Evaluation of Selected Sorghum Lines and Hybrids for Resistance to Grain Mold and Long Smut Fungi in Senegal, West Africa

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ABSTRACT

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Grain mold in sorghum [*Sorghum bicolor* (L.) Moench] is a major problem worldwide. Damage caused by this fungal disease complex includes a reduction in yield (loss of seed mass), grain density, and germination. Long smut is another important fungal disease in sorghum and is a threat to food security in West Africa. Studies identifying potential sources of resistance for these two diseases in Senegal are limited. The objective of this research was to assess the vulnerability of selected breeding lines and hybrids from the United States to grain mold and long smut in two locations in 2009 and 2010. Four sorghum lines (Sureno, RTx2911, SC719-11E, and IS18760) and four hybrids (Sorghum

Partners NK6638, Asgrow A571, AN600 × RN610, and Pioneer 83G19) exhibited low grain mold severity at both locations. The cultivars 3694 and SC748-5 and one hybrid, Novartis 2030/C, were resistant to long smut infection at both locations. Lines BTx623 and RTx430 were found to be highly susceptible to long smut, and therefore the available commercial sorghum hybrids involving these two parental lines' genetic backgrounds are likely to be vulnerable to long smut. There are no differential responses between lines and hybrids for both grain mold and long smut disease severity. None of the lines or hybrids showed resistance to both diseases.

INTRODUCTION

Grain mold is one of the principal constraints to sorghum [*Sorghum bicolor* (L.) Moench] productivity and grain quality in areas where moist conditions occur later in the growing season (2,7). A number of fungi in several genera are associated with the grain mold disease complex, including *Fusarium thapsinum* Klittich, Leslie, Nelson et Marasas; *F. semitectum* Berk. & Ravenel; *Curvularia lunata* (Wakk.) Boedijn; *Colletotrichum graminicola* (Ces.) G.W. Wilson; *Alternaria alternata* (Fr.: Fr.) Keissl.; and *Phoma sorghina* (Sacc.) Boerema, Dorenbosch, & Van Kesteren (2,4,11,31). Worldwide, *F. thapsinum* and *C. lunata* are considered the most important species in the complex (2,5,31). Management strategies for controlling the grain mold disease complex include planting genotypes that mature during periods of dry weather and chemical treatment to enhance seed germination and vigor. The use of resistant genotypes offers the best means for controlling the disease complex (5,31); however, few genotypes are available. Furthermore, differences in environmental conditions and genotype × isolate interactions hinder the development of lines with stable resistance (27,28).

Long smut of sorghum, caused by *Sporisorium ehrenbergii* Vánky (syn. *Tolyposporium ehrenbergii* (Kühn) Patouillard), is an important fungal disease in Africa and Asia, especially in areas with low soil moisture due to poor rainfall and high temperature (3,12,13,29). In Nigeria, the severity of the disease due to persistent drought resulted in yield losses ranging from 20 to 60% (15,21,22,25). The pathogen infects the host when airborne teliospores are washed into the boot and germinate to produce

sporidia, which infect the spikelets (12,21,25). Infection occurs only during the boot stage to anthesis (8,12,21). Symptoms are evident at heading 11 to 14 days after infection as elongated, cylindrical, and slightly curved sori that contain millions of teliospores (12,25). The teliospores are dispersed within fields as well as long distances by air, insects, contaminated soil, and seeds (14,21,25). Teliospores of *S. ehrenbergii* often adhere to one another to form "spore balls," which can survive in the soil for many years and serve as primary inocula. As a result, the infection becomes recurrent and the use of chemicals as seed dressings to control the disease becomes more challenging (12,25). Studies on physiological races are limited; however, the existence of at least two races of long smut has been reported earlier by Tarr (33). So far, the disease has not been observed in the United States (19,26); therefore, little information on the reactions of U.S. sorghum lines to the disease is available.

Host plant resistance is the most effective control method and a number of sorghum genotypes (Hegari, Redlan, Spur Feterita, Impi fodder cultivar, C45, AUS6, NK125, NK263, Cr 51-16, SC630-11E, QL3, and SC326-6) with high levels of resistance to long smut have been identified (21,31,32). Prom et al. (26) identified two lines, B9612 and R9645, from the United States that possess genes for long smut resistance. However, no sorghum genotype that is immune to long smut has been identified (12,24). Thus, continuous evaluation to identify new sources of resistance to grain mold and long smut is needed for successful management. This study was designed to compare the selected sorghum lines and hybrids from the United States that differed in susceptibility and to identify potential sources for grain mold and long smut resistance at two locations in two growing seasons (2009 and 2010) in Senegal.

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FIELD EVALUATION OF SORGHUM GENOTYPES IN SENEGAL AT TWO LOCATIONS

The field evaluation was conducted at the Agronomic Research Stations in Bambey (14°42' N, 16°28' W) and Nioro (13°45' N, 15°47' W). Though similar environmental conditions prevailed during the two growing seasons, the soil types of the locations are different. At Bambey, there is a deep soil that is slightly leached, tropical ferruginous, 7% clay, and pH 7.0, while the Nioro soil has a higher clay content (7 to 10%) and is acidic (pH 5.4). Dry weather with low rainfall and moderate humidity at Bambey and Nioro during the 2009 and 2010 growing seasons favored differential infection by grain mold and long smut fungi (Table 1). A total of 27 sorghum genotypes, including 11 adaptable lines and 16 hybrids from several seed companies sold in the United States, were used for grain mold and long smut resistance screening. Lines RTx2911 and Sureno (resistant) and RTx430 (susceptible) were used as checks for grain mold. A complete randomized block design with three replications was utilized at both locations. Each genotype was planted with two-row plots, 5 m long with 0.8 m row-to-row and 0.4 m plant-to-plant spacing. Regular agronomic practices were followed, with 22:15:15 NPK application following two split doses each with 50 kg/ha of urea, one after thinning and the next at the boot stage.

INOCULATION, DISEASE RATINGS, AND STATISTICAL ANALYSIS

Grain mold was assessed on naturally-infected panicles in the field using a 1 to 5 scale where 1 = no mold observed on the panicle; 2 = 1 to 9 % of the panicle molded; 3 = 10 to 24 % of the panicle molded; 4 = 25 to 49 % of the panicle molded; and 5 = 50% or more of the panicle molded (6,9). *Sporisorium ehrenbergii* inoculum preparation, inoculation method, and long smut disease assessment have been previously described by Prom et al. (26). Briefly, a mixture of teliospores from sori of different previously planted sorghum plants were collected to represent the available races and were suspended in water to prepare the inoculum. After an incubation period of 16 to 20 h at room temperature, the suspension was filtered through nylon mesh and used for inoculation. Four plants per plot were inoculated at the boot stage. Approximately 7-10 ml of inoculum was applied between the flag leaf and panicle using a pipette. The number of infected plants per plot (both inoculated and noninoculated) were counted at maturity and expressed as percent incidence. In this study, disease incidence of 0 to 10% was considered as low, 10 to 30% as moderate, and > 30% as high. Plant height was assessed for genotypes at Bambey at maturity. The data were combined over two years and analyzed using the command PROC GLM (SAS version 9.2, SAS Institute Inc., Cary, NC). Differences in means among sorghum lines and hybrids were determined at the 5% probability level based on pairwise comparisons of least-square means with *t*-tests.

PLANT HEIGHT

At Bambey, significant differences in plant height were exhibited among lines and hybrids (Table 2); however, no relationship was observed between plant height and grain mold/long smut incidence (*data not shown*). The sorghum lines IS18760 (253.3 cm) and Sureno (225.0 cm), and the hybrid Pioneer 83G19 (253.3 cm) were the tallest, whereas the breeding line RTx2536 (118.3 cm) and the hybrid Novartis 2030/C (113.3 cm) were the shortest. Plant height ranged from 118.3 to 253.3 cm and 113.3 to 253.3 cm for the lines and hybrids, respectively. Plant height was short to medium (113 to < 150 cm) in all the lines and hybrids evaluated at Bambey, except three sorghum lines (IS18760, Sureno, and RTx2911) and one hybrid (Pioneer 83G19) where the plant height was medium to tall (178 to 253 cm). The increased plant height was due to differences in day length (photoperiod) in Senegal in which all twelve months have mean temperatures of at least 18°C (64°F).

IDENTIFYING SOURCES OF RESISTANCE TO GRAIN MOLD

The grain mold complex results from infection of developing grain by parasitic and saprophytic fungi prior to black layer formation and subsequent discoloration caused by weathering. These factors combine to reduce grain and seed quality (17,18,23). The disease is more prevalent when moist weather conditions prevail after flowering. Some sorghum genotypes often escape grain mold because they are photoperiod sensitive, with flowering timed so that grains mature only after the rains have ceased (10). In this study, the main effect of genotypes was significant in the Bambey but not the Nioro location, indicating that there were differences and no differences for grain mold severity among the lines/hybrids in these locations, respectively. The reason for nonsignificant differences among the selected lines and hybrids for grain mold severity at Nioro may be dry weather with poor rainfall after flowering. Earlier studies have clearly shown that the intensity of grain mold severity varies with rainfalls during grain development to maturity (27,30).

Grain mold severity at Bambey ranged from 1.2 (Sureno) to 4.0 (Wct7B70) for lines and 2.2 (Sorghum Partners NK6638) to 4.2 (Novartis 2030/C) for the hybrids. The grain mold-resistant checks Sureno and RTx2911 exhibited the lowest ratings of 1.2 and 1.7, respectively. In addition, two lines (SC719-11E and IS18760) and four hybrids (Sorghum Partners NK6638, Asgrow A571, AN600 × RN610 and Pioneer 83G19) exhibited low grain mold severities of 2.5 or less at both locations (Table 2). In earlier studies, Audilakshmi et al. (1) identified different colored-seeded lines (IS14375, IS14387, IS18144, and IS18528) and three white-seeded lines (IS21443, IS24495, and IS25017) that exhibited resistance to grain mold when grown under sprinkler irrigation in India. Thakur et al. (34) reported seven exotic sources (IS2815, IS21599, IS10288, IS3436, IS10646, IS10475, and IS23585) were resistant to grain mold and are currently being used to develop new parental lines and hybrids in India. Kumar et al. (16)

TABLE 1
Weather parameters for Bambey and Nioro, Senegal, West Africa during the growing seasons between July and October in 2009 and 2010.

Location, and year	Mean				
	Precip ^x	Tmin	Tmax	% RH min	% RH max
Bambey					
2009	184.85	23.82	34.41	55.97	98.16
2010	139.60	24.08	33.86	61.13	97.75
Nioro					
2009	201.50	23.80	33.41	64.09	93.98
2010	292.58	24.02	33.22	65.66	93.57

Abbreviations: Precip = total precipitation in mm; Tmin = minimum temperature (°C); Tmax = maximum temperature (°C); % RH min = percent minimum relative humidity; and RH max = percent maximum relative humidity.

TABLE 2
Reaction of selected U.S. sorghum lines and hybrids to infection by grain mold and long smut fungi in two locations averaged over two growing seasons (2009 and 2010) in Bambey and Nioro, Senegal.

Genotype	Bambey			Nioro	
	Plant height (cm)	Grain mold ^y	Long smut incidence (%)	Grain mold	Long smut incidence (%)
Lines					
IS18760	253.3 a ^x	2.5 bcde	12.3 de	1.8	26.0 ab
Sureno	225.0 b	1.2 e	16.7 cde	1.5	0.0 b
RTx2911	178.3 c	1.7 de	43.0 bcd	2.0	0.2 b
BTx623	148.3 de	3.4 ab	95.3 a	2.3	0.0 b
Cultivar 3700	143.3 de	2.7 bcd	20.7 cde	1.7	0.0 b
Cultivar 3694	140.0 def	3.2 ab	6.7 de	2.2	0.0 b
SC748-5	138.3 defg	2.7 bcd	0.0 e	2.2	10.2 b
Wct7B70	133.3 defgh	4.0 ab	12.3 de	3.0	20.0 ab
SC719-11E	130.0 defgh	1.8 cde	0.0 e	1.8	60.0 a
RTx2536	118.3 gh	3.2 ab	60.0 abc	2.5	6.7 b
RTx430	— ^z	4.0 ab	60.9 abc	1.1	22.3 ab
Hybrids					
Pioneer 83G19	253.3 a ^x	2.5 bcde	12.3 de	2.8	19.0 b
Cargill 647	146.7 de	2.6 bcd	17.7 cde	2.5	37.7 ab
NC+ Hybrid7B52	145.0 de	3.2 ab	33.3 cde	2.5	43.7 ab
NC+ Hybrid8R18	145.0 de	3.0 abcd	12.3 de	2.2	26.7 ab
Garst 5464	143.3 de	3.5 ab	9.3 de	2.4	50.7 ab
Novatis K73-J6/C	141.7 de	2.8 bcd	27.7 cde	1.9	46.5 ab
Asgrow A581	140.0 def	3.8 ab	31.0 cde	2.3	6.7 b
NC+ Hybrid 7R83	138.7 defg	3.0 abc	0.0 e	2.7	20.0 b
Sorghum Partners NK6638	136.7 defg	2.2 bcde	23.7 cde	1.3	33.3 ab
Triumph TR458	135.0 defg	2.7 bcd	12.3 de	1.7	6.7 b
Pioneer 8313	135.0 defg	2.3 bcde	6.7 de	3.3	21.7 b
Asgrow A571	133.3 defgh	2.4 bcde	30.0 cde	2.0	0.0 b
AN600 × RN610	133.3 defgh	2.4 bcde	76.3 ab	1.8	41.7 ab
Wheatland × RTx430	120.0 fgh	3.2 ab	15.3 de	3.4	60.0 a
AN599 × RN609	120.0 fgh	2.7 bcd	44.3 bcd	3.0	47.0 ab
Novatis 2030/C	113.3 h	4.2 a	11.0 de	2.7	0.0 b
Overall mean	149.5	2.9	25.6	2.2	22.1

^x Means within a column followed by the same letter(s) are not significantly different at the 5% probability level based on pairwise comparisons of least-square means with *t*-tests.

^y Grain mold was assessed on naturally infected panicles in the field using a 1 to 5 scale, where 1 = no mold observed on the panicle; 2 = 1 to 9% of the panicle molded; 3 = 10 to 24% of the panicle molded; 4 = 25 to 49% of the panicle molded; and 5 = 50% or more of the panicle molded.

^z Missing data.

identified three hybrids (ICSA101 × PVK801, ICSA382 × GD65055, and ICSA400 × GD65028) that exhibited resistance to grain mold. Prom and Erpelding (27) showed that seven exotic Sudan germplasms (PI570011, PI570022, PI569992, PI569882, PI571312, PI570759, and PI267548) possessed high levels of resistance to grain mold in the United States. The aforementioned study clearly indicated that the complexity of the grain mold pathogens have enormous genotype × environment interactions and played a vital role with differential resistance reaction in diversified sources with different genetic backgrounds.

IDENTIFYING SOURCES OF RESISTANCE TO LONG SMUT

Long smut is a limiting factor to sorghum productivity and is therefore a threat to food security in West Africa. The disease has not yet been observed in the United States. By determining the vulnerability of U.S. sorghum genotypes and by identifying the sources of resistance to this foreign disease, control strategies can be implemented if long smut is detected in the United States in the future. In this study, low rainfall with moderate humidity favored significant differences for long smut infection among the sorghum lines and hybrids in both locations. Kumar and Nath (14) reported yield losses due to long smut in areas with annual rainfall below 635 mm. Kollo and Frederiksen (13) noted that in areas in Niger with annual mean rainfall above 700 mm, long smut incidence was minor even though the sorghum lines grown in these areas are highly susceptible. However, these authors noted that long smut infections may increase due to secondary spread if rain is available. In Bambey, long smut infection

(< 10%) was significantly lower in three lines (cultivar 3694, Wct7B70, and IS18760) with no symptoms observed on SC748-5 and SC719-11E. Six hybrids (Pioneer 8313, Garst 5464, Novatis 2030/C, NC+Hybrid 8R18, Pioneer 83G19, and Triumph TR458) had significantly lower incidence or severity and no symptoms on NC+Hybrid 7R83. Three lines (BTx623, RTx2536, and RTx430) and two hybrids (AN600 × RN610 and AN599 × RN609) exhibited the greatest long smut incidence (Table 2). Similarly, there was a significant difference in long smut reactions among the breeding lines and hybrids ($P < 0.01$) in Nioro. Seven out of eleven sorghum lines exhibited zero to low incidence, three lines (Wct7B70, RTx430, and IS18760) exhibited moderate, and SC719-11E exhibited the highest incidence of long smut. Similarly, hybrids Novartis 2030/C, Asgrow A571, Triumph TR458, and Asgrow A581 recorded the lowest and Wheatland × RTx430 recorded the highest levels of long smut infection (Table 2). Two lines (cultivar 3694 and SC748-5) and the hybrid Novartis 2030/C were identified as potential sources in both locations for long smut resistance. Sureno is a food quality cultivar grown commonly in Central America (20) and is used as a source of weathering resistance and improved food quality lines in the United States; it had no long smut infection in Nioro, but showed a moderate incidence in Bambey (Table 2).

LONG SMUT IN THE UNITED STATES

In a routine visual screening at the Washington D.C. Inspection Station, Mabry and Lightfield (19) observed the presence of long smut sori in sorghum seed packages imported from Africa and

India. Eight to 100% of the seeds in these packages and panicles were infected with one sorus to 40 sori. To date, long smut has not been observed in the United States. However, the above study clearly indicated that there is always a chance for long smut fungus introduction into the United States via contaminated soil or infected seeds. In addition, with increasing world trade and ease of travel, the threat has increased substantially in recent years. In this study, sorghum parental lines such as BTx623 and RTx430 were found to be highly susceptible in one or both locations in Senegal and hence the available commercial sorghum hybrids involving these two parental lines' genetic backgrounds are likely to be vulnerable to long smut. However, two sorghum lines (SC748-5 and cultivar 3694) from the United States showed zero to very low infection to long smut disease in both locations. Hence, continuous screening of large numbers of exotic germplasms would help to identify new sources of resistance to *S. ehrenbergii*.

CONCLUSIONS

There are no differential responses between lines and hybrids for both grain mold and long smut disease severity. Four sorghum lines (Sureno, RTx2911, SC719-11E, and IS18760) and four hybrids (Sorghum Partners NK6638, Asgrow A571, AN600 × RN610 and Pioneer 83G19) exhibited low grain mold severity in both locations. Two lines (cultivar 3694 and SC748-5) and one hybrid, Novartis 2030/C, may possess genes for resistance to long smut at both locations. None of the lines and hybrids showed high levels of resistance to both diseases as they are under the control of different genes.

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