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Assessing the vulnerability of selected sorghum lines from the United States of America to long smut (*Sporisorium ehrenbergii* Vánky) disease

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Abstract

Long smut is a limiting factor in sorghum productivity in some countries and therefore, a threat to food security. Long smut (*Sporisorium ehrenbergii* Vánky) disease response was assessed in experiments on 51 sorghum accessions including 31 commercial hybrids and 20 cultivars from the United States of America (USA) in 2004 and 2005 at the Agronomic Research Stations in Bambey and Nioro, Senegal, West Africa. The highest disease incidence of 44.33% in 2004 and 16.47% in 2005 was observed in hybrid A425, and no infection was noted in hybrids 3552 and A571 in 2005 at both locations. Hybrids 730, 837, P84552, TR438, TR65G, and Wac660 exhibited low levels of infection. Among the cultivars and parental lines, SRN39 recorded the highest disease incidence of 48.0% followed by B.Tx623 with 45.8%, whereas B.9612 and R.9645 consistently recorded low levels of infection. These two cultivars B.9612 and R.9645 may possess genes for long smut resistance. All other promising sorghum cultivars and parental lines to be released/registered in the USA exhibited varied levels of susceptibility. In order to establish the sources of long smut resistance, it is of paramount importance to conduct additional screenings of aforesaid hybrids/lines in a wide spectrum of selections that would be carried out under varied environmental conditions.
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1. Introduction

Long smut of sorghum (*Sorghum bicolor* (L.) Moench) incited by *Sporisorium ehrenbergii* Vánky (syn. *Tolyposporium ehrenbergii* (Kühn) Patouillard) is an important disease in several African and Asian countries (de Milliano et al., 1991;Kollo, 2000; Kollo and Frederiksen, 1998; Kumar and Nath, 1991a; Mirza and Hamid, 1984; Tamimi, 1970/1971). The pathogen infects the host when airborne teliospores land on the leaves, are washed into the boot, and germinate to produce sporidia that infect individual spikelets (Kollo, 2000; Manzo, 1976; Parlak and Karaca, 1976). Infection occurs only during the booting stage until anthesis and not later (Hassan et al., 1970; Kollo, 2000; Manzo, 1976). Symptoms, which are evident at heading, appear 11–14 d after infection as elongated, cylindrical, and slightly curved sori (Kollo, 2000; Parlak and Karaca, 1976). The random development of sori on the sorghum panicle is the evidence that long smut is not a systemic disease. Florets are individually infected, with sori replacing the developing grain (Kollo, 2000; Manzo, 1976). Physiological races of *S. ehrenbergii* have been identified in Egypt where the disease was first reported (Botros et al., 1999).

The long smut disease can be spread within fields and to distant areas by airborne spores, insects, contaminated soil and seeds (Kumar and Nath, 1991a; Manzo, 1976; Parlak and Karaca, 1976). Teliospores of *S. ehrenbergii* often stick together to form balls which can survive in the soil for many years. These teliospore balls can adhere to the sorghum seeds and with other infective propagules serve as the primary source of inoculum. In the spring or under conducive environmental conditions, the chlamydospores will germinate to produce sporidia which can be carried by wind currents to the flag leaves and washed down into the

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boot to initiate infection (Kollo, 2000; Parlak and Karaca, 1976). Strong winds can also lift soil contaminated with teliospores and deposit the spores on the flag leaves, with subsequent infection of the plant (Manzo, 1976). Kumar and Nath (1991a) observed and collected several insects from fields containing long smut-infected sorghum plants and noted that the paddy bug [*Leptocorisa acuta* (Thunberg)] has the capacity to transmit the disease.

Areas with low rainfall, high temperature, and low soil moisture favor long smut infection (Kollo and Frederiksen, 1998; Rao and Sarwar, 1982). Manzo (1976) noted that the disease was most severe during drought years in Nigeria. Yield losses of up to 20% in India, 20–22% in Turkey, and 40–60% in Multan and Muzaffargarh districts in Pakistan have been reported (Kumar and Nath, 1991b; Mirza and Hamid, 1984; Parlak and Karaca, 1976).

Although the pathogen survives in the soil as teliospores, infection of the host via seed or soil does not occur; as a result, chemical seed treatment will not control the disease (Kollo, 2000; Manzo, 1976). Host plant resistance is considered to be the best control strategy for this disease (Kollo, 2000; Kumar and Nath, 1991b; Manzo, 1976). So far, no sorghum genotype that is immune to the disease has been identified (Kollo, 2000; Omer et al., 1985). However, several sorghum lines have exhibited high level of resistance to the disease; these include: Regular Hegari, Redlan, and Spur Feterita (Tamimi, 1970/1971), Impi fodder (Rao and Sarwar, 1982), four Pakistani cultivars C-45, AUS-6, NK-125, and NK-263 (Mirza and Hamid, 1984) and Cr 51:16, SC630-11E, QL-3 (India), and SC326-6 (Omer et al., 1985). Long smut is not present in the United States of America (USA), and as a result, there is little or no information on the reactions of USA sorghum lines (Mabry and Lightfield, 1974). Thus, this research was conducted to assess the vulnerability of selected USA commercial hybrids and sorghum cultivars to long smut.

2. Materials and methods

Experiments on sorghum hybrids and cultivars were conducted separately in 2004 and 2005 growing seasons at the Agronomic Research Stations in Bambey (14°42′N, 16°28′W) and Nioro (13°45′N, 15°47′W), Senegal, West Africa. The disease is endemic in Senegal. The soil is a deep, slightly leached, tropical ferruginous with 7% clay and a pH of 7.0 at Bambey, whereas at Nioro, the soil has a slightly higher percentage of clay (7–10%) and a pH of 5.4. Annual precipitations were 474.5 and 678.8 mm at Bambey, and 770 and 811.5 mm at Nioro in 2004 and 2005, respectively. Experiments were conducted on fields where cowpea at Bambey and peanut at Nioro had been grown in the previous year. In the hybrid trials, 20 and 28 USA sorghum hybrids were screened for long smut resistance, respectively, in 2004 and 2005 at Nioro, and at Bambey 26 hybrids were tested in 2005. In the cultivar trials, 20 USA cultivars were evaluated in 2 years (2004 and 2005) at Nioro and in 1 year (2005) at Bambey. Each experimental trial uniformly utilized a complete randomized block design replicated three times. Plots were two rows, each 5 m long with 0.8 m row and 0.4 m plant spacing. Regular agronomic practices were followed with 22:15:15 NPK application followed by 50 kg ha^{-1} of urea each in equal split doses, one after thinning and the next at boot stage.

Long smut inocula for this study were collected from volunteer plants in an off-season crop in August. Sori were crushed to collect the spores, and a spore suspension (1×10^6 spores ml^{-1}) was made with distilled water. After an incubation period of 16–20 h at room temperature, the suspension was filtered through a nylon mesh and used for inoculation. Four plants per plot were inoculated at boot stages. Using a pipette, approximately 7–10 ml of inoculum was placed between the flag leaf and panicle. A plant exhibiting long smut sori on the panicle was scored as infected. The number of infected plants per plot (inoculated and non-inoculated) were counted at maturity and expressed as percent incidence. In this study, disease incidence of 0–10% was considered low, 10–30% as moderate and >30% as high. Two other components of long smut resistance measured were flowering date (number of days from planting until anthers had extruded half way down the panicles of at least 50% of the plants within a row) and plant height (measured in centimeters from soil surface to the top of the panicle at maturity).

A severe locust attack was experienced on the disease nursery at Bambey in mid-October 2004, and as a result, data could not be collected in 2004 at this location.

3. Statistical analysis

Data for disease incidence were analyzed using the command PROC GLM procedure (SAS Institute, SAS version 9.1, Cary, NC). Due to homogeneity of error variance, disease incidence data for the cultivars in Nioro were pooled across years and analyzed. Differences in means among hybrids/cultivars were determined by pairwise comparisons of least-square means with *t*-tests at the 5% probability level. The Pearson correlation coefficient was calculated between disease incidence and flowering date, plant height, and weather parameters for the hybrids and cultivars in each year. Average weather values for rainfall, minimum temperature, and maximum temperature during the growing season, i.e., June–September, were used for the analysis (data not presented).

4. Results

4.1. Nioro

The long smut infection level in hybrids ranged from 0.00% (920) to 44.3% (A425) in 2004 and 0.00% (3552 and A571) to 16.47% (A425) in 2005 (Table 1). Hybrid A425 significantly recorded the highest level of infection. Early-maturing hybrids AP2800, 3696, and NC + 6B67 with 55–57 d flowering date recorded moderate to high levels of

Table 1
Percent incidence of long smut in selected USA commercial sorghum hybrids under field conditions at two different locations in Senegal, West Africa, during the 2004 and 2005 growing seasons

Hybrid	Location/year								
	Nioro						Bambey		
	2004			2005			2005		
	FD	PH	Incidence (%)	FD	PH	Incidence (%)	FD	PH	Incidence (%)
1498E	61	90	25.33 abc	65	108	11.50 bcd	63	107	5.50 ab
3696	57	97	17.33 abc	60	113	4.67 abc	62	100	1.17 ab
372	64	97	2.00 a	66	128	12.83 cd	64	123	9.83 ab
5789	64	98	14.33 abc	68	137	7.67 abcd	66	132	9.50 ab
730	62	95	0.83 a	65	137	6.17 abcd	60	130	1.00 ab
837	64	117	1.50 a	65	125	4.50 abc	66	120	0.00 a
920	63	112	0.00 a	—	—	—	—	—	—[a]
A425	65	93	44.33 c	64	129	16.47 d	—	—	—
A570	63	97	13.50 abc	66	117	1.33 ab	64	111	4.00 ab
AP2800	55	102	43.83 bc	—	—	—	—	—	—
DK51	61	98	30.33 abc	—	—	—	—	—	—
N9208	61	98	23.17 abc	62	135	0.50 a	60	130	0.67 ab
N9212	60	103	27.67 abc	60	130	5.67 abcd	60	127	14.50 ab
NC + 6B67	57	93	21.17 abc	57	113	1.83 ab	58	108	2.17 ab
NC + 7B29	61	83	12.00 ab	59	118	5.83 abcd	59	113	7.17 ab
P83G66	62	98	11.00 a	63	142	1.33 ab	63	135	11.33 ab
P84G52	63	105	5.00 a	66	142	3.33 abc	61	133	1.33 ab
TR438	63	108	1.17 a	64	138	2.83 abc	60	133	0.00 a
TR65G	62	95	1.00 a	62	135	0.83 a	61	128	0.00 a
Wac660	63	130	4.67 a	68	158	1.67 ab	64	153	0.33 ab
3552	—	—	—	61	175	0.00 a	59	172	0.00 a
A571	—	—	—	58	135	0.00 a	58	132	0.00 a
BH3822	—	—	—	65	140	2.67 abc	64	137	6.67 ab
DK19	—	—	—	58	138	0.83 a	57	137	4.67 ab
NK6641	—	—	—	63	135	15.67 d	60	130	9.67 ab
NK8831	—	—	—	71	117	0.33 a	68	112	13.50 ab
TRX44631	—	—	—	62	153	0.67 a	60	147	0.17 ab
W-851-DR	—	—	—	63	133	5.33 abc	60	130	1.00 ab
W-858-E	—	—	—	66	143	0.83 a	—	—	—
W-876-DR	—	—	—	63	142	0.33 a	61	137	1.50 ab
XP503	—	—	—	57	148	1.00 a	58	143	0.50 ab

FD, flowering date in days; PH, plant height in cm.
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.
[a]Hybrid was not tested.

infection (17.33–43.83%) in 2004, whereas hybrids A571, DK90, XP503, NC + 6B67 with 57–58 d flowering date recorded low levels of infection (0.00–1.83%). However, hybrids 920, 730, 837, P84G52, TR438, TR65G and Wac660 in 2004, and hybrids 3552, TR65G, Wac660, NK8831, TRX44631, W-858-E and W-876-DR in 2005 recorded low levels of 0.00–5.00% and 0.00–1.67% infection, respectively, with late-flowering date (> 60 d). The hybrid plant heights ranged from 83 to 130 cm with an average 100.5 cm in 2004, whereas the range was 108–178 cm with a high average of 134 cm in 2005 (Table 1).

Among the cultivars, BTx 631 recorded the highest disease incidence (39.10%), whereas no infection was observed in B9612 (Table 2). All other sorghum cultivars had disease infections ranging from 1.1% (R9645) to 34.2% (Sureno). The earliest maturing cultivars were TX7078, BTx378, and R9645. Plant height ranged from 91 cm (R.Tam428) to 154 cm (Sureno) across years with an average of 112.4 cm (Table 2).

4.2. Bambey

In the hybrids, low to moderate disease levels ranging from 0.2% (TRX44631) to 14.5% (N9212) were recorded in 2005 (Table 1). The hybrids 3552, 837, A571, TR438, and TR65G recorded no disease infection. All the hybrids planted at Bambey flowered within 57 d (DK19) to 68 d (NK8831), and plant height ranged from 100 (3696) to 172 cm (3552) with an average of 129.2 cm (Table 1).

No disease infection was observed in cultivars B9612 and BTx378. Cultivar SRN39 recorded the highest disease

incidence of 48.0% followed by BTx623 with 45.8%. The levels of long smut infection in SRN39 and B.Tx623 were significantly higher than the disease levels noted in TX2911, TX7078, SC414-14, R.Tx2917, R.9645, Sureno, and B.Tx635. Flowering date ranged from 59 d (Tx 7078) to 92 d (SC326-6) and the plant height ranged between 78 (R.TAM428) and 203 cm (Sureno) with an average of 155 cm (Table 2).

Table 2
Percent incidence of long smut in selected USA sorghum cultivars under field conditions at two different locations in Senegal, West Africa, during the 2004 and 2005 growing seasons

Cultivar	Location and (year)					
	Nioro (2004 and 2005 combined)			Bambey (2005)		
	FD	PH	Incidence (%)	FD	PH	Incidence (%)
86EON361	79	111	9.10 ab	85	105	37.30 bc
B9612	65	103	0.00 a	64	98	0.00 a
BTx378	63	107	14.10 abc	61	118	0.00 a
BTx623	73	116	24.80 bcd	74	128	45.80 c
BTx631	73	117	39.10 d	77	125	24.20 abc
BTx635	74	119	27.90 bcd	71	130	2.50 ab
Malisor84-7	75	119	27.80 bcd	70	135	12.80 abc
R8901	64	110	20.70 abcd	60	113	14.30 abc
R9645	71	128	1.10 a	73	135	1.50 ab
R.TAM428	80	91	24.60 abcd	85	78	37.30 abc
RTx2917	67	101	6.50 ab	60	103	2.70 ab
RTx2918	65	103	11.30 abc	63	107	19.80 abc
RTx2919	64	102	9.50 ab	60	102	16.50 abc
RTx436	65	109	7.50 ab	60	118	21.00 abc
SC326-6	81	107	5.50 ab	92	83	29.50 abc
SC414-14	67	103	28.10 bcd	63	108	7.00 ab
SRN39	68	120	27.60 bcd	71	133	48.00 c
Sureno	77	154	34.20 cd	77	203	0.70 a
Tx7078	62	105	21.10 abcd	59	105	5.30 ab
Tx2911	67	123	28.30 bcd	63	135	2.20 ab

FD, flowering date in days; PH, plant height in cm.
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.

5. Association analysis

There was some level of consistency ($r = 0.54$, $P < 0.0670$) in our disease scoring for the hybrids between the 2 years at Nioro, and between locations—Bambey and Nioro ($r = 0.42$, $P < 0.0313$) in 2005 based on Pearson correlation analysis. Disease scoring for the cultivars also showed some consistency ($r = 0.42$, $P < 0.0665$) between the locations in 2005. Table 3 shows the correlation between disease incidence and weather parameters (average rainfall, minimum and maximum average temperature), flowering date, and plant height. Disease incidence was significantly correlated with minimum average temperature and flowering date for the hybrids and with flowering date for the cultivars evaluated at Bambey. On the other hand, a significant negative correlation between disease incidence and flowering date was noted for the hybrids evaluated at Nioro in 2004. There was a significant negative correlation between disease incidence and maximum temperature for the cultivars evaluated at Nioro in 2004. There were positive moderately significant correlations between days to flowering and disease incidence for the cultivars in 2004, and between plant height and disease incidence for the hybrids in 2005 at Nioro.

6. Discussion

Long smut is a limiting factor in sorghum productivity and therefore, a threat to food security in West Africa. Although the disease has not been observed in the USA, the pathogen may yet be introduced there. Typically, importation of exotic plant pathogens goes unnoticed until a disease epidemic of economic concern develops. Often by

Table 3
Correlation coefficients between long smut incidence and weather parameters, days to flowering, and plant height obtained from the 2004 and 2005 experiments conducted in two locations in Senegal, West Africa

Location	Year	Rainfall		Min[a]		Max[b]		Flowering		Plant height	
		r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Nioro	2004 H[c]	0.21764	0.4359	−0.24184	0.3852	−0.04521	0.8729	−0.45937**	0.0416	−0.34652	0.1345
	2005 H	−0.10045	0.7217	0.31627	0.2508	0.13246	0.6379	0.18684	0.3411	0.34038*	0.0763
	2004 C[d]	−0.02665	0.9249	−0.28143	0.3096	−0.56638**	0.0277	0.42362*	0.0798	−0.18944	0.4237
	2005 C	−0.20663	0.4600	−0.16740	0.5510	−0.34434	0.2088	−0.01596	0.9468	−0.11782	0.6208
Bambey	2005 H	0.17392	0.5353	0.52140**	0.0462	0.13271	0.6373	0.39711**	0.0446	−0.27390	0.1757
	2005 C	−0.34121	0.2133	−0.18883	0.5003	0.36245	0.1843	0.52809**	0.0167	−0.26095	0.2665

r, correlation coefficient.
[a]Min: minimum average temperature.
[b]Max: maximum average temperature.
[c]H: hybrid.
[d]C: cultivar.
*Moderately significant at the 10% probability level.
**Significant at the 5% probability level.

the time the new disease is identified, it is too late to eradicate the pathogen, which has established itself in native species or spread to distant areas (Campbell and Madden, 1990). Such was the case with the fungus *Claviceps africana* Frederickson, Mantle, and de Milliano causing sorghum ergot which arrived into the USA in 1997 (Isakeit et al., 1998) and currently poses a serious threat to the sorghum hybrid seed production industry, as the pathogen infects unfertilized ovaries. Long smut cannot be controlled with chemical seed treatment, and therefore, it is imperative to determine the vulnerability of USA sorghum genotypes and to identify the sources of resistance to this disease. In the future, if long smut is detected in the USA, sound control strategies could be implemented rapidly to protect sorghum growers and the seed industry.

In the present study, the hybrids 730, 837, P84552, TR438, TR65G, and Wac660 and the cultivars B9612 and R9645 were identified as potential sources of long smut resistance. Significantly low levels of long smut infection in these sorghum lines were recorded in 2004 and 2005 at Nioro and Bambey, Senegal, West Africa (Tables 1 and 2). Although the other hybrids 3552 and A571 followed by XP503, W-876-DR, and TRX44631 recorded low levels of infection at both locations in 2005, disease levels were considered low to moderate in the nurseries at both locations. An additional year of evaluation will be needed to confirm their resistance. Unfortunately, 15 out of 31 hybrids studied expressed moderate to high levels of infection in at least in one location/year evaluation. Cultivars B.9612 and R.9645 consistently recorded low levels of infection. These two cultivars B.9612 and R.9645 may possess genes for long smut resistance. All the other cultivars, including the parental lines, which are in the background of some of the released or registered sorghum in the USA exhibited various levels of susceptibility. Sureno, a food quality cultivar commonly grown in Central America (Mackenstock et al., 1993) and used as a parental line in the USA, was found to be highly susceptible at the Nioro location (Table 2). Other parental sorghum lines such as BTx378, BTx623, BTx631, BTx635, and RTx436 were found to be highly susceptible in either one or both locations. These results suggest that commercial sorghum hybrids/cultivars with genetic backgrounds from one or more of the parental lines tested in this study are likely to be vulnerable to long smut. Contrary to Omer et al. (1985), SC326-6 was also found to be susceptible to long smut in this study.

Climatic conditions during the study may have influenced the levels of long smut incidence. In the present study, the maximum disease incidences recorded were 44% (Nioro-Hybrid trial-2004) and 48% (Bambey-Cutivar trial-2005), with 770 mm average rainfall in Nioro-2004 and 679 mm in Bambey-2005. However, Kumar and Nath (1991b) reported higher losses due to long smut in areas with annual rainfall below 635 mm. Kollo and Frederiksen (1998) 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. This indicates that environmental factors such as rainfall differentially influence the occurrence of long smut disease. The level of disease cannot be predicted by rainfall alone as evinced by the fact that there was no significant correlation between disease incidence and rainfall (Table 3). However, as reported earlier by Kollo and Frederiksen (1998), long smut infections may increase due to secondary spread, if rain is available. Flowering date and plant height also affected long smut infection as demonstrated by Moghal and Jagirdar (1979). Kollo and Frederiksen (1998) noted that early-maturing sorghum genotypes tended to escape infection when compared with tall and late-maturing genotypes.

In an earlier routine visual screening at the Washington DC Inspection Station, Mabry and Lightfield (1974) cautioned that packages of sorghum seeds collected from Africa and India were found to contain long smut. They noted that infection in these packages ranged from 8% to 100%, with panicles containing from a single sorus to as many as 40 sori. So, there is always a chance that long smut may be introduced into the USA via contaminated soil or sorghum seeds. In addition, with increasing world trade and more people traveling, the threat of introducing exotic pathogens is always a concern. Environmental conditions which favor long smut infection often occur in Texas and Kansas, where the bulk of the USA sorghums are grown. The present study indicates that there is a very limited number of sorghum lines from the USA that exhibit low levels of long smut infection from the selection tested. Identification of potential sources of resistance to this disease must be continued by screening a broader selection of USA sorghum germplasm.

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