Anthracnose Field Evaluation of Sorghum Germplasm from Botswana

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Abstract

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Sorghum anthracnose is a disease of worldwide importance and host-plant resistance is the most practical method of disease management. In this study, 154 sorghum accessions from the Botswana collection maintained by the United States National Plant Germplasm System were inoculated with *Colletotrichum sublineolum* and evaluated for disease resistance at the Tropical Agriculture Research Station in Isabela, Puerto Rico during 2007 and 2008. A resistant response was observed for 69 accessions in 2007 and for 48 accessions in 2008 with no acervuli development observed on inoculated leaves. The low frequency of resistant germplasm is expected from a region of low annual rainfall. However, disease severity was low for the susceptible accessions with a mean severity of 11% for the 85 susceptible accessions observed in 2007 and 17% for the 106 susceptible accessions identified in 2008. The highest frequency of resistant accessions was observed for the Ngamiland district with 58% of the accessions rated as resistant, whereas the frequency of resistant accessions ranged from 22% to 36% for the other districts. The lowest mean disease severity was also observed for the susceptible accessions from the Ngamiland district with the highest mean disease severity observed for susceptible accessions from the Kgatleng district. The resistant accessions identified in this study would be useful for the development of disease resistant varieties and the results indicated an ecogeographic association with disease resistance.

Keywords: African germplasm; *Colletotrichum sublineolum*; disease resistance; ecological zones; genetic resources; *Sorghum bicolor*

Sorghum anthracnose occurs worldwide, but is more typically observed in tropical and subtropical regions where frequent rainfalls and high humidity contribute to the development and spread of the disease (Pande *et al*. 1994; Thakur & Mathur 2000). *Colletotrichum sublineolum* (Henn.) is the fungal pathogen responsible for sorghum anthracnose (Crouch *et al*. 2006) and disease symptoms are typically observed on leaves, but the stalk, panicle, and seed can also show symptoms (Thakur & Mathur 2000; Hess *et al*. 2002). Symptoms of foliar disease appear approximately 30 days after seedling emergence, but infection can occur at every stage of plant development. Disease lesions can be circular, elliptical, or elongated in shape depending on host-plant response and acervuli (asexual fruiting bodies) develop in the centre of the lesions of susceptible varieties. Disease development before anthesis can have the greatest effect on grain yield with reported losses ranging from 30% to 67% (Ali *et al*. 1987; Thomas *et al*. 1996). Grain yield losses from foliar disease are commonly associated with a reduction in seed size (Ali *et al*. 1987).

The use of resistant varieties provides the most effective method of managing the disease. However, the pathogen is highly variable and multiple pathotypes are typically found in the pathogen population (Marley *et al*. 2001; Valério *et al*. 2005), thus the pathogen may overcome varieties

with a single source of resistance (Rosewich *et al.* 1998). Pyramiding of resistance genes is one method to increase the longevity of resistance and evaluation of germplasm collections is necessary to identify additional sources of host-plant resistance. The germplasm collection from Botswana maintained by the United States National Plant Germplasm System was evaluated for anthracnose disease response to identify resistant sources, to determine the frequency of resistance within the collection, and to evaluate an ecogeographic association with resistance.

MATERIAL AND METHODS

The United States Department of Agriculture, Agricultural Research Service (USDA-ARS), National Plant Germplasm System maintains 157 sorghum (*Sorghum bicolor* /L./ Moench) accessions from Botswana (GRIN 2009). Seed samples for 154 accessions were obtained from the USDA-ARS, Plant Genetic Resources Conservation Unit in Griffin, Georgia. The anthracnose evaluation was conducted at the USDA-ARS, Tropical Agriculture Research Station in Isabela, Puerto Rico. The first experiment was planted November 5, 2007 and the second experiment was planted November 19, 2008. Experiments were planted in a randomised complete block design with each accession planted in a single row and replicated three times. Rows were 1.8 m in length with 0.9 m row spacing. Eighteen control genotypes showing diversity in anthracnose disease response were included in the evaluation. Using data from previous evaluations, eight resistant control genotypes, NSL 4025 (Redlan), PI 515649, PI 533752 (SC103), PI 533794 (SC110), PI 533909 (SC48), PI 534131 (SC30), PI 535792, and PI 595735 (SC1313), and 10 susceptible control genotypes, PI 173112, PI 211633, PI 247136, PI 533772 (SC271), PI 533831 (SC414), PI 534157 (SC170), PI 561472 (Sureño), PI 564163 (BTx623), PI 609251, and PI 655996 (RTx430), were selected. A border row of anthracnose susceptible genotypes was planted around each experimental field to provide similar competition for rows not flanked by experimental genotypes. The border row was not inoculated, but showed disease symptoms indicating that sufficient inoculum was present. At planting, Lorsban 15G granular insecticide (chlorpyrifos, Dow AgroSciences, Indianapolis, USA) was applied in the seed furrow at a rate of 1.2 kg a.i./ha to prevent seed loss from fire ants. No fertilizer was applied to the experiments and weeds were controlled with mechanical tillage and hand hoeing. Overhead irrigation was applied twice before disease inoculation in 2007 and 2008, and no irrigation was applied after inoculation. Rainfall events occurred on 35 days before inoculation and on 26 days after inoculation in 2007 with a total of 342 mm received before inoculation and 102 mm received after inoculation. A tropical storm occurred on December 11, 2007 with 45 mm of rainfall, resulting in severe lodging, and inoculation was delayed 10 days to allow plants to recover. In 2008, rainfall events occurred on 25 days before inoculation with a total of 196 mm received and, after inoculation, rainfall events occurred on 29 days with a total of 128 mm received.

To represent the pathogen population, anthracnose fungal cultures were established from diseased leaf tissue randomly collected from susceptible plants in experimental fields at the Isabela research farm. Preparation of fungal cultures, field inoculation, and disease evaluation were described by Erpelding and Prom (2006). *Colletotrichum sublineolum*-colonised sorghum seed was used for inoculation and plants were inoculated 40 days after planting in 2007 and 37 days after planting in 2008. Rainfall was received on the day of inoculation for both experiments and 43 mm of rainfall was received before the first disease rating in 2007 and 35 mm was received before the first rating in 2008. Disease evaluations were conducted 33, 46, and 66 days after inoculation in 2007. For the 2008 evaluation, disease readings were conducted at 28 and 55 days after inoculation. Weather conditions delayed the final evaluation in 2007 by 6 days. In 2008, weather conditions prevented the second evaluation at approximately 40 days after inoculation. During both years, the final evaluation was conducted at physiological maturity; however, maturity occurred earlier in 2008 than in 2007. Anthracnose disease response was evaluated using a 1 to 5 rating scale based on disease development observed on inoculated leaves and disease progression on non-inoculated leaves (Erpelding & Prom 2004). Resistant plants showing no acervuli development were rated as 1 or 2 with plants rated as 2 showing the reddening of inoculated leaves. Susceptible plants with acervuli development observed on inoculated leaves were rated as 3, 4, or 5. Plants rated as 4 and 5 showed disease

development on non-inoculated leaves, with acervuli formation observed on the flag leaf for plants rated as 5. Disease severity was also evaluated for the accessions, which was based on a visual rating of the percentage of leaf area showing disease symptoms for the susceptible plants within a row. All plants in a row were visually evaluated with the number of plants within a row ranging from 16 to 25 due to variation in germination rate. The disease severity from the final rating was used for statistical analysis. The Statistix 9 software package (Analytical Software, Tallahassee, USA) was used to conduct an analysis of variance with Tukey's standardized range test at the 5% probability level used for mean comparisons. For 129 accessions included in the evaluation, passport information was available in the village where the accessions were collected (GRIN 2009) and this information was used for the ecogeographic evaluation.

RESULTS

The anthracnose disease response and mean disease severity for the 154 sorghum accessions from the Botswana collection are presented in Table 1. A resistant response was observed for 69 accessions in 2007. For the 85 accessions rated as susceptible in 2007, 46 accessions showed a susceptible response across three replications, 26 accessions showed a susceptible response across two replications, and 13 accessions showed a susceptible response for one replication. More accessions showed a susceptible response in 2008, with 106 accessions rated as susceptible and 48 accessions rated as resistant. Fewer accessions also showed variation in susceptibility across replications in 2008, with eight accessions showing a susceptible response across two replications and 14 accessions showing susceptibility in one replication. Overall, 47 accessions were rated as resistant. A susceptible response was observed in one growing season for 23 of the 107 susceptible accessions and only one accession was rated as susceptible in 2007 that was not rated as susceptible in 2008.

All accessions showed the reddening of inoculated leaves within 7 days after inoculation and within 10 days after inoculation acervuli were observed on inoculated leaves of susceptible genotypes. Most of the susceptible accessions also showed the senescence of leaf margins for the inoculated leaves within 30 days after inoculation. Some of the susceptible accessions showed extensive senescence of leaf margins followed by acervuli development resulting in leaf death for the inoculated leaves. This rapid leaf death reduced colonisation resulting in lower disease severities observed for the leaves. The majority of the accessions rated as susceptible for the final evaluation, conducted approximately 60 days after inoculation, showed acervuli formation within 30 days after inoculation. For the 2007 experiment, 63 accessions showed susceptibility 33 days after inoculation with 19 accessions showing susceptibility across the three replications (data not shown). At 46 days after inoculation in 2007, a susceptible response was observed for 71 accessions and 27 accessions showed susceptibility across the three replications. The majority of the accessions showing a susceptible response across replications showed acervuli development on the flag leaf during the final evaluation. Disease progression was more rapid for the 2008 experiment with 87 accessions rated as susceptible 28 days after inoculation and 58 accessions showing a susceptible response across the three replications (data not shown). Forty-one accessions that showed a susceptible response across the three replications 28 days after inoculation in 2008 showed acervuli development on the flag leaf for the final evaluation.

Mean disease severity was greater in 2008 for the susceptible accessions (Table 1). For the 106 accessions rated as susceptible in 2008, mean disease severity was 17% compared to a mean of 11% for the 85 susceptible accessions observed in 2007. Mean disease severity was 21% for the 84 susceptible accessions that showed a susceptible response across replications in 2008. For the 46 susceptible accessions that showed a susceptible response across replications in 2007, mean disease severity was 16% compared to a mean of 27% for these accessions in 2008. Disease severity was generally less than 1% for the susceptible accessions that showed variation across replications and growing seasons.

The disease response observed for the control genotypes included in the evaluation was as expected (Table 1). Reddening of inoculated leaves was observed for the 18 control genotypes within 7 days after inoculation and no acervuli formation was observed for the eight resistant control genotypes during the final evaluation. For the susceptible control genotypes, acervuli formation was observed within 30 days after inoculation with acervuli observed on the flag leaf within 60 days after inoculation. Disease

Table 1. Anthracnose disease rating and mean disease severity (%) for 154 sorghum accessions from the Botswana germplasm collection inoculated with *Colletotrichum sublineolum* and evaluated for disease response in Isabela, Puerto Rico during 2007 and 2008

Accession[1]	2007		2008		Accession[1]	2007		2008	
	disease rating[2]	disease severity[3]	disease rating[2]	disease severity[3]		disease rating[2]	disease severity[3]	disease rating[2]	disease severity[3]
Grif 829	2	0.0[a]	2	0.0[a]	PI 540518	2	0.0[a]	2	0.0[a]
PI 499293	2	0.0[a]	2	0.0[a]	PI 510982	2\2\4	0.3[a]	2	0.0[a]
PI 510904	2	0.0[a]	2	0.0[a]	Grif 827	2	0.0[a]	2\2\4	0.1[a]
PI 510905	2	0.0[a]	2	0.0[a]	Grif 849	2	0.0[a]	2\2\4	0.3[a]
PI 510907	2	0.0[a]	2	0.0[a]	PI 510947	2	0.0[a]	2\2\4	0.2[a]
PI 510921	2	0.0[a]	2	0.0[a]	PI 510959	2	0.0[a]	2\2\4	0.2[a]
PI 510922	2	0.0[a]	2	0.0[a]	PI 510974	2	0.0[a]	2\2\4	0.1[a]
PI 510923	2	0.0[a]	2	0.0[a]	PI 510976	2	0.0[a]	2\2\4	0.1[a]
PI 510924	2	0.0[a]	2	0.0[a]	PI 510986	2	0.0[a]	2\2\4	0.2[a]
PI 510925	2	0.0[a]	2	0.0[a]	PI 511002	2	0.0[a]	2\2\4	0.3[a]
PI 510931	2	0.0[a]	2	0.0[a]	PI 511003	2	0.0[a]	2\2\4	0.1[a]
PI 510934	2	0.0[a]	2	0.0[a]	PI 511005	2	0.0[a]	2\2\4	0.2[a]
PI 510937	2	0.0[a]	2	0.0[a]	PI 511013	2	0.0[a]	2\2\4	0.1[a]
PI 510938	2	0.0[a]	2	0.0[a]	PI 562771	2	0.0[a]	2\2\4	0.1[a]
PI 510939	2	0.0[a]	2	0.0[a]	PI 510968	2	0.0[a]	2\2\4	3.3[ab]
PI 510946	2	0.0[a]	2	0.0[a]	PI 510997	2\2\4	0.2[a]	2\2\4	0.7[a]
PI 510948	2	0.0[a]	2	0.0[a]	PI 510954	2	0.0[a]	2\4\4	0.3[a]
PI 510949	2	0.0[a]	2	0.0[a]	PI 510981	2	0.0[a]	2\4\4	0.8[a]
PI 510950	2	0.0[a]	2	0.0[a]	PI 510995	2	0.0[a]	2\4\4	0.7[a]
PI 510951	2	0.0[a]	2	0.0[a]	PI 510998	2	0.0[a]	2\4\4	0.1[a]
PI 510952	2	0.0[a]	2	0.0[a]	PI 511006	2	0.0[a]	2\4\4	2.0[a]
PI 510953	2	0.0[a]	2	0.0[a]	PI 511009	2	0.0[a]	2\4\4	0.5[a]
PI 510956	2	0.0[a]	2	0.0[a]	PI 510962	2\4\4	2.0[ab]	2\4\4	0.5[a]
PI 510958	2	0.0[a]	2	0.0[a]	PI 510909	2\4\4	1.8[ab]	2\4\4	3.7[ab]
PI 510961	2	0.0[a]	2	0.0[a]	PI 510975	2	0.0[a]	4	1.9[a]
PI 510965	2	0.0[a]	2	0.0[a]	PI 510912	2	0.0[a]	4	4.3[ab]
PI 510972	2	0.0[a]	2	0.0[a]	PI 510944	2	0.0[a]	4	10.0[a–e]
PI 510977	2	0.0[a]	2	0.0[a]	PI 510970	2\2\4	0.3[a]	4	0.4[a]
PI 510979	2	0.0[a]	2	0.0[a]	PI 499289	2\2\4	0.2[a]	4	0.7[a]
PI 510985	2	0.0[a]	2	0.0[a]	PI 510967	2\2\4	0.2[a]	4	0.7[a]
PI 510989	2	0.0[a]	2	0.0[a]	PI 510928	2\2\4	0.2[a]	4	0.8[a]
PI 510991	2	0.0[a]	2	0.0[a]	PI 510918	2\2\4	0.2[a]	4	5.0[ab]
PI 510992	2	0.0[a]	2	0.0[a]	PI 510943	2\2\4	0.3[a]	4	5.2[ab]
PI 510993	2	0.0[a]	2	0.0[a]	PI 510996	2\2\4	0.3[a]	4	5.7[ab]
PI 510994	2	0.0[a]	2	0.0[a]	PI 510966	2\2\4	0.3[a]	4	6.8[a–c]
PI 510999	2	0.0[a]	2	0.0[a]	PI 499290	2\2\4	0.3[a]	4	6.8[a–c]
PI 511000	2	0.0[a]	2	0.0[a]	PI 510957	2\2\4	0.3[a]	4	9.3[a–e]
PI 511001	2	0.0[a]	2	0.0[a]	PI 511004	2\4\4	0.7[a]	4	0.4[a]
PI 511008	2	0.0[a]	2	0.0[a]	PI 510899	2\4\4	6.7[a-d]	4	2.0[a]
PI 511010	2	0.0[a]	2	0.0[a]	PI 510955	2\4\4	3.7[a-c]	4	4.0[ab]
PI 511011	2	0.0[a]	2	0.0[a]	PI 644566	2\4\4	1.3[ab]	4	4.0[ab]
PI 511012	2	0.0[a]	2	0.0[a]	PI 510916	2\4\4	0.8[a]	4	4.2[ab]
PI 511015	2	0.0[a]	2	0.0[a]	PI 510920	2\4\4	2.0[ab]	4	6.8[a–c]
PI 511016	2	0.0[a]	2	0.0[a]	PI 510983	2\4\4	10.0[a-e]	4	7.3[a–c]
PI 511018	2	0.0[a]	2	0.0[a]	PI 499291	2\4\4	0.3[a]	4	8.3[a–d]
PI 511020	2	0.0[a]	2	0.0[a]	Grif 850	2\4\4	2.0[ab]	4	8.7[a–d]
PI 510898	2\4\5	30.0[a–g]	4	11.0[a–e]	PI 510894	4	10.3[a-e]	4\5\5	43.3[e–k]
PI 510926	2\4\5	2.3[ab]	4	30.0[a–j]	PI 510963	4\4\5	26.7[a-f]	4\5\5	50.0[g–l]
PI 510897	2\5\5	16.7[a–e]	4	16.7[a–g]	PI 510933	4\4\5	10.7[a-e]	4\5\5	51.7[h–l]
PI 510964	4	4.0[a–c]	4	2.3[a]	PI 576352	4\5\5	35.0[a-h]	4\5\5	21.7[a–i]
PI 510919	4	2.7[ab]	4	3.0[ab]	PI 644326	4\5\5	20.0[a-f]	4\5\5	25.0[a–j]

Table 1 to be contiued

Accession[1]	2007		2008		Accession[1]	2007		2008	
	disease rating[2]	disease severity[3]	disease rating[2]	disease severity[3]		disease rating[2]	disease severity[3]	disease rating[2]	disease severity[3]
PI 511023	2\4\4	3.7$^{a–c}$	4	18.3$^{a–h}$	Grif 835	4	23.3$^{a–f}$	4\5\5	26.0$^{a–j}$
PI 510980	2\4\4	7.0$^{a–d}$	4	30.0$^{a–j}$	PI 510913	4	11.7$^{a–e}$	4\5\5	40.0$^{c–k}$
PI 510945	4	1.3^{ab}	4	6.7$^{a–c}$	PI 510942	4\5\5	40.0$^{d–h}$	4\5\5	33.3$^{a–j}$
PI 510929	4	7.2$^{a–d}$	4	7.0$^{a–c}$	PI 510935	2\4\4	11.7$^{a–e}$	5	56.7$^{j–m}$
PI 644286	4	2.3^{ab}	4	9.0$^{a–d}$	PI 510902	2\4\5	26.7$^{a–f}$	5	36.7$^{b–k}$
PI 644330	4	15.3$^{a–e}$	4	11.7$^{a–e}$	PI 510927	4	4.7$^{a–d}$	5	33.3$^{a–j}$
PI 267498	4	2.3^{ab}	4	14.0$^{a–f}$	PI 510932	4\4\5	38.3$^{c–h}$	5	33.3$^{a–j}$
PI 511014	4	2.3^{ab}	4	15.7$^{a–f}$	PI 510990	4\4\5	18.3$^{a–f}$	5	36.7$^{b–k}$
PI 499295	4	5.3$^{a–d}$	4	21.7$^{a–i}$	PI 499296	4\4\5	30.0$^{a–g}$	5	51.7$^{h–l}$
PI 510978	4	3.7$^{a–c}$	4	28.3$^{a–j}$	PI 510988	4\4\5	13.3$^{a–e}$	5	53.3$^{i–l}$
PI 510940	4\4\5	17.3$^{a–e}$	4	7.7$^{a–d}$	Grif 833	4\5\5	43.3$^{e–i}$	5	23.3$^{a–j}$
PI 499294	4\4\5	5.2$^{a–d}$	4	23.3$^{a–j}$	PI 510960	4\5\5	34.0$^{a–h}$	5	41.7$^{d–k}$
PI 511022	2\2\4	0.3^{a}	4\4\5	11.7$^{a–e}$	PI 510906	4\5\5	53.3$^{f–i}$	5	46.7$^{f–k}$
PI 644305	2\4\4	0.7^{a}	4\4\5	7.0$^{a–c}$	PI 510896	4\5\5	31.7$^{a–h}$	5	51.7$^{h–l}$
PI 510910	2\4\4	10.0$^{a–e}$	4\4\5	15.3$^{a–f}$	PI 510903	4\5\5	30.3$^{a–g}$	5	53.3$^{i–l}$
PI 511017	2\4\4	0.7^{a}	4\4\5	23.3$^{a–j}$	PI 511019	4\5\5	30.3$^{a–g}$	5	53.3$^{i–l}$
PI 510900	2\4\5	16.7$^{a–e}$	4\4\5	17.0$^{a–g}$	Grif 834	5	33.3$^{a–h}$	5	50.0$^{g–l}$
PI 511021	2\4\5	7.0$^{a–d}$	4\4\5	23.5$^{a–j}$	NSL 4025	2	0.0^{a}	2	0.0^{a}
PI 510917	4	2.3^{ab}	4\4\5	11.7$^{a–e}$	PI 515649	2	0.0^{a}	2	0.0^{a}
PI 510911	4	4.0$^{a–c}$	4\4\5	14.0$^{a–f}$	PI 533752	2	0.0^{a}	2	0.0^{a}
PI 510914	4	14.0$^{a–e}$	4\4\5	15.0$^{a–f}$	PI 533794	2	0.0^{a}	2	0.0^{a}
PI 510971	4	7.7$^{a–d}$	4\4\5	18.3$^{a–h}$	PI 533909	2	0.0^{a}	2	0.0^{a}
PI 510973	4	5.3$^{a–d}$	4\4\5	18.3$^{a–h}$	PI 534131	2	0.0^{a}	2	0.0^{a}
PI 511007	4	2.2^{ab}	4\4\5	18.3$^{a–h}$	PI 535792	2	0.0^{a}	2	0.0^{a}
PI 510895	4	12.0$^{a–e}$	4\4\5	23.3$^{a–j}$	PI 595735	2	0.0^{a}	2	0.0^{a}
PI 510908	4	16.7$^{a–e}$	4\4\5	25.0$^{a–j}$	PI 533831	4	2.3^{ab}	4	2.3^{a}
PI 510901	4	3.5$^{a–c}$	4\4\5	31.7$^{a–j}$	PI 561472	5	6.7$^{a–d}$	5	13.3$^{a–f}$
PI 510915	4	17.3$^{a–e}$	4\4\5	31.7$^{a–j}$	PI 655996	4\5\5	30.0$^{a–g}$	4\4\5	5.0^{ab}
PI 510930	4	30.0$^{a–g}$	4\4\5	40.0$^{c–k}$	PI 564163	5	33.3$^{a–h}$	5	26.7$^{a–j}$
PI 510893	4\4\5	10.3$^{a–e}$	4\4\5	3.4^{ab}	PI 247136	4\5\5	40.0$^{d–h}$	4\5\5	43.3$^{e–k}$
PI 510987	4\4\5	8.7$^{a–e}$	4\4\5	21.7$^{a–i}$	PI 534157	5	36.7$^{b–h}$	5	46.7$^{f–k}$
Grif 832	4\5\5	16.7$^{a–e}$	4\4\5	18.3$^{a–h}$	PI 211633	5	63.3$^{g–j}$	5	70.0$^{k–m}$
PI 510936	2\4\4	20.0$^{a–f}$	4\5\5	26.7$^{a–j}$	PI 173112	5	66.7$^{h–j}$	5	83.3^{lm}
PI 510969	2\4\4	5.0$^{a–d}$	4\5\5	43.3$^{e–k}$	PI 533772	5	76.7^{ij}	5	83.3^{lm}
PI 510984	2\4\4	10.0$^{a–e}$	4\5\5	53.3$^{i–l}$	PI 609251	5	90.0^{j}	5	90.0^{m}

[1]Plant introduction numbers for the Botswana accessions (GRIN 2009). Accessions are arranged from resistant to susceptible using data from 2008. The eight resistant control genotypes, NSL 4025 (Redlan), PI 515649, PI 533752 (SC103), PI 533794 (SC110), PI 533909 (SC48), PI 534131 (SC30), PI 535792, and PI 595735 (SC1313), and 10 susceptible control genotypes, PI 173112, PI 211633, PI 247136, PI 533772 (SC271), PI 533831 (SC414), PI 534157 (SC170), PI 561472 (Sureño), PI 564163 (BT×623), PI 609251, and PI 655996 (RT×430), were listed at the end of the table

[2]Disease rating is based on a 1 to 5 scale (Erpelding & Prom 2004). Resistant accessions were rated as 2 and showed the reddening of inoculated leaves with no acervuli development. Susceptible accessions were rated as 4 or 5 and showed the development of acervuli on inoculated leaves. For plants rated as 5, acervuli development was observed on most leaves including the flag leaf. No accessions were rated as 1 or 3. Data are presented for the three replications for accessions that showed variation in disease response across replications

[3]Disease severity is based on a visual estimate of the percentage of leaf area showing symptoms for the susceptible plants within a row and averaged across the three replications. Numbers followed by the same letter are not significantly different based on Tukey's standardized range test at the 5% probability level

Table 2. Administrative district, disease rating, and mean disease severity (%) for sorghum accessions from Botswana evaluated for anthracnose resistance in Puerto Rico[1]

Adminstrative district	Resistant accessions	Susceptible accessions	Total number of accessions	Disease severity
Central	19	33	52	10.0[a]
Kgatleng	8	15	23	20.1[b]
Kweneng	6	21	27	14.9[ab]
Ngamiland	7	5	12	6.2[ab2]
Southern	4	11	15	9.8[a]

[1]Passport information on the collection site was available for 129 of the 154 accessions (GRIN 2009). Anthracnose disease rating and severity were summarised across the 2007 and 2008 experiments. Statistical analysis was conducted using a two sample *t*-test for mean comparison of the disease severity for the susceptible accessions from each district. Numbers followed by the same letter were not significantly different at the 5% probability level

[2]Disease severity for the susceptible accessions from the Ngamiland and Kgatleng was significantly different at the 10% probability level

severity was similar between growing seasons for the 10 susceptible control genotypes with a mean of approximately 44% for the 2007 experiment and 46% for the 2008 experiment.

Sorghum accessions from five of the 10 administrative districts of Botswana were included in the evaluation (Table 2). The majority of the accessions were collected from the Central district with approximately 34% of the accessions from this region. For the other four districts, 18% of the accessions were collected from the Kweneng district, 15% from the Kgatleng district, 10% from the Southern district, and the lowest number of accessions was collected from the Ngamiland district with 8% of the accessions. Annual rainfall is similar for the five districts and ranges from 300 to 500 mm. Accessions from the Ngamiland district showed a greater frequency of anthracnose resistance with 58% of the accessions rated as resistant, and the accessions rated as susceptible from this district showed the lowest mean disease severity. The frequency of resistant accessions was similar for the other districts with 36% of the accessions from the Central district, 35% from the Kgatleng district, 28% from the Southern district, and 22% from the Kweneng district rated as resistant. The accessions rated as susceptible from the Kgatleng district showed the highest mean disease severity and disease symptoms were observed on the flag leaf for the majority of the susceptible accessions from this region. For the Central, Kweneng, and Southern districts, mean disease severity was similar for the accessions rated as susceptible from these regions.

DISCUSSION

Approximately 30% of the accessions from the Botswana collection were rated as resistant to anthracnose in Puerto Rico, which indicates that the germplasm from Botswana is an important source of anthracnose resistance for sorghum improvement. Additionally, 35% of the accessions rated as susceptible showed less than 6% disease severity and these accessions could also be a source of resistance. Accessions with less than 6% disease severity were classified as resistant by Pande *et al.* (1994). Overall, most of the susceptible accessions showed low disease severity and no accession showed a mean severity greater than 60%; whereas, the highly susceptible control genotype, PI 609251, showed a mean severity of 90%. Senescence of the inoculated leaves was a typical response observed for the accessions and, for the accessions rated as susceptible with low disease severities, acervuli development was observed on the senescent leaves with little or no infection observed on non-inoculated leaves. This would suggest that a mechanism of resistance is being maintained in the germplasm from Botswana. The resistant control genotype, PI 535131, showed a similar disease response, when inoculated leaves showed extensive reddening followed by senescence of leaf margins with infrequent formation of acervuli observed on the margins of inoculated leaves. Resistance can be inherited as a qualitative or quantitative trait (Mehta *et al.* 2005; Mohan *et al.* 2010) and extensive variation in disease response has been observed in populations developed to determine the genetics of resistance (Erpelding 2007); therefore, the diversity

in disease response and overall lower disease severity would suggest genetic variation for host resistance. Additionally, quantitative resistance resulting in lower disease severities is frequently observed in sorghum landraces and disease response often shows regional specificity (Erpelding 2008, 2010; Erpelding & Prom 2004) as was observed for the accessions from Botswana.

The low frequency of resistant accessions would be expected for the Botswana collection as annual rainfall is less than 700 mm and the majority of the accessions were collected from regions receiving 350 to 500 mm of annual rainfall. An anthracnose evaluation of the Mali sorghum germplasm collection reported that 30% of the accessions from regions receiving less than 800 mm of annual rainfall showed resistance (Erpelding 2008). Regional variation in the frequency of anthracnose resistance was also observed for the Botswana collection. Germplasm from the Ngamiland district showed the highest frequency of anthracnose resistant accessions and the lowest mean disease severity for the accessions rated as susceptible. Even though annual rainfall is similar across the administrative districts, the Okavango Delta is located in the Ngamiland district, which may contribute to the higher frequency of accessions showing anthracnose resistance from this region. Several studies have reported that annual rainfall is an important weather variable influencing disease severity (Néya & Le Normand 1998; Hess *et al*. 2002; Ngugi *et al*. 2002); however, other climatic conditions that would contribute to a greater leaf wetness period would also affect disease severity (Pande *et al*. 1994) and may contribute to the variation observed between regions. Pathogenic diversity may also occur between regions (Marley *et al*. 2001) and could contribute to the observed diversity in disease response for the germplasm from the different districts. The factors contributing to the variation in disease response between districts and the genetics of resistance for the germplasm are unknown; however, this association between anthracnose resistance and ecogeographic regions would aid in the acquisition of additional germplasm from Botswana. In addition to a source of anthracnose resistance, many of the accessions from Botswana were white seeded and could be useful for the development of food or feed quality grain sorghum hybrids.

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