later spread to the states west of the Rocky Mountains (Chen et al., 1995). The disease has caused major damage to barley crops in the U.S., mainly in California and the Pacific Northwest (Brown et al., 2001; Chen, 2004).

Chen et al. (1995) selected 11 barley genotypes for differentiating races of *P. striiformis* f. sp. *hordei*. Later, the barley cultivar 'Bancroft' was added to the differential set (Chen and Line, 2001). Using the differential genotypes, 69 races were identified from the early 1990s to 2003 (Chen et al., 1995; Chen and Line, 2001; Chen, 2004). The objectives of this study were to 1) monitor the occurrence and distribution of barley stripe rust and 2) identify races and determine their frequencies and distributions in the United States in 2004.

Materials and Methods
Monitoring barley stripe rust. Stripe rust was monitored by surveying commercial fields during the growing season. Trap plots consisting of the set of differential genotypes (Table 1) and other cultivars either susceptible or resistant to *P. striiformis* f. sp. *hordei* were planted at various locations. For commercial field survey, infection type, severity (percentage of leaf areas infected), prevalence (percentage of plants infected), and information on cultivar, location, and growth stage were recorded. For the trap plots, infection type and severity were recorded one to three times during the growing season. Stripe rust infected leaf samples were collected for race identification.

Race identification. Races of stripe rust samples were determined using a set of differential genotypes following the methods described by Chen et al. (1995). In this study, 12 barley

genotypes (Table 1) were used to differentiate races of *P. striiformis* f. sp. *hordei*. Samples of infected leaves that were usually shipped in glassine envelops were used to inoculate seedlings of 'Steptoe' or 'Topper', which are susceptible to all races of *P. striiformis* f. sp. *hordei*, for increasing urediniospores. For samples of poor quality (received more than 7 days after collection or with limited uredia), leaf pieces were placed on moist filter paper in a Petri dish that was kept at temperatures of 4-12°C overnight. Fresh spores produced on the leaves were used in inoculation for spore increase.

Inoculated plants were kept in a dew chamber at 10°C for 18 to 24 hours for infection and then grown in a greenhouse growth chamber at a diurnal temperature cycle gradually changing from 4°C at 2:00 am to 20°C at 2:00 pm. The light period consisted of day light supplemented with metal halide lights to extend the photoperiod to 16 hours. Urediniospores that were collected 16 to 30 days after inoculation were used to inoculate seedlings of the set of differential genotypes. Inoculated plants were kept in the dew chamber for infection and then grown in a growth chamber for symptom development under the same conditions as described for the spore increase. Infection type (IT) data were recorded 18-22 days after inoculation according to the 0-9 scale described by Line and Qayoum (1991). Isolates that produced ITs 0 - 5 were considered avirulent and 6 - 9 were considered virulent on individual barley differential genotypes. New races that had virulence patterns different from previously identified races were confirmed at least in one more test with the differential genotypes. Frequency of each race was determined as percentage of the isolates that were identified as that race from the total of isolates in the study.

Table 1. Barley genotypes used to differentiate races of *Puccinia striiformis* f. sp. *hordei*

Differential genotype			Resistance gene[a]
Number	Name	ID number	
1	Topper	-	-
2	Heils Franken	PI 290183	*Rps4*, *rpsHF*
3	Emir	CIho 13541	*rpsEm1*, *rpsEm2*
4	Astrix	CIho 13862	*Rps4*, *rpsAst*
5	Hiproly	CIho 03947	*rpsHi1*, *rpsHi2*
6	Varunda	PI 410865	*rpsVa1*, *rpsVa2*
7	Abed Binder 12	PI 327961	*rps2*
8	Trumpf	PI 548762	*rpsTr1*, *rpsTr2*
9	Mazurka	PI 399501	*Rps1.c*
10	Bigo	CIho 11795	*Rps1.b*
11	I 5	PI 288187	*Rps3*, *rpsI5*
12	Bancroft	PI 605474	Not determined

[a] Chen and Line (2003).

Results and Discussion

In 2004, stripe rust occurred in California, Oregon, Washington, and Idaho. Of a total of 39 viable isolates of *P. striiformis* f. sp. *hordei*, 18 were obtained from California, 3 from Oregon, 13 from Washington, and 5 from Idaho. All isolates were from barley (*Hordeum vulgare*) cultivars, except for one isolate that was collected from wild barley (*H. spontaneum*) in California. The isolate from wild barley was identified as race PSH-33 that was virulent only on two (Topper and Abed Binder 12) of the differential genotypes. As shown in Table 2, a total of 15 PSH races were identified, of which three were new and designated as PSH-70, PSH-71, and PSH-72 (Table 3). PSH-70 was virulent on four (Topper, Abed Binder 12, Bigo, and Bancroft) of the 12 differential genotypes. PSH-71 was virulent on nine (Topper, Emir, Hiproly, Varunda, Abed Binder 12, Trumpf, Mazurk, Bigo, and Bancroft). PST-72

was virulent on all 12 differential genotypes. Of the 15 races, nine were presented by only one isolate, one by two isolates, three by four isolates, one by five isolates, and one by 14 isolates. Although PSH-71 was new, it was the most predominant race. Nearly 85% of the isolates were collected from disease monitoring and germplasm screening nurseries. Only 15% of the isolates were obtained from commercial fields, indicating that the severity levels of stripe rust in commercial field were generally low.

The barley stripe rust incidence was relatively low compared to wheat stripe rust in 2004. The barley yield losses due to stripe rust were estimated as 63,000 bushels in the four states (http://www.cdl.umn.edu/loss/loss.html). In contrast, wheat stripe rust had a much wider spread and severer epidemic, which caused yield losses of about 6.6 million bushels (http://www.cdl.umn.edu/loss/loss.html), plus millions of dollars spent on fungicide application in the four states. The relatively light stripe rust epidemic on barley compared to wheat stripe rust epidemic in the Pacific Northwest were attributed to 1) the smaller barley acreage, 2) the lack of winter barley, which reduces rust inoculum from previous crops, and 3) the use of high-temperature, adult-plant resistant cultivars such as Baronesse (Chen, 2004). In California, the reduced barley acreage compared to that in early 1990s and growing resistant cultivars have contributed the low level of stripe rust in the recent years.

Even though stripe rust was generally light in commercial fields, susceptible cultivars in various nurseries had up to 100% of severity in California and western Washington. The disease monitoring data suggest that stripe rust is still a threat to barley production in the western United States. For this region, stripe rust resistance should remain as one of the top priorities for barley breeding programs.

Table 2. Races of *Puccinia striiformis* f. sp. *hordei* (PSH) and their frequencies and distributions in 2004

PSH race	Virulence[a]	1st year detected	No. of isolates	Frequency (%)	Distribution state (No.)
19	1,3,5,6,7,8	1995	1	2.4	WA(1)
22	1,4,7,8,9,10	1995	1	2.4	WA(1)
33	1,7	1996	1	2.4	CA(1)
35	1,4,7	1996	2	4.8	CA(2)
45	1,3,4,6,7,8	1996	1	2.4	CA(1)
46	1,7,8	1996	1	2.4	WA(1)
52	1,5,7,8	1998	1	2.4	CA(1)
56	1,5,7,8,12	2001	4	9.5	CA(1), WA(3)
60	1,5,7,8,9,10,12	2001	4	9.5	CA(2), WA(2)
64	1,5,7,8,10,12	2002	5	11.9	CA(3), ID(1), WA(1)
65	1,2,3,4,7,8,12	2002	1	2.4	CA(1)
69	1,5,6,7,8,9,10,11,12	2003	1	2.4	ID(1)
70	1,7,10,12	2004	1	2.4	CA(1)
71	1,3,5,6,7,8,9,10,12	2004	14	33.3	CA(6), ID(2), WA(5)
72	1,2,3,4,5,6,7,8,9,10,11,12	2004	4	9.5	CA(1), ID(1), OR(2)

[a] See Table 1 for the barley genotypes used to differentiate races of *P. striiformis* f. sp. *hordei*.

Table 3. New races of *Puccinia striiformis* f. sp. *hordei* (PSH) detected in 2004, type isolates, and dates, locations, and cultivars collected

PSH	Type	Date	Collected from		
race	Isolate	Collected	State	Location	Cultivar
70	04-304	7/14/2004	California	Tulelake	Steptoe
71	04-023	3/29/2004	California	Davis	APB b-12
72	04-51-12	4/9/2004	Oregon	Corvallis	88Ab536

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