Differential Resistance to Stripe Rust (*Puccinia striiformis*) in Collections of Basin Wild Rye (*Leymus cinereus*)

Frank M. Dugan, Michael J. Cashman, and **Richard C. Johnson,** USDA-ARS Western Regional Plant Introduction Station, **Meinan Wang,** Department of Plant Pathology, and **Xianming Chen,** USDA-ARS Wheat Genetics, Quality, Physiology, and Disease Research Unit, Washington State University, Pullman 99164

Accepted for publication 19 May 2014. Published 23 June 2014

ABSTRACT

Dugan, F. M., Cashman, M. J., Johnson, R. C., Wang, M. N., and Chen, X. M. 201X. Differential resistance to stripe rust (*Puccinia striiformis*) in collections of Basin wild rye (*Leymus cinereus*). Plant Health Progress doi:10.1094/PHP-RS-14-0002

Differential resistance to stripe rust (*Puccinia striiformis*) in a planting of 111 wild collections of Basin wild rye (*Leymus cinereus*) was noted 2011-2013. In 2011, rust severity was rated on a scale of 1-9. Much lighter infection in 2012 and 2013 was rated as the number of symptomatic leaves per plant divided by plant circumference (to adjust for plant size). Effect of collection was significant in 2011 ($P = 0.0042$), 2012 ($P = 0.0032$), and 2013 ($P = 0.0095$), with a relatively weak (0.23) but significant ($P = 0.0149$) correlation between 2011 and 2012 and a stronger (0.38) and highly significant ($P < 0.0001$) correlation between 2012 and 2013. Correlation between results of 2011 and 2013 was near zero and insignificant unless the ratings from 2011 were adjusted for plant size. Representative resistant and susceptible collections will be conserved as accessions in the National Plant Germplasm System.

INTRODUCTION

Basin wild rye [*Leymus cinereus* (Scribn. & Merr.) Á. Löve, synonym *Elymus cinereus* Scribn. & Merr.] is a large, coarse perennial bunchgrass native to arid and semiarid regions of western North America. It is useful for grazing, wildlife habitat, and soil stabilization; its large size provides wind protection for livestock and wildlife during winter (26). Basin wild rye exists as a natural tetraploid or octoploid (10,12), from which commercial cultivars have been derived for use in restoration (10,18). Hybrids have been established between *L. cinereus* and *L. triticoides* (Buckley) Pilg., beardless wild rye (19); and of the latter with *L. condensatus* (J. Presl) Á. Löve, giant wild rye (3), and *Hordeum jubatum* L., foxtail barley (2). Hybrids of *L. cinereus* can also be established with *Elymus canadensis* L., Canada wild rye (12). Both *E. canadensis* and *H. jubatum* have been used to establish hybrids with *H. vulgare* L., common barley (24,27). Of the Triticeae in general, "members are connected by a network of introgressants and hybrids" (4).

Stripe rust (*Puccinia striiformis* Westend.) is a rust disease of cereals and grasses especially important on wheat and barley (7). Sources of resistance to stripe rust are usually available in cultivars and landraces of these cereals (7,8). We first noticed a highly variable occurrence of orange, striate sori in a field trial of Basin wild rye in June of 2011. Given the numerous and varied collections of Basin rye for which we could document differential resistance, and given the propensity for hybridization within the Triticeae, we thought it prudent to document our observations.

APPROACH AND DESIGN

Wildland *L. cinereus* populations from the Columbia Basin in Washington State and the Great Basin in southeastern Oregon, southwestern Idaho, and northern Nevada were collected in 2009 according to the protocol of Bradley St. Clair et al. (5). At each of 111 locations ("collections") (Table 1), seed was collected from individual parent plants separated by a minimum of 5 m to promote collection of unrelated individuals within locations. The progeny from two parent plants at each location, defined as families, were used to represent each of the 111 populations. This approach provided a pooled estimate of variance among families within populations, which was used as an error term to test differences among populations for rust.

In 2010, seeds from two families at each collection location were germinated on moist vermiculite in sealed germination boxes measuring 14 × 13 × 3.5 cm deep. Germination boxes were covered to prevent exposure to light, and seeds stratified at 4°C for two weeks beginning 23 November 2009. Boxes were subsequently exposed to ambient light and temperature to promote germination. Individual seedlings were planted to 1 cm depth in Sunshine #5 plug mix (Bellevue, WA) and organized in 36-cell Compak tray inserts (HPS, Randoph, WI) with cell dimensions of 5 × 6.25 × 6.25 cm deep.

Plants were over-wintered in a greenhouse for three months before being moved to a lath-house for acclimation prior to field transplanting. They were fertilized twice with a solution of 145 g Peters 20-20-20 (Allentown, PA), 15 g Fe sequestrene 330, 50 g $MgSO_4$, 0.6 ml Soluble Trace Element Mix, and 1.2 ml EDTA per 19 liters of water applied by siphon mixer at a ratio of 1 to 15. Well-established plugs were outplanted by hand to a common garden field trial in Pullman, WA (46°43′9″ N, 117°8′29″ W) on 16-17 September 2010.

The field trial consisted of two families for each of 111 collections nested within six randomized complete blocks. Six collections were represented by only one family per block due to poor seed germination. Thus the common garden consisted of 1308 total plants.

Corresponding author: F. M. Dugan. Email: fdugan@wsu.edu

doi:10.1094/PHP-RS-14-0002

TABLE 1
Stripe rust on *Leymus cinereus* planted at Pullman, WA, 2010 and rated 2011-2013.

Location ID	County	State	Date collected	Collector(s)	2011 rust rating[x]	2012 rusted lvs/circum[y]	2013 rusted lvs/circum[y]	Consistency over years[z]
LECI09R-43	Owyhee	ID	9/5/2009	R. Johnson/W. Kaiser	1.80	0.011	0.002	
LECI09-116	Elmore	ID	9/22/2009	R. Johnson/W. Kaiser	2.09	0.021	0.000	
LECI09R-34	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	2.20	0.000	0.000	low 40
LECI09R-38	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	2.25	0.074	0.000	
LECI09R-67	Walla Walla	WA	9/10/2009	R. Johnson/W. Kaiser	2.27	0.001	0.000	
LECI09R-51	Owyhee	ID	9/6/2009	R. Johnson/W. Kaiser	2.44	0.000	0.011	
LECI09R-37	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	2.45	0.005	0.000	low 30
LECI09M-43	Elko	NV	9/15/2009	M. Cashman/M. Scholten	2.45	0.046	0.002	
LECI09M-24	Lincoln	NV	9/12/2009	M. Cashman/M. Scholten	2.45	0.002	0.000	low 30
LECI09R-62	Adams	WA	9/9/2009	R. Johnson/W. Kaiser	2.50	0.000	0.000	low 40
LECI09R-45	Owyhee	ID	9/5/2009	R. Johnson/W. Kaiser	2.50	0.104	0.074	
LECI09M-5	Humboldt	NV	9/8/2009	M. Cashman/M. Scholten	2.50	0.043	0.199	
LECI09R-35	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	2.55	0.015	0.000	
LECI09R-21	Humboldt	NV	9/2/2009	R. Johnson/W. Kaiser	2.58	0.036	0.000	
LECI09R-18	Elko	NV	9/2/2009	R. Johnson/W. Kaiser	2.60	0.165	0.025	
LECI09R-57	Lincoln	WA	9/9/2009	R. Johnson/W. Kaiser	2.64	0.011	0.003	
LECI09M-2	Pershing	NV	9/8/2009	M. Cashman/M. Scholten	2.64	0.029	0.000	
LECI09R-19b	Elko	NV	9/2/2009	R. Johnson/W. Kaiser	2.64	0.000	0.015	
LECI09R-60	Adams	WA	9/9/2009	R. Johnson/W. Kaiser	2.67	0.006	0.000	
LECI09R-32	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	2.67	0.035	0.000	
LECI09R-26	Humboldt	NV	9/3/2009	R. Johnson/W. Kaiser	2.67	0.164	0.002	
LECI09R-27	Humboldt	NV	9/3/2009	R. Johnson/W. Kaiser	2.67	0.050	0.031	
LECI09R-52	Twin Falls	ID	9/6/2009	R. Johnson/W. Kaiser	2.67	0.014	0.003	
LECI09M-25	White Pine	NV	9/12/2009	M. Cashman/M. Scholten	2.67	0.007	0.000	low 40
LECI09R-65	Franklin	WA	9/10/2009	R. Johnson/W. Kaiser	2.70	0.055	0.008	
LECI09R-9	Elko	NV	9/1/2009	R. Johnson/W. Kaiser	2.70	0.078	0.028	
LECI09M-44	Elko	NV	9/15/2009	M. Cashman/M. Scholten	2.70	0.102	0.078	
LECI09R-69	Whitman	WA	9/21/2009	R. Johnson/W. Kaiser	2.73	0.001	0.000	low 40
LECI09R-17	Elko	NV	9/2/2009	R. Johnson/W. Kaiser	2.73	0.033	0.018	
LECI09M-33	Elko	NV	9/13/2009	M. Cashman/M. Scholten	2.75	0.003	0.001	
LECI09R-23	Humboldt	NV	9/2/2009	R. Johnson/W. Kaiser	2.75	0.068	0.029	
LECI09M-36	Elko	NV	9/14/2009	M. Cashman/M. Scholten	2.75	0.023	0.009	
LECI09R-12	Elko	NV	9/1/2009	R. Johnson/W. Kaiser	2.75	0.019	0.007	
LECI09R-53	Jerome	ID	9/6/2009	R. Johnson/W. Kaiser	2.78	0.010	0.007	
LECI09R-61	Adams	WA	9/9/2009	R. Johnson/W. Kaiser	2.80	0.092	0.003	
LECI09M-4	Pershing	NV	9/8/2009	M. Cashman/M. Scholten	2.80	0.149	0.013	
LECI09M-35	Elko	NV	9/14/2009	M. Cashman/M. Scholten	2.80	0.007	0.000	
LECI09M-9	Lander	NV	9/9/2009	M. Cashman/M. Scholten	2.80	0.025	0.000	
LECI09R-68	Columbia	WA	9/10/2009	R. Johnson/W. Kaiser	2.82	0.001	0.000	
LECI09M-39	Elko	NV	9/14/2009	M. Cashman/M. Scholten	2.82	0.072	0.024	
LECI09M-22	White Pine	NV	9/12/2009	M. Cashman/M. Scholten	2.82	0.010	0.000	
LECI09M-41	Eureka	NV	9/14/2009	M. Cashman/M. Scholten	2.83	0.028	0.001	
LECI09M-29	White Pine	NV	9/13/2009	M. Cashman/M. Scholten	2.83	0.018	0.000	
LECI09R-25	Humboldt	NV	9/3/2009	R. Johnson/W. Kaiser	2.90	0.084	0.033	
LECI09M-38	Elko	NV	9/14/2009	M. Cashman/M. Scholten	2.90	0.042	0.000	
LECI09R-64	Garfield	WA	9/10/2009	R. Johnson/W. Kaiser	2.91	0.015	0.002	
LECI09-115	Blaine	ID	9/18/2009	R. Johnson/W. Kaiser	2.91	0.000	0.000	
LECI09R-54	Whitman	WA	9/9/2009	R. Johnson/W. Kaiser	2.92	0.005	0.001	
LECI09R-1	Adams	ID	8/30/2009	R. Johnson/W. Kaiser	2.92	0.003	0.000	
LECI09R-58	Lincoln	WA	9/9/2009	R. Johnson/W. Kaiser	3.00	0.000	0.000	
LECI09R-47	Owyhee	ID	9/5/2009	R. Johnson/W. Kaiser	3.00	0.035	0.000	

(continued)

TABLE 1 (continued)
Stripe rust on *Leymus cinereus* planted at Pullman, WA, 2010 and rated 2011-2013.

Location ID	County	State	Date collected	Collector(s)	2011 rust rating[x]	2012 rusted lvs/circum[y]	2013 rusted lvs/circum[y]	Consistency over years[z]
LECI09R-24	Humboldt	NV	9/3/2009	R. Johnson/W. Kaiser	3.00	0.053	0.013	
LECI09R-48	Owyhee	ID	9/6/2009	R. Johnson/W. Kaiser	3.00	0.009	0.000	
LECI09R-39	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	3.00	0.042	0.000	
LECI09R-30	Lake	OR	9/3/2009	R. Johnson/W. Kaiser	3.00	0.000	0.000	
LECI09R-3	Cassia	ID	8/31/2009	R. Johnson/W. Kaiser	3.00	0.017	0.003	
LECI09M-37	Elko	NV	9/14/2009	M. Cashman/M. Scholten	3.00	0.018	0.000	
LECI09M-3	Pershing	NV	9/8/2009	M. Cashman/M. Scholten	3.00	0.023	0.004	
LECI09M-32	Elko	NV	9/13/2009	M. Cashman/M. Scholten	3.00	0.000	0.000	
LECI09R-46	Owyhee	ID	9/5/2009	R. Johnson/W. Kaiser	3.00	0.091	0.000	
LECI09M-26	White Pine	NV	9/12/2009	M. Cashman/M. Scholten	3.00	0.003	0.002	
LECI09R-22	Humboldt	NV	9/2/2009	R. Johnson/W. Kaiser	3.00	0.199	0.000	
LECI09R-8	Twin Falls	ID	9/1/2009	R. Johnson/W. Kaiser	3.08	0.114	0.018	
LECI09M-28	Nye	NV	9/13/2009	M. Cashman/M. Scholten	3.08	0.003	0.000	
LECI09M-8	Lander	NV	9/9/2009	M. Cashman/M. Scholten	3.09	0.034	0.042	
LECI09M-31	White Pine	NV	9/13/2009	M. Cashman/M. Scholten	3.09	0.110	0.063	
LECI09M-13	Nye	NV	9/11/2009	M. Cashman/M. Scholten	3.11	0.073	0.014	
LECI09R-56	Lincoln	WA	9/9/2009	R. Johnson/W. Kaiser	3.17	0.000	0.005	
LECI09M-40	White Pine	NV	9/14/2009	M. Cashman/M. Scholten	3.17	0.016	0.000	
LECI09M-23	White Pine	NV	9/12/2009	M. Cashman/M. Scholten	3.17	0.113	0.007	
LECI09R-15	Elko	NV	9/1/2009	R. Johnson/W. Kaiser	3.18	0.015	0.010	
LECI09R-40	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	3.20	0.138	0.024	high 40
LECI09R-28	Lake	OR	9/3/2009	R. Johnson/W. Kaiser	3.20	0.094	0.025	high 40
LECI09M-12	Nye	NV	9/11/2009	M. Cashman/M. Scholten	3.20	0.215	0.019	high 40
LECI09R-42	Malheur	OR	9/5/2009	R. Johnson/W. Kaiser	3.25	0.007	0.002	
LECI09R-16	Elko	NV	9/1/2009	R. Johnson/W. Kaiser	3.25	0.004	0.004	
LECI09M-45	Elko	NV	9/15/2009	M. Cashman/M. Scholten	3.27	0.036	0.022	
LECI09R-20	Elko	NV	9/2/2009	R. Johnson/W. Kaiser	3.27	0.004	0.000	
LECI09M-15	Lander	NV	9/11/2009	M. Cashman/M. Scholten	3.27	0.175	0.088	high 40
LECI09R-44	Owyhee	ID	9/5/2009	R. Johnson/W. Kaiser	3.29	0.046	0.000	
LECI09M-30	White Pine	NV	9/13/2009	M. Cashman/M. Scholten	3.30	0.002	0.007	
LECI09R-63	Whitman	WA	9/10/2009	R. Johnson/W. Kaiser	3.33	0.028	0.000	
LECI09M-1	Pershing	NV	9/8/2009	M. Cashman/M. Scholten	3.33	0.066	0.003	
LECI09R-7	Cassia	ID	8/31/2009	R. Johnson/W. Kaiser	3.33	0.003	0.000	
LECI09R-11	Elko	NV	9/1/2009	R. Johnson/W. Kaiser	3.33	0.037	0.003	
LECI09M-27	White Pine	NV	9/13/2009	M. Cashman/M. Scholten	3.33	0.020	0.000	
LECI09M-10	Lander	NV	9/9/2009	M. Cashman/M. Scholten	3.38	0.148	0.037	high 30
LECI09M-11	Mineral	NV	9/10/2009	M. Cashman/M. Scholten	3.40	0.354	0.026	high 30
LECI09R-5	Cassia	ID	8/31/2009	R. Johnson/W. Kaiser	3.43	0.037	0.004	
LECI09R-19a	Elko	NV	9/2/2009	R. Johnson/W. Kaiser	3.45	0.013	0.045	
LECI09R-14	Elko	NV	9/1/2009	R. Johnson/W. Kaiser	3.45	0.111	0.001	high 30
LECI09M-17	Churchill	NV	9/11/2009	M. Cashman/M. Scholten	3.50	0.143	0.026	high 30
LECI09M-21	Eureka	NV	9/12/2009	M. Cashman/M. Scholten	3.56	0.000	0.000	
LECI09R-29	Lake	OR	9/3/2009	R. Johnson/W. Kaiser	3.64	0.039	0.021	
LECI09R-49	Owyhee	ID	9/6/2009	R. Johnson/W. Kaiser	3.67	0.017	0.003	
LECI09R-59	Grant	WA	9/9/2009	R. Johnson/W. Kaiser	3.73	0.009	0.000	
LECI09M-16	Churchill	NV	9/11/2009	M. Cashman/M. Scholten	3.73	0.078	0.015	high 30
LECI09M-20	Eureka	NV	9/12/2009	M. Cashman/M. Scholten	3.73	0.271	0.051	high 40
LECI09M-18	Lander	NV	9/12/2009	M. Cashman/M. Scholten	3.75	0.123	0.123	
LECI09R-55	Whitman	WA	9/9/2009	R. Johnson/W. Kaiser	3.82	0.055	0.009	high 40
LECI09R-41	Malheur	OR	9/5/2009	R. Johnson/W. Kaiser	3.82	0.055	0.014	high 40
LECI09M-6	Humboldt	NV	9/9/2009	M. Cashman/M. Scholten	3.89	0.105	0.008	high 40

(continued)

TABLE 1 (continued)
Stripe rust on *Leymus cinereus* planted at Pullman, WA, 2010 and rated 2011-2013.

Location ID	County	State	Date collected	Collector(s)	2011 rust rating[x]	2012 rusted lvs/circum[y]	2013 rusted lvs/circum[y]	Consistency over years[z]
LECI09M-42	Eureka	NV	9/14/2009	M. Cashman/M. Scholten	3.89	0.000	0.000	
LECI09R-50	Owyhee	ID	9/6/2009	R. Johnson/W. Kaiser	3.90	0.003	0.000	
LECI09R-66	Franklin	WA	9/10/2009	R. Johnson/W. Kaiser	3.91	0.008	0.000	
LECI09R-4	Cassia	ID	8/31/2009	R. Johnson/W. Kaiser	3.91	0.000	0.000	
LECI09M-34	Elko	NV	9/14/2009	M. Cashman/M. Scholten	3.91	0.052	0.012	high 40
LECI09-117	Blaine	ID	9/17/2009	R. Johnson/W. Kaiser	3.92	0.015	0.005	
LECI09M-7	Lander	NV	9/9/2009	M. Cashman/M. Scholten	4.00	0.271	0.040	high 30
LECI09R-33	Harney	OR	9/4/2009	R. Johnson/W. Kaiser	4.08	0.083	0.027	high 30
LECI09R-31	Harney	OR	9/3/2009	R. Johnson/W. Kaiser	4.25	0.046	0.003	

[x] Rust rating on 1-9 scale, with 1 = no rust, 9 = most rust; stripe rust was heavy in 2011 and collections are listed in order of lowest to highest rust in 2011.

[y] Number of symptomatic (rusted) leaves per plant divided by plant circumference; stripe rust was light in 2012-2013.

[z] Low 30 or Low 40 indicates consistent membership in 30 or 40 plants with lowest rust across all three years.
High 30 or High 40 indicates consistent membership in 30 or 40 plants with highest rust across all three years.

The field trial was established for evaluation of quantitative plants traits associated with phenology, production, and morphology. In summer 2011, a significant rust infection appeared extemporaneously. As a result, susceptibility to rust was recorded for each plant from 29 June-1 July 2011, as a rating of 1 (least) to 9 (most) susceptible, analogous to a scale for wheat (20). Severity of rust was much diminished when recorded 16-17 July 2012 and 24-30 July 2013. In those latter years, nearly all plants would have been rated at the very low end of the 1-9 scale, obscuring differences between plants. So in 2012 and 2013 each plant was rated by counting the number of symptomatic (rusted) leaves per plant, later adjusted by dividing this number of rusted leaves per plant by the plant's circumference as a correction for plant size.

The rust was keyed and compared with descriptions in literature (1,11,16,23,28). Teliospores and urediniospores were mounted in 85% lactic acid, or (for observation of pores) aniline blue, measured at 400×, and photographed with a Nikon D5000 digital camera mounted on an Olympus BH2 microscope. To confirm identification based on symptoms and morphological criteria, DNA was extracted from leaf tissue with visible uredinia. A piece of 1.0 × 2.0-cm tissue was cut and put into a 2.0-ml tube with 100-µl 0.7-mm Zirconia beads (BioSpec Products, Bartlesville, OK). The sample was shaken by a Mini Beadbeater (BioSpec Products) for 3 min. DNA was extracted using the modified hexadecyltrimethylammonium bromide method (30). Two markers were used for identifying *P. striiformis* f. sp. *tritici*, the wheat stripe rust pathogen: Marker 10I12 based on a conidiation gene (22) and ITS3puc/ITS4B based on ribosomal DNA (rDNA) internal transcribed spacer (ITS) region 2. Primers 10I12F (5′-ATCATCAGCATCACCCTC-3′), 10I12R (5′-AACCGACTAAATACAACCAG-3′) and ITS3puc (5’-ACATCGATGAAGAACACAGT-3′) were developed in our lab (22; Wang and Chen, *unpublished*). ITS4B (5′-CAGGAGACTTGTACACGGTCCAG-3′) was used as previously described (14). PCR conditions, gel electrophoresis, and visualization were performed following the published procedures for the 10I12 marker (22) and the ITS region (14). Resultant bands were compared with those from standards for *P. striiformis* f. sp. *tritici*; *P. striiformis* f. sp. *hordei* (causing barley stripe rust); *P. pseudostriiformis* M. Abbasi, Hedjar. & M. Scholler (= *P. striiformis* f. sp. *poae*, causing bluegrass stripe rust); *P. striiformoides* M. Abbasi, Hedjar. & M. Scholler (= *P. striiformis* f. sp. *dactylidis*, causing orchardgrass stripe rust); *P. graminis* Pers. f. sp. *tritici* (causing wheat stem rust); *P. triticina* Eriks. (causing wheat leaf rust); and *P. coronata* Corda (causing oat crown rust). Vouchers were deposited (WSP 72510, WSP 72511).

Analysis of variance was completed using the mixed procedure (Proc Mixed, SAS Institute Inc., Cary, NC) in SAS/STAT version 9.2 (21). Separate analyses were conducted each year with blocks and families within collections as random effects; collections were considered fixed effects.

RESULTS AND SIGNIFICANCE

Effect of collection on rust rating was significant in 2011 (P = 0.0042), 2012 (P = 0.0032), and 2013 (P = 0.0095), with a relatively weak (0.2339) but significant (P = 0.0149) correlation between 2011 and 2012 and a stronger (0.37830) and highly significant (P < 0.0001) correlation between 2012 and 2013. However, the correlation between 2011 and 2013 was very weak and insignificant unless the 1-9 rating of 2011 was adjusted by plant circumference, in which case the correlation (0.21763) was significant (P = 0.0218). The most consistently resistant (low 30, low 40) and susceptible (high 30, high 40) collections are indicated in Table 1.

Symptoms and signs on leaves consisted of pustules arranged in lines (Fig. 1A). Uredinia, telia, urediniospores (mostly 26-32 × 22.5-29.5 µm, Fig. 1B), including arrangement of germ pores (typically ~12, scattered, Fig. 1C), and teliospores (mostly 42-66 × 14-23 µm, Figs. 1D, 1E) matched descriptions for *P. striiformis*, and the fungus consistently keyed to that species (or its synonym *P. glumarum* Erikss. & Henning). With regard to DNA of our specimen, primer ITS3puc/ITS4B amplified a 519 bp fragment having the same size as a fragment from a standard isolate (PST-130) of the wheat stripe rust pathogen, and smaller than a 531 bp fragment from a standard isolate of *P. graminis*, agent of wheat stem rust. Marker 10I12 amplified a 750-bp fragment in the standard isolate of *P. striiformis* f. sp. *tritici* and in our specimen, but did not amplify DNA in *P. graminis* or other *Puccinia* taxa (Figs 2A, 2B).

This study demonstrated variability of susceptibility to stripe rust in an extensive series of collections of Basin rye. Basin rye has been previously documented as being of variable susceptibility to stripe rust (6). Those authors (6), expanding on a previous study, used seedlings representing a collection of 64 plants from a single, undisclosed location (but possibly Wyoming, from the collection number Wy 107).

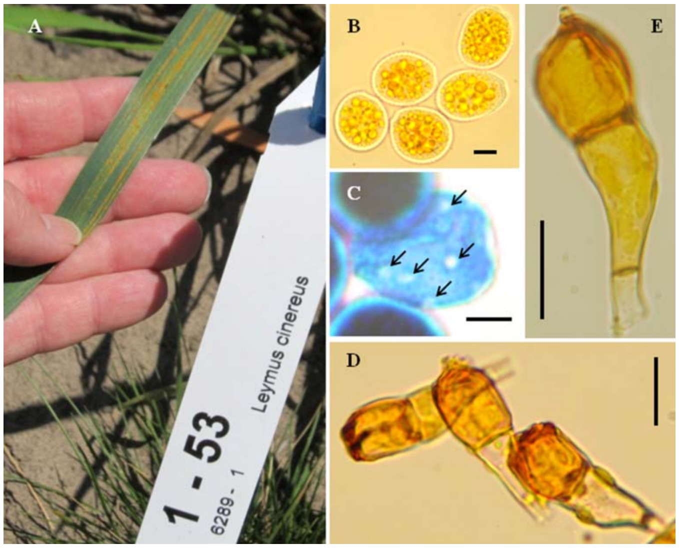

FIGURE 1

Stripe rust (*Puccinia striiformis*) on Basin wild rye, symptoms and morphology: **A,** linear pattern of erumpent, orange sori on leaves; **B,** urediniospores, bar = 10µm; **C,** scattered pores (arrows) in urediniospore in aniline blue, bar = 10 µm; and **D, E,** teliospores, bars = 20 µm.

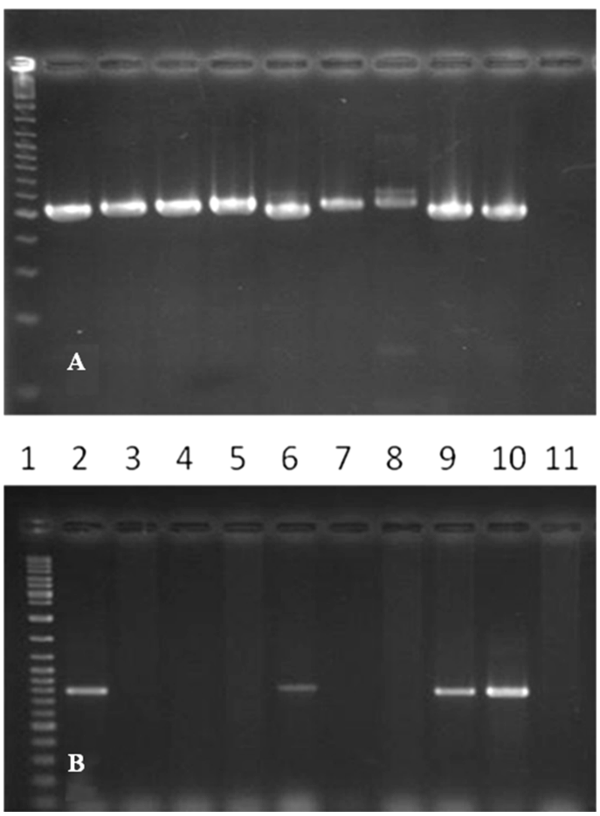

FIGURE 1

Stripe rust (*Puccinia striiformis*) on Basin wild rye, molecular identification. **A,** PCR amplification with primers ITS3puc/ITS4B. **B,** PCR amplification with primer 10I12. Lane 1: DNA ladder, lane 2: PST-130 (wheat stripe rust), lane 3: PSP-91WA-1 (bluegrass stripe rust), lane 4: PSD-94WA-1 (orchard grass stripe rust), lane 5: PGT-A10-07 (wheat stem rust), lane 6: PSH-63 (barley stripe rust), lane 7: PT-WA10-01 (wheat leaf rust), lane 8: PC-WA06MYZ-01 (oat crown rust), lane 9: PST-130, lane 10: Leymus stripe rust, lane 11: H_2O.

Puccinia striiformis and closely related taxa have been documented on multiple species of *Leymus*, *Elymus*, and other grasses and cereals (13,15,17,29). Although stripe rust collected from *Leymus* spp. was considered as a different forma specialis, *P. striiformis* f. sp. *leymi* (25), samples of the stripe rust pathogen collected from *Leymus* species were often identified as predominant races of *P. striiformis* f. sp. *tritici*, the wheat stripe rust pathogen, in the U.S. Pacific Northwest (9). The more severe stripe rust in 2011 and less severe stripe rust in 2012 and 2013 in our Basin wild rye plots well correlated to the wheat stripe rust epidemic levels in the region. We know of no other instances in which numerous collections from multiple locations were rated for resistance/susceptibility in sequential years, and in which the collections have been conserved and made available for distribution.

Future research entails outplanting of selected collections of Basin wild rye, exposure to natural inoculum of *P. striiformis*, and testing of recovered rust isolates against differentials of wheat and barley for determination of race structure.

ACKNOWLEDGMENTS

The authors thank Donna Ayling, Shari Lupien, and Melissa Scholten for technical assistance, and Steve Alderman and Les Szabo for constructive comments on the manuscript. Partial funding was provided by the BLM Great Basin Native Plant Project.

LITERATURE CITED

1. Arthur, J. C. 1962. Manual of the Rusts in United States and Canada, with Illustrations and a New Supplement by G. B. Cummins. Hafner, New York.
2. Barkworth, M. E. 1997. Taxonomic and nomenclatural comments on the Triticeae in North America. Phytologia 83:302-311.
3. Barkworth, M. E., and Atkins, R. J. 1984. *Leymus* Hochst. (Gramineae: Triticeae) in North America: Taxonomy and distribution. Am. J. Bot. 71:609-625.
4. Barkworth, M. E., Dewey, D. R., and Atkins, R. J. 1983. New generic concepts in the Triticeae of the Intermountain Region: Key and concepts. Great Basin Nat. 43:561-572.
5. Bradley St. Clair, J., Kilkenny, F. F., Johnson, R. C., Shaw, N. L., and Weaver, G. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. Evol. Appl. 6:933-948.
6. Chapman, S. R., Sharp, E. L., and Sally, B. K. 1975. Possible simple inheritance of resistance to stripe rust in Basin wild rye. Phytopathology 65:409-411.
7. Chen, X. M. 2005. Epidemiology and control of stripe rust (*Puccinia striiformis* f. sp. *tritici*) on wheat. Can. J. Plant Pathol. 27:314-337.
8. Chen, X. M. 2013. High-temperature adult-plant resistance, key for sustainable control of stripe rust. Am. J. Plant Sci. 4:608-627.
9. Chen, X. M., Penman, L., Wan, A. M., and Cheng, P. 2010. Virulence races of *Puccinia striiformis* f. sp. *tritici* in 2006 and 2007 and development of wheat stripe rust and distributions, dynamics, and evolutionary relationships of races from 2000 to 2007 in the United States. Can. J. Plant Pathol. 32:315-333.
10. Culumber, C. M., Larson, S. R., Jones, T. A., and Jensen, K. B. 2013. Wide-scale population sampling identifies three phylogeographic races of basin wild rye and low-level genetic admixture with creeping wild rye. Crop Sci. 53:996-1007.
11. Cummins, G. B. 1971. The Rust Fungi of Cereals, Grasses and Bamboos. Springer-Verlag, New York.
12. Dewey, D. R. 1966. Synthetic hybrids of *Elymus canadensis* x octoploid *Elymus cinereus*. Bull. Torrey Bot. Club 93:323-331.
13. Farr, D. F., and Rossman, A.Y. n.d. Fungal Databases, Systematic Mycology and Microbiology Laboratory, ARS, USDA. http://nt.ars-grin.gov/fungaldatabases.
14. Gardes, M., and Bruns, D. 1993. ITS primers with enhanced specificity for basidiomycetes: Application to the identification of mycorrhizae and rusts. Mol. Ecol. 2:113-118.
15. Hendrix, J. W., Burleigh, J. R., and Tu, J. C. 1965. Oversummering of stripe rust at high elevations in the Pacific Northwest-1963. Plant Dis. Rep. 49:275-278.

16. Hotson, J. W. 1934. Key to the Rusts of the Pacific Northwest. University of Washington Publications in Biology 3:1-193.
17. Hovmøller, M. S., Sørensen, C. K., Walter, S., and Justesen, A. F. 2011. Diversity of *Puccinia striiformis* on cereals and grasses. Ann. Rev. Phytopathol. 49:197-217.
18. Jones, T. A., Parr, S. D., Winslow, S. R., and Rosales, M. A. 2009. Notice of release of 'Continental' basin wild rye. Native Plants J. 10:57-61.
19. Larson, S. R., Wu, X., Jones, T. A, Jensen, K. B., Chatterton, N. J., Waldron, B. L., Robins, J. G., Bushman, B. S., and Palazzo, A. J. 2006. Comparative mapping of growth habit, plant height, and flowering QTLs in two interspecific families of *Leymus*. Crop Sci. 46:2526-2539.
20. Line, R. F., and Qayoum, A. 1992. Virulence, aggressiveness, evolution, and distribution of races of *Puccinia striiformis* (the cause of stripe rust of wheat) in North America. USDA-ARS Tech. Bull. 1788.
21. Littell, R. C., Milliken, G. M., Stroup, W. W., and Wolfinger, R. D. 1996. SAS system for mixed models. SAS Institute Inc., Cary, NC.
22. Liu, B., Chen, X. M., and Kang, Z. S. 2012. Gene sequencing reveals heterokaryotic variations and evolutionary mechanisms in *Puccinia striiformis*. Open Genomics J. 1:1.
23. Liu, M., and Hambleton, S. 2010. Taxonomic study of stripe rust, *Puccinia striiformis* senus lato, based on molecular and morphological evidence. Fungal Biol. 114:881-899.
24. Mujeeb-Kazi, A., and Rodriguez, R. 1982. Cytogenetics of hybrids of *Elymus canadensis* x *Hordeum vulgare*. J. Hered. 73:77-79.
25. Niu, Y. C., Li, Z. Q., and Shang, H. S. 1991. *Puccinia striiformis* West. f. sp. *leymi* and f. sp. *elymi*, two new formae speciales. Acta Univ. Agric. Boreali-Occident (Suppl.) 19:58-62.
26. Ogle, D. G. 2003. Basin wild rye *Leymus cinereus* Scribn. & Merr. A. Love plant guide. Aberdeen Plant Materials Center, Aberdeen, ID. http://plants.usda.gov/plantguide/pdf/pg_leci4.pdf
27. Orton, T. J. 1979. A quantitative analysis of growth and regeneration from tissue cultures of *Hordeum vulgare*, *H. jubatum* and their interspecific hybrid. Environ. Exp. Bot. 19:319-335.
28. Saville, D. B. O. 1984. Taxonomy of the cereal rust fungi. Pages 79-112 in: The Cereal Rusts, Vol. 1. W. R. Bushnell, and A. P. Roelfs, eds. Academic Press, London.
29. Tu, J. C. 1967. The summer biology of *Puccinia striiformis* West. in southeastern Washington. Diss. Washington State University.
30. Yan, G. P., Chen, X. M., Line, R. F., and Wellings, C. R. 2003. Resistance gene-analog polymorphism markers co-segregating with the *Yr5* gene for resistance to wheat stripe rust. Theor. Appl. Genet. 106:636-643.