

Reactions of Rp-Resistant, Processing Sweet Corn Hybrids to Populations of *Puccinia sorghi* Virulent on Corn with the *Rp1-D* Gene

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Abstract. Resistance to *Puccinia sorghi* Schwein. based on the *Rp1-D* gene has been used successfully in North America for the past 15 years to control common rust on sweet corn (*Zea mays* L.). The objective of this preliminary research was to examine rust reactions of Rp-hybrids grown for processing in the midwestern United States against biotypes of *P. sorghi* virulent against *Rp1-D*. In Sept. 1999, isolates of *P. sorghi* virulent on corn with the *Rp1-D* gene were collected throughout the midwestern United States. Rust reactions of 41 Rp-resistant, processing sweet corn hybrids and nine non-Rp hybrids were evaluated during the 1999–2000 season in Argentina, Hawaii, Mexico, and South Africa, where populations of *P. sorghi* are virulent against *Rp1-D*. Sporulating uredinia were observed on all hybrids in all locations. Although rust reactions varied among locations, mean standardized scores of nine non-Rp hybrids that were included in the trial as controls ranked nearly the same as in previous trials. Thirteen hybrids with standardized scores above 0.25 were more susceptible than the hybrid with the lowest mean rust rating, ‘Green Giant Code 27’. Thirty-two hybrids were intermediate in reaction to *P. sorghi* virulent against *Rp1-D*. Reactions were moderately resistant for nine hybrids with mean standardized scores below –0.50, including two moderately resistant, non-Rp hybrids (‘GG Code 27’ and ‘GG Code 6’) that were included as controls. Additional trials are necessary to confirm reactions of these hybrids. If the Rp-hybrids that were moderately susceptible or susceptible in this trial are infected by *P. sorghi* virulent against *Rp1-D*, secondary inoculum will be abundant and infection will be severe if the weather is wet.

Resistance based on single, dominant genes has been used successfully to control common rust (*Puccinia sorghi*) on sweet corn (*Zea mays* L.) in the continental United States for the past 15 years. Most, but not all, rust-resistant sweet corn hybrids carry the *Rp1-D* gene. Most sweet corn breeders in the United States preferred *Rp1-D* to other Rp genes because virulence against *Rp1-D* was rare in populations of *P. sorghi* in the continental

United States (Bergquist and Pryor, 1984; Groth et al., 1992; Hooker, 1969; Hulbert, 1997; Hulbert et al., 1991; Pataky, 1987b). In Aug. and Sept. 1999, isolates of *P. sorghi* were collected from Rp-resistant sweet corn hybrids grown in Illinois, Wisconsin, Minnesota, Michigan, and New York. As much as 40% of the plant leaf area was symptomatic (i.e., sporulating uredinia) in some of these fields. This is the first widespread occurrence in the continental United States of *P. sorghi* virulent on corn with the *Rp1-D* gene (Pataky and Tracy, 1999). Sporulating uredinia were observed on 121 of 125 Rp-resistant sweet corn hybrids inoculated with these isolates of *P. sorghi* in greenhouse trials in the fall of 1999 (Pataky and Pate, 2000). In Mar. 2000, isolates of *P. sorghi* virulent on *Rp1-D* were collected from Los Mochis, Mexico, where Rp-resistance had been effective prior to 1999 (Pataky et al., 2000). Central Mexico is considered by many plant pathologists to be the

source of common rust inocula for the midwestern United States because the aecial stage of *P. sorghi* does not occur in the continental United States. Initial infection of sweet corn in the Midwest coincides with the arrival of urediniospores from the south. Rp-resistance in commercially available sweet corn hybrids will not be effective in the Midwest if biotypes of *P. sorghi* virulent on *Rp1-D* spread north annually from Mexico.

Prior to the development of Rp-resistant sweet corn in the 1980s, many hybrids grown for processing were moderately susceptible or susceptible to common rust (Groth et al., 1983a; Kim et al., 1988; Pataky et al., 1988). Sweet corn yields are reduced ≈0.5% for each 1% of the leaf area infected by rust (Pataky, 1987a; Pataky et al., 1988). Yield of susceptible and moderately susceptible hybrids can be reduced substantially when weather is favorable for infection (Dillard and Seem, 1990b; Groth et al., 1983b; Pataky et al., 1988). Timely applications of fungicides can prevent rust from developing to levels that affect yield substantially (Dillard and Seem, 1990b; Pataky and Eastburn, 1993). Decisions to apply fungicides are based on rust thresholds, information obtained from scouting fields, and weather. These decisions can be more exact when reactions of hybrids (e.g., resistant, moderately resistant, moderate, moderately susceptible, and susceptible) are known (Dillard and Seem, 1990a, 1990b; Headrick and Pataky, 1988; Pataky and Headrick, 1988, 1989; Pataky et al., 1988).

Reactions of hybrids with the *Rp1-D* gene to populations of *P. sorghi* virulent against *Rp1-D* depend on the background (i.e., general resistance or susceptibility) of the hybrid. If an inbred parent is converted to *Rp1-D*-resistance by backcrossing, the Rp-hybrid probably will have the same reaction to biotypes of *P. sorghi* virulent against *Rp1-D* as the non-Rp version of the hybrid had to avirulent biotypes. Therefore, rust reactions of Rp-resistant hybrids with a resistant inbred parent developed from backcrossing probably can be predicted from reactions of genetically similar, non-Rp hybrids (Pataky and Pate, 2000); however, these predictions need to be confirmed in field trials. Rust reactions of Rp-resistant hybrids cannot be predicted if the resistant inbred parent was developed by pedigree line breeding and non-Rp versions of the inbred and its hybrids do not exist. Reactions of these Rp-hybrids must be determined from trials in which plants are infected by *P. sorghi* virulent against *Rp1-D*.

Populations of *P. sorghi* virulent against *Rp1-D* occur throughout the world (Bergquist, 1981; Brewbaker, 1983; Gonzalez, 2000; Hooker, 1969; Hulbert, 1997). The objective of this research was to assess the rust reactions of Rp-hybrids that are grown for processing in the midwestern United States against *P. sorghi* virulent on *Rp1-D*. This information will affect disease management practices if populations of *P. sorghi* virulent against *Rp1-D* are prevalent again in the Midwest.

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Materials and Methods

The rust reactions of 41 Rp-resistant, processing sweet corn hybrids and nine non-Rp hybrids (Table 1) were evaluated during the 1999–2000 season in Argentina, Hawaii, and Mexico, and at two locations in South Africa. Each location was treated as a replicate for the comparison of hybrid reactions. Six of the 41 Rp-hybrids evaluated have non-Rp versions for which rust reactions were evaluated previously (Pataky, 1999). Three pairs of Rp- and non-Rp hybrids were included, ‘WHT

2801’ and ‘Sterling’, ‘Prime Plus’ and ‘Primetime’, and ‘GSS 9377’ and ‘Supersweet Jubilee’. Rust reactions of six additional non-Rp hybrids included as controls were known from previous experiments (Pataky, 1999). At each location, plants were exposed to naturally-occurring populations of *P. sorghi*, which were virulent against *Rp1-D*.

At each location, an experimental unit was a single row of a hybrid with ≈20 plants per row. Replicates at a location were treated as subsamples in the overall analysis. Two replicates of the 50 hybrids were planted in

Rosario, Argentina, in Nov. 1999. Soon after pollination, severity of rust was rated from 0% to 100% leaf area infected (i.e., modified Cobb scale). Two replicates of the 50 hybrids were planted 2 Nov. 1999 at the Waimanalo Research Station, Oahu, Hawaii. On 11 Jan. 2000, rust symptoms were rated from 1 (resistant) to 9 (susceptible), based on the amount of leaf area infected and density of uredinia. One replicate of the hybrids was planted in Greytown, South Africa on 16 Nov. 1999 and one was planted in Delmas, South Africa, on 2 Dec. 1999. Symptoms were rated from 1

Table 1. Standardized scores and common rust ratings for Rp-resistant sweet corn hybrids in Argentina, Hawaii, Mexico, and South Africa

Hybrid	Seed source	Previous rust rxn	Mean	Standardized score ^z of rust rating					Rust rating ^y				
							South Africa					South Africa	
				Argentina	Hawaii	Mexico	Greytown	Delmas	Argentina	Hawaii	Mexico	Greytown	Delmas
						%	(1–9)	%	(1–9)	(1–9)			
GG Code 27	Green Giant	MR	-0.90	-1.56	-1.06	-0.39	-1.06	-0.44	7	6.5	27	2	4
Topacio	Harris Moran	Rp	-0.66	-0.5	-1.82	0.84	-1.06	-0.78	14	6	37	2	3.5
Intrique	Crookham	Rp	-0.65	-0.91	-1.06	-1.61	-0.57	0.88	11	6.5	17	3	6
HMX 8389	Harris Moran	Rp	-0.64	-0.1	-0.30	-0.63	-1.06	-1.11	16	7	25	2	3
Esquire	Asgrow	Rp	-0.61	-1.39	-0.30	-0.02	-0.57	-0.78	8	7	30	3	3.5
Marvel	Crookham	Rp	-0.61	-0.26	-0.30	-1.61	-0.08	-0.78	15	7	17	4	3.5
GG Code 62	Green Giant	Rp	-0.58	-1.07	-1.82	1.20	-0.08	-1.11	10	6	40	4	3
Legacy	Harris Moran	Rp	-0.56	0.23	-0.30	-1.24	-1.06	-0.44	18	7	20	2	4
GG Code 6	Green Giant	MR	-0.55	-1.07	-0.30	-0.39	-0.57	-0.44	10	7	27	3	4
XP 8410347	Asgrow	Rp	-0.46	0.23	0.45	-1.61	-0.57	-0.78	18	7.5	17	3	3.5
Bonus	Rogers	Rp	-0.44	-0.26	-0.30	-0.63	-0.57	-0.44	15	7	25	3	4
Kandy Plus	Rogers	Rp	-0.42	0.06	-1.82	-0.63	-0.57	0.88	17	6	25	3	6
FMX 516	Harris Moran	Rp	-0.37	-0.91	-0.30	-0.63	0.41	-0.44	11	7	25	5	4
GG Code 60	Green Giant	Rp	-0.36	-0.58	-0.30	1.20	-0.57	-1.57	13	7	40	3	2.3
GG Code 64	Green Giant	Rp	-0.35	-0.42	-1.82	-0.63	1.89	-0.78	14	6	25	8	3.5
GG Code 74	Green Giant	Rp	-0.34	-0.42	-0.30	-0.63	-0.57	0.22	14	7	25	3	5
Sprswt Jubilee	Rogers	M	-0.26	-0.91	-0.30	0.59	-0.57	-0.11	11	7	35	3	4.5
Dynamo	Harris Moran	Rp	-0.24	-0.42	1.21	-0.63	-0.57	-0.78	14	8	25	3	3.5
GG Code 67	Green Giant	Rp*(M) ^x	-0.22	-0.42	0.45	-0.63	-0.08	-0.44	14	7.5	25	4	4
EX 8414667	Asgrow	Rp	-0.21	-0.1	-0.30	-0.63	0.41	-0.44	16	7	25	5	4
GG Code 78	Green Giant	Rp	-0.19	-0.26	-0.30	-0.02	0.41	-0.78	15	7	30	5	3.5
EX 8414657	Asgrow	Rp	-0.17	-0.1	-0.45	-0.02	-1.06	-0.11	16	7.5	30	2	4.5
Empire	Rogers	Rp	-0.16	-0.75	-0.30	-0.39	1.40	-0.78	12	7	27	7	3.5
Contender	Crookham	Rp	-0.12	0.39	0.45	-1.24	0.90	-1.11	19	7.5	20	6	3
GSS 7831	Rogers	Rp*(MS)	-0.08	-0.26	0.45	0.59	-1.06	-0.11	15	7.5	35	2	4.5
Jackpot	Rogers	Rp	-0.08	0.23	-0.30	-0.63	-0.57	0.88	18	7	25	3	6
GG Code 77	Green Giant	Rp	-0.07	-0.58	1.21	-0.63	-0.57	0.22	13	8	25	3	5
Excellency	Harris Moran	Rp*(M/MS)	-0.07	-0.91	1.21	1.20	-1.06	-0.78	11	8	40	2	3.5
GG Code 76	Green Giant	Rp	-0.07	-0.42	0.45	-0.02	-0.57	0.22	14	7.5	30	3	5
Esteem	Harris Moran	MR/R	-0.07	-1.07	-0.30	-0.63	-0.57	2.21	10	7	25	3	8
Terminator	Crookham	Rp	-0.07	-0.50	-1.06	0.59	-0.57	1.21	14	6.5	35	3	6.5
XSC 1025	Asgrow	Rp	-0.01	0.06	0.45	-0.02	-0.08	-0.44	17	7.5	30	4	4
Assure	Crookham	Rp	0.08	1.85	-0.30	-0.63	-0.08	-0.44	28	7	25	4	4
Eliminator	Crookham	Rp	0.11	-0.10	-1.06	-0.39	0.90	1.21	16	6.5	27	6	6.5
GSS 9299	Rogers	Rp	0.14	-0.42	1.21	-0.39	1.40	-1.11	14	8	27	7	3
El Toro	Asgrow	Rp	0.14	-0.58	-0.30	0.59	-0.57	1.55	13	7	35	3	7
Lobo	Asgrow	Rp	0.22	0.55	-0.30	-1.24	1.89	0.22	20	7	20	8	5
GG Code 79	Green Giant	Rp	0.30	0.23	-0.30	0.59	1.40	-0.44	18	7	35	7	4
GSS 9377	Rogers	Rp*(M)	0.36	-0.10	0.45	-0.02	1.89	-0.44	16	7.5	30	8	4
Prime Plus	Rogers	Rp*(M/MS)	0.40	0.71	0.45	-0.63	1.89	-0.44	21	7.5	25	8	4
HMX 8392S	Harris Moran	Rp	0.41	1.28	1.21	0.59	-0.57	-0.44	25	8	35	3	4
GH 2547	Rogers	Rp	0.49	-0.26	0.45	-0.02	2.38	-0.11	15	7.5	30	9	4.5
Conquest	Crookham	Rp	0.50	2.09	-0.30	0.59	0.90	-0.78	30	7	35	6	3.5
Primetime	Rogers	M/MS	0.51	-0.50	1.97	-0.02	0.90	0.22	14	8.5	30	6	5
Krispy King	Rogers	MS	0.67	0.06	1.21	2.43	-0.57	0.22	17	8	50	3	5
WHT 2801	Rogers	Rp*(S)	1.05	0.96	1.21	2.43	-0.57	1.21	23	8	50	3	6.5
Peter 235	Sakata	S	1.15	2.33	-1.82	1.82	1.89	1.55	31	6	45	8	7
ACX 97CN405	Abbott & Cobb	S	1.21	2.33	1.97	0.59	-1.06	2.21	31	8.5	35	2	8
Bold	Rogers	Rp	1.39	1.36	1.21	2.43	-0.57	2.54	25	8	50	3	8.5
Sterling	Rogers	S	1.59	3.14	1.97	1.20	-0.57	2.21	36	8.5	40	3	8
	FLSD _{0.05}		1.15										
	mean								16.7	7.2	30.2	4.2	4.7
	SD								6.2	0.66	8.18	2.03	1.51

^zStandardized score = [(rust score – location mean)/location SD].

^yMethod of rating rust differed among locations: 0% to 100% leaf area infected in Argentina and Mexico, 1 to 9 scale in Hawaii and South Africa.

^xRp* = rating in parentheses is for a non-Rp version of the hybrid.

(resistant) to 9 (susceptible) on 14 Feb. and 9 Mar. 2000 in Greytown and Delmas, respectively. One replicate of the hybrids was planted in the Harris Moran Seed Company nursery in Los Mochis, Mexico, on 8 Dec. 1999. Rust severity was rated from 0% to 100% leaf area infected on 23 Mar. 2000, \approx 10 d after pollination.

Since rating scales differed among locations, data were standardized before analysis. Standardized scores (z-scores) were calculated according to the formula: standard score = [(rating - location mean)/location SD]. Hybrid means from two replicates (sub-samples) in Argentina and Hawaii, and rust ratings for each hybrid from each replicate in Mexico, and in South Africa, were converted to z-scores. Standardized scores were analyzed by analysis of variance (ANOVA). Each of the five locations was a replicate, and the hybrid term was tested by the hybrid \times location term. FLS_D-values were used to compare hybrid means.

Results and Discussion

Sporulating uredinia were observed on all hybrids at all locations. None of the hybrids had chlorotic fleck reactions typical of Rp-resistance; thus, *Rp1-D* was not effective against the populations of *P. sorghi* at any of the five locations. All hybrids were relatively susceptible in the extremely rust-conducive environment in Hawaii, but reactions were more diverse in the other four locations.

Rust severity ranged from 7% to 36% leaf area infected with a mean of 16.6% in Argentina (Table 1). In Hawaii, most hybrids were severely infected with common rust, southern rust (*Puccinia polysora* Underw.), and maize mosaic virus. Common rust ratings ranged from 6 to 8.5 with a mean of 7.2. Tropical sweet corn hybrids (e.g., 'Hawaiian supersweet') planted adjacent to this trial had rust ratings from 1.5 to 3.5. In Mexico, common rust and maize dwarf mosaic were prevalent. Rust severity ranged from 17% to 50% with a mean of 30.2%. In South Africa, ratings ranged from 2 to 8 with a mean of 4.2 at Greytown and from 2.3 to 8.5 with a mean of 4.7 at Delmas.

Although rust ratings varied among locations (replicates), the mean standardized scores for the nine non-Rp hybrids included as controls ranked nearly the same as in previous trials (Pataky, 1999) except for 'Esteem', which ranked higher than expected because of high rust ratings at Delmas, South Africa (Table 1). The susceptible controls had mean standardized scores above one (i.e., more rust than one SD above average). Mean scores for the moderately resistant controls, except for 'Esteem', were below -0.5, and those for moderate and moderately susceptible control hybrids were between -0.26 and 0.67. Ranks and mean scores also were similar for the Rp and non-Rp versions of the susceptible and moderately susceptible hybrids ('WHT 2801' and 'Sterling', and 'Prime Plus' and 'Primetype', respectively). Ranks and mean scores were farther apart for the Rp

and non-Rp hybrids with moderate reactions ('GSS 9377' and 'Supersweet Jubilee'), which reflects the variability of ratings and ranks among hybrids in this trial with intermediate reactions to rust.

Based on the analysis of standardized scores, 13 hybrids with mean scores above 0.25 were more susceptible than the hybrid with the lowest mean rust score, 'Green Giant Code 27'. Nine hybrids with standardized scores above 0.45 were not different from the most susceptible hybrid, 'Sterling'. This group included five control hybrids with moderately susceptible to susceptible reactions and one Rp-hybrid, 'WHT 2801', the non-Rp version of which was previously rated as susceptible (Pataky, 1999). The four Rp-hybrids in this group, 'Bold', 'Conquest', 'GH 2547', and 'WHT 2801', were more susceptible to populations of *P. sorghi* virulent against *Rp1-D* than to other Rp-hybrids. If weather is wet or dew is frequent, fungicides probably will be needed to prevent rust from becoming severe on these hybrids. Applications of fungicides also may be beneficial to other Rp-hybrids with mean standardized scores above zero, since each of these hybrids was among the group of hybrids that were most susceptible in at least one replicate (location).

Nine hybrids had mean standardized scores below -0.50, but those means were not significantly different from scores for many other hybrids due, in part, to variation among replicates. These nine hybrids included two non-Rp hybrids with previously known moderately resistant reactions and seven Rp-hybrids. If these Rp-hybrids have moderately resistant reactions similar to the two controls ('GG Code 27' and 'GG Code 6'), rust will not be as severe on them as on other Rp-hybrids infected in the Midwest by *P. sorghi* virulent against *Rp1-D*. Although they may have better partial rust resistance than other Rp-hybrids evaluated in this trial, none of these hybrids were highly resistant. Additional evaluations are necessary to confirm these moderately resistant reactions. Higher levels of general resistance, such as that observed in Hawaiian supersweet hybrids, should be incorporated into hybrids adapted for the Midwest.

The 32 hybrids with mean standardized scores between -0.5 and 0.45 probably are intermediate in reaction to *P. sorghi* virulent against *Rp1-D*. Through additional trials, the reactions of many of these hybrids probably can be separated into moderately resistant, moderate, and moderately susceptible categories. When midwestern environments are favorable for infection, rust may be quite severe on hybrids with moderate to susceptible reactions; fungicides may be necessary to prevent reductions in yield under rust-conducive environments.

Common rust is controlled most effectively when the amount of secondary inoculum is minimized. If the Rp-hybrids that were moderately susceptible or susceptible in this trial are infected by *P. sorghi* virulent against *Rp1-D*, secondary inoculum will be abundant

and infection will be severe if weather is wet. Precautions should be taken to scout fields and apply fungicides as necessary in order to avoid substantial reductions in yield of these hybrids.

Although populations of *P. sorghi* were virulent against *Rp1-D* at each location of this trial, these populations may not be similar for any trait other than virulence against *Rp1-D*. Additional characterization of populations of *P. sorghi* and additional trials with multiple replicates per location may help determine whether variation among replicates (locations) in this trial was primarily due to random error or the result of genotype \times environment interaction.

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