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Research Article
The Occurrence and Distribution of Sorghum Diseases in Major Production Regions of Senegal, West Africa

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Abstract

Background and Objective: Sorghum ranks third behind millet and maize among dry land cereal production and plays a critical part in subsistence farming in Senegal. This study aimed to establish the occurrence, distribution and identify 'hotspots' of sorghum foliar and panicle diseases in major production regions of Senegal, West Africa. **Materials and Methods:** In 2019, a survey was conducted on 206 farmers' fields along paved and unpaved roads and around rural villages in major sorghum production regions of Thies, Kolda, Kaolack, Tambacounda, Kaffrine, Diourbel and Fatick. At each field, 40 plants were assessed arbitrarily using a W-shaped pattern to cover the whole field. Stops were made at intervals of 30 km and at each stop, 2-5 fields were surveyed for disease prevalence and incidence. **Results:** Fifteen different sorghum diseases were documented. Leaf blight was the most prevalent disease, followed by anthracnose, zonate leaf spot, rough leaf spot, sooty stripe and target leaf spot across the regions. Prevalence of covered kernel smut, gray leaf spot, oval leaf spot, long smut, grain mold and maize mosaic virus were observed in low frequencies. The highest incidence of leaf blight and anthracnose was recorded in the region of Kolda. The incidence of sooty stripe was highest in the regions of Thies and Kaffrine, while zonate leaf spot incidence was highest in Tambacounda. **Conclusion:** The work is significant because for the first time this information was documented and can be utilized as a guide by researchers such as Plant Pathologists, students, government and funding agencies and producers on the occurrence, distribution and relative importance of each sorghum disease in major sorghum-growing regions in Senegal, West Africa. The "hot spots" for evaluating sorghum germplasm for resistance to leaf blight, anthracnose, zonate leaf spot, sooty stripe and rough leaf spot also were identified.

Key words: Senegal, sorghum, sorghum fungal diseases, prevalence, incidence, disease survey, hot spots

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sorghum [*Sorghum bicolor* (L.) Moench] is one of the most important crops, especially in the arid and semi-arid tropics of Africa, Asia, Australia and Latin America[1-3]. Globally, sorghum provides the daily calorie needs for hundreds of millions people[1-4]. The crop is used primarily for human consumption in the form of baked foodstuff, boiled and traditional beverages, pasta, syrup and semolina accompanied sauce and in industries, sorghum is utilized in the production of fiber, starch, paper, recently, it used as a source of biofuel[1,2,4-6]. Sorghum is also used in animal feed, especially their haulms[1,3,7]. In Senegal, sorghum ranks third behind millet and maize among dry land cereal production and plays a critical part in subsistence farming[4,8]. The crop is planted in over 221,329 ha of land and producing about 225,865 tons with an average yield reaching 1,020 kg ha^{-1} [8]. When compared to North America, Mexico and India sorghum yield in some African Countries is still low and this can be attributed to the unpredictability of rainfall, low soil fertility, low farm input and biotic stresses[3,8]. In Senegal, landraces yields are low; however, some of the improved sorghum varieties developed and released by Institut Sénégalais de Recherches Agricoles/ Centre National de Recherches Agronomiques, yields can range from 2-5 t ha^{-1} in Experiment Stations with high farm inputs[4,9]. However, these improved varieties often yield about half when planted in farmers' fields[9]. Sorghum will continue to play an important part in food security, especially in the drier tropics as the world's population increases which is predicted to reach around 9.1 billion by 2050[3,10]. New challenges due to climate change and increases in sorghum production will likely increase diseases incited fungi, bacteria and other micro-organisms. Yield will be severely impacted and in addition, some of these pathogens are mycotoxigenic, thereby limiting the crop uses in human consumption and animal feed[11]. Therefore, an effective management strategy will require knowledge of the occurrence, distribution and relative economic importance of each disease across major sorghum growing regions. Due to the inadequate information regarding the biotic stresses that impact sorghum in major production regions of Senegal, West Africa, this study was undertaken to investigate the occurrence, distribution and 'hotspots' of sorghum foliar and panicle diseases in farmers' fields.

MATERIALS AND METHODS

Study area: Major sorghum production regions of Thies, Kolda, Kaolack, Tambacounda, Kaffrine, Diourbel and Fatick in Senegal, West Africa were surveyed for foliar and panicle diseases during the 2019 growing season (Fig. 1)[12]. Senegal is located between latitudes 12°30′ and 16°30′ N and longitudes 11°30′ and 17°30′ W, with the Sahelian zone lying in the northern part of Country, while the southern part which receives more rains belongs to the Sudanian zone[13]. There are two distinct seasons, a long dry period and 3-4 months rainy season[14,15]. Annual rainfall for the surveyed regions ranges from 380 mm (Thies) in the north to 1072 mm in Kolda which lies in the south and the soil types consisted of cambisols, arenosols, gleysols, regosols, acrisols, lixisols and solonchacks either individually as in Fatick or in combination as in the other regions as shown in Table 1. Sorghum cultivation in the Country is mainly by rainfed.

Data collection: The survey was conducted on 206 farmers' fields located along paved and unpaved roads and around rural villages. To identify farmers' fields, department agents from each region were contacted and team drove to the locations to conduct the survey. Due to the late planting in most regions, plants at soft to early hard dough stages of development were assessed for disease prevalence and incidence. Stops were made at intervals of 30 km. At each stop, 2-5 fields (40 plants/field) were surveyed using a W-shaped pattern to cover the whole field. For sampling

Table 1:Climatic data and soil types for the agroecological regions surveyed[1]

Region	Rainfall (mm)[2]	Max. temp. (°C)[3]	Min. tem. (°C)[4]	Soil type
Thies	379.6	33.10	23.16	Cambisols/Arenosols/Gleysols
Tambacounda	510.1	35.91	24.51	Regosols/Acrisols/Gleysols
Kolda	1072.4	35.1	24.08	Acrisols/Gleysols
Kaolack	751.6	35.3	24.84	Arenosols/Regosols/Lixisols/Solonchacks
Kaffrine	504.6	35.92	24.04	Arenosols/Regosols/Lixisols/Gleysols
Diourbel	390.7	36.6	24.5	Arenosols/Cambisols
Fatick	617.8	35.1	24.3	Cambisols

[1]Climatic data on the regions surveyed during the 2019 growing season. [2]Annual rainfall in millimeters. [3]Max Temp: mean maximum temperature during the growing season (June to October). [4]Min Temp: Mean minimum temperature during the growing season (June to October)

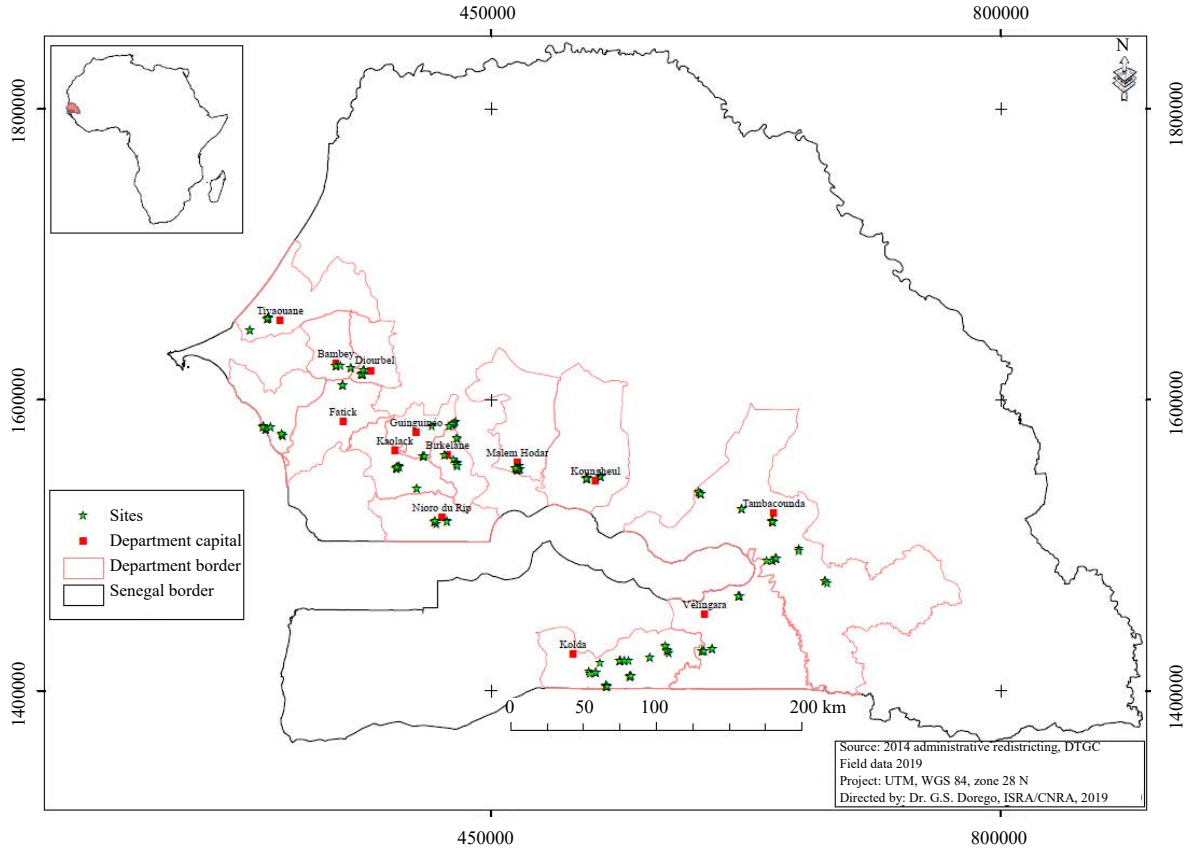

Fig. 1: Map of Senegal, regions and surveyed districts[12]

plants in a diseased field, the use of a W-shaped pattern is more effective than a simple random sample because diverse locations within the field will be sampled[16]. Equations for prevalence and incidence as per Prom *et al.*[11] and Njoroge *et al.*[17] used.

Statistical analysis: Pearson correlation coefficients between weather conditions and sorghum disease prevalence and incidence were calculated:

$$\text{Prevalence rate } (\%) = \frac{\text{Number of fields with the disease}}{\text{Total number of fields surveyed}} \times 100$$

$$\text{Incidence } (\%) = \frac{\text{Number of plants with the disease in a field}}{\text{Number of plants assessed in a field}} \times 100$$

RESULTS

A total of 206 farmers' fields in 7 major sorghum producing regions of Thies, Tambacounda, Kolda, Kaolack, Kaffrine, Diourbel, Fatick, Senegal and West Africa were surveyed for the prevalence and incidence of diseases during the 2019 growing season (Fig. 1). The vast majority of fields evaluated were planted with different landraces with few exceptions that were cultivated with improved varieties developed and released by Institut Sénégalais de RecherchesAgricoles/Centre National de Recherches Agronomiques (ISRA/CNRA). The fields surveyed consisted of different production practices, including pure sorghum stand, intercropping with either peanut or cowpea and field sizes ranged from 0.25-2.5 ha. The fields were relatively well maintained. Weather parameters and the soil types for the 7 regions which consisted of cambisols, arenosols, gleysols, regosols, acrisols, lixisols and solonchacks either individually as in Fatick or in combination as in the other regions are noted in Table 1.

Disease prevalence and incidence: In each field, 40 plants were assessed for disease prevalence and incidence using a W-shaped pattern to cover the whole site. Fifteen different sorghum diseases, including leaf blight, anthracnose, long smut, target leaf spot zonate leaf spot, rough leaf spots, oval leaf spot, sooty stripe, covered kernel spot and gray leaf spot were observed across the surveyed regions. Figure 2 shows

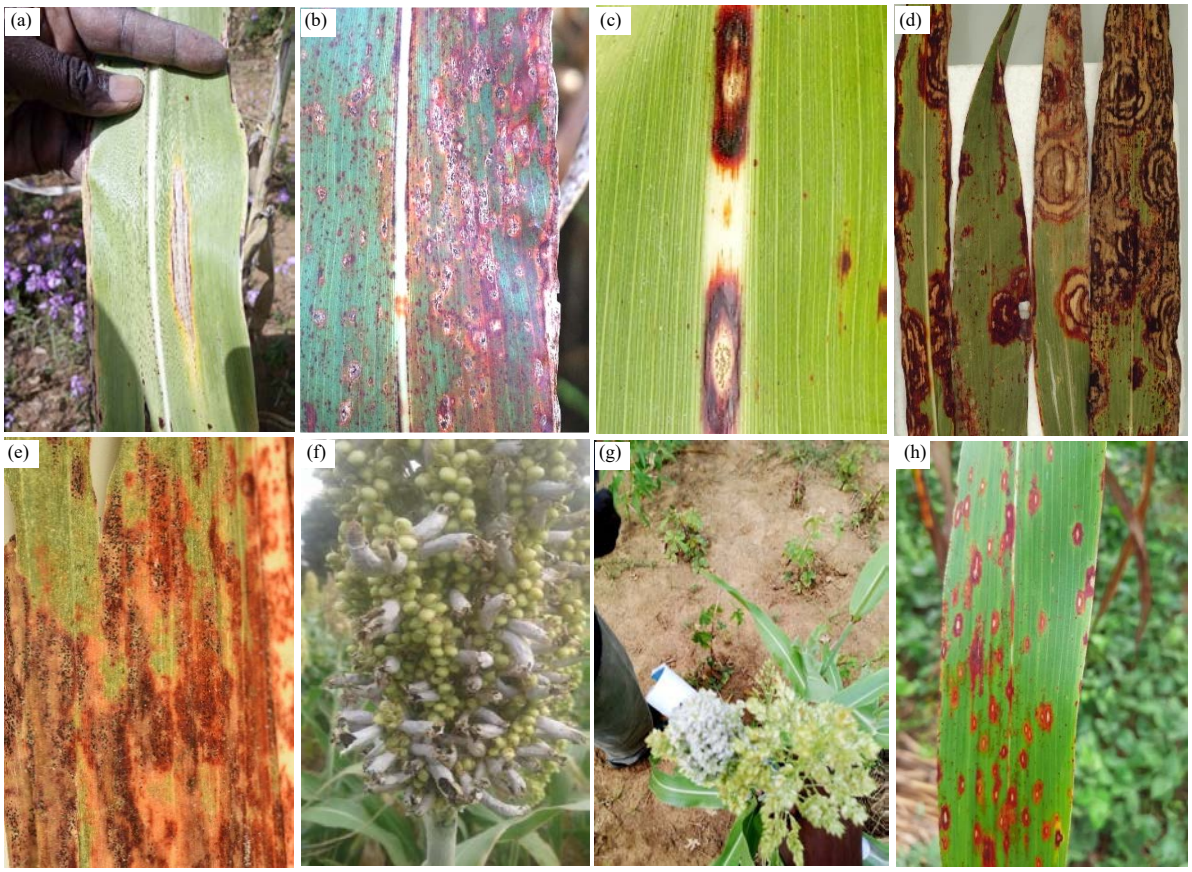

Fig. 2(a-b): Images of sorghum diseases encountered during the survey of farmers' fields in 7 regions of Senegal, West Africa, (a) Leaf blight, (b) Anthracnose infected leaf with acervuli, (c) Anthracnose infected midrib with acervuli, (d) Zonate leaf spot, (e) Rough leaf spot, (f) Long smut, (g) Covered kernel smut and (h) Oval leaf spot

Table 2: Overall prevalence of sorghum diseases across 206 farmers' fields observed during the survey in Senegal, 2019

Disease	Prevalence rate (%)
Leaf blight (*Exserohilum turcicum*)	96
Long smut (*Sporisorium ehrenbergii*)	10
Target leaf spot (*Bipolaris sorghicola*)	35
Anthracnose (*Colletotrichum sublineola*)	68
Bacterial stripe (*Burkholderia andropogonis*)	10
Zonate leaf spot (*Gloeocercospora sorghi*)	61
Bacterial leaf blight (*Acidovorax avenae*)	3
Bacterial leaf streak (*Xanthomonas campestris* pv. *holcicola*)	4
Oval leaf spot (*Ramulispora sorghicola*)	12
Rough leaf spot (*Ascochyta sorghina*)	42
Maize Mosaic virus	1
Sooty stripe (*Ramulispora sorghi*)	41
Covered smut (*Sporisorium sorghi*)	19
Gray leaf spot (*Cercospora sorghi*)	13
Grain mold (associated with several fungal genera)	2

[1]206 sorghum fields were surveyed from 7 regions in Senegal and at each field, 40 plants were assessed using a W-shaped pattern to cover the whole field. Prevalence rate was based on number of fields with the particular disease divided by the total number of fields surveyed and then multiplied by 100

2a Leaf blight; 2b Anthracnose infected leaf with acervuli; 2c Anthracnose infected midrib with acervuli; 2d Zonate leaf spot; 2e Rough leaf spot; 2f long smut; 2g Covered kernel smut and 2h Oval leaf spot. Overall, leaf blight was the most prevalent disease found in 96% of the 206 fields surveyed, followed by anthracnose (68%), zonate leaf spot (61%), rough leaf spot (42%), sooty stripe (41%) and target leaf spot (35%) across the regions (Table 2). Prevalence of covered kernel smut was 19%, gray leaf spot (13%), oval leaf spot (12%), long smut (10%) and bacterial stripe (10%). Out of the 206 fields surveyed, bacterial leaf streak was observed in 8 fields, bacterial leaf blight (9 fields), grain mold (5 fields) and maize mosaic virus (2 fields) accounting for less than 10% prevalence for each of these diseases (Table 2). The mean prevalence of leaf blight ranged from 88% in Thies region to a 100% in the regions of Kolda, Kaolack and Fatick (Table 3). The highest prevalence of anthracnose (88%) was recorded in the region of Thies, followed by 82 and 80% in the regions of Tambacounda and Kaffrine, respectively. Zonate leaf spot was

Table 3: Percent prevalence of sorghum diseases observed in the seven regions surveyed during the 2019 growing season[1]

	Region						
Disease	Thies	Tambacounda	Kolda	Kaolack	Kaffrine	Dioubel	Fatick
Leaf blight	88	95	100	100	94	90	100
Long smut	28	0	0	17	6	25	33
Target leaf spot	36	38	14	33	66	10	83
Anthracnose	88	82	78	53	80	10	0
Bacterial stripe	28	10	12	3	3	5	0
Zonate leaf spot	80	97	45	53	66	20	33
Bacterial leaf blight	12	3	2	0	0	0	17
Bacterial leaf streak	20	5	0	0	0	0	17
Oval leaf spot	12	8	8	10	29	5	0
Rough leaf spot	44	41	6	50	83	45	67
Maize mosaic virus	4	0	0	0	3	0	0
Sooty stripe	24	64	14	63	37	45	83
Covered smut	20	38	18	3	26	5	0
Gray leaf spot	0	15	12	0	34	5	33
Grain mold	4	3	0	3	3	5	0

The number of fields surveyed from each region: Thies (25 fields), Tambacounda (39), Kolda (51), Kaolack (30), Kaffrine (35), Diourbel (20) and Fatick (6). At each field, 40 plants were assessed using a W-shaped pattern to cover the whole field. Prevalence rate was based on number of fields with the particular disease divided by the total number of fields surveyed and then multiplied by 100

Table 4: Mean incidence of various sorghum diseases observed across the seven regions surveyed in 2019, Senegal[1]

Region[2]	LBL[3]	LSM	TAR	BACB	ANTH	BACSTRI	ZONA	OVL	BACSTRE	SOOTY	MOSAI	RLS	CSMUT	GLS	GM
Thies	27	6	5	6	20	6	23	3	3	30	3	19	15	0	13
Kolda	81	0	16	3	49	13	10	5	0	11	0	9	8	5	0
TAM	37	0	10	3	36	7	35	7	13	15	0	11	8	6	33*
KAF	34	4	11	0	32	3	31	6	0	21	3	30	19	7	3
KAOL	31	3	14	0	16	3	24	14	0	23	0	21	3	0	5
Diour	22	19	8	0	4	3	7	3	0	14	0	18	5	5	53*
FAT	30	20	17	3	0	0	10	0	3	28	0	21	0	4	0

[1]At each field, 40 plants were assessed using a W-shaped pattern to cover the whole field. Incidence was based on number of infected plants with particular disease divided by the total number of plants surveyed and then multiplied by 100 and averaged across each region. [2]Region: Thies, Kolda, TAM: Tambacounda, KAF: Kaffrine, KAOL: Kaolack, Diour: Diourbel and FAT: Fatick. [3]Sorghum diseases: LBL: Leaf blight, LSM: Long smut, TAR: Target leaf spot, BACB: Bacterial leaf blight, ANTH: Anthracnose, BACSTRI: Bacterial leaf strip, ZONA: Zonate leaf spot, OVL: Oval leaf spot, BACSTRE: Bacterial leaf streak, SOOTY: Sooty stripe, MOSAI: Maize dwarf mosaic, RLS: Rough leaf spot, CSMUT: Covered kernel smut, GLS: Gray leaf spot and GM: Grain mold. *Incidence based on one infected field

most prevalent in the region of Tambacounda (97%), while rough leaf spot (83%) and sooty stripe (83%) were most prevalent in the regions of Kaffrine and Fatick, respectively. The highest mean incidences of leaf blight (81%) and anthracnose (49%) were observed in the region of Kolda, while the highest incidences of long smut (20%) and target leaf spot (17%) were recorded in the region of Fatick (Table 4). Among the regions, the highest mean incidence of sooty stripe (30%) was noted in Thies region followed by 28% in Fatick. Whereas, the mean incidences of rough leaf spot (30%) and covered kernel smut (19%) were highest in the region of Kaffrine. Grain mold was recorded in 5 fields out of the 206 fields surveyed. In two separate fields, one each in Tambacounda and Diourbel where grain mold was observed, the incidences were 33 and 53% (Table 4).

Out of the 51 fields surveyed in the region of Kolda, 39% (i.e., 20 fields) and 14% (i.e., 7 fields) recorded 100% incidence of leaf blight and anthracnose in each field, respectively. The locations and their coordinates also are listed in Table 5. The highest incidence of sooty stripe was recorded in three different fields and regions, field # 5 (98%) located in Pointe Sarene, Thies region; field # 112 (98%), Fass Bamba, Kaffrine and field # 134 (90%) located in Keur Kory, Kaolack (Fig. 3a). Figure 3b also shows the highest incidence 98% of zonate leaf spot was recorded in field # 78 located in Djinkore, Tambacounda. The other three fields with next highest zonate leaf spot incidence also were located in the region of Tambacounda. The highest incidence of rough leaf spot was observed in field # 160 (95%) located in Keur Ismaila, in the region of Kaffrine (Fig. 4). These aforementioned fields can be considered 'hot spots' for leaf blight, anthracnose, sooty stripe and zonate leaf spot evaluation sites to identify resistant sources.

Pearson correlation coefficients were calculated among rainfall, maximum temperature, minimum temperature and various sorghum diseases (Table 6 and 7). A significant positive correlation ($p = 0.80710$, $r = 0.0282$) between rainfall and leaf blight was noted, indicating that higher rainfall results

Table 5: Region, location and coordinate of surveyed fields with 100% incidence of leaf blight and anthracnose[1]

Region	Field	Location	Coordinates
Leaf blight			
Kolda	26	Ndissane	X: 516953,4180; Y: 1413539,155
Kolda	27	Guire yero Bocar	X: 517727,7440; Y: 1412081,713
Kolda	28	Daiffa	X: 521513,9300; Y: 1413153,928
Kolda	29	Daiffa	X: 521807,0650; Y: 1413292,644
Kolda	30	Daiffa	X: 521871,7540; Y: 1413389,547
Kolda	31	Daiffa	X: 521575,0000; Y: 1413148,000
Kolda	33	Kountima	X: 528607,0000; Y: 1403727,000
Kolda	35	Kountima	X: 528655,0150; Y: 1403879,317
Kolda	37	Kountima	X: 528962,8410; Y: 1403935,477
Kolda	39	Kountima	X: 529709,9930; Y: 1403637,415
Kolda	40	Kountima	X: 529713,0000; Y: 1403614,000
Kolda	41	TementoTobo	X: 545115,0190; Y: 1410285,206
Kolda	42	TementoTobo	X: 545146,3170; Y: 1410455,802
Kolda	45	TementoTobo	X: 545899,7430; Y: 1410453,071
Kolda	47	Thiefana	X: 558836,6990; Y: 1423776,053
Kolda	50	Mampatim	X: 570928,6510; Y: 1427866,363
Kolda	55	Salamata	X: 524627,5720; Y: 1420004,502
Kolda	56	Sarékael	X: 538530,3010; Y: 1420941,607
Kolda	61	Salamata	X: 541153,0000; Y: 1421078,000
Kolda	63	Thiara	X: 541141,0000; Y: 1420931,000
Anthracnose			
Kolda	29	Daiffa	X: 521807,0650; Y: 1413292,644
Kolda	30	Daiffa	X: 521871,7540; Y: 1413389,547
Kolda	54	Mampatim	X: 569455,4110; Y: 1431706,120
Kolda	60	Salamata	X: 538120,0000; Y: 1420927,000
Kolda	67	kabedou	X: 595872,7580; Y: 1427690,361
Kolda	68	kabedou	X: 595883,4930; Y: 1427536,085
Kolda	71	Thimfara Maoundé	X: 601730,2790; Y: 1429751,850

At each field, 40 plants were assessed using a W-shaped pattern to cover the whole field. Incidence was based on number of infected plants divided by the total number of plants surveyed and then multiplied by 100. These fields are considered 'hotspots' for leaf blight and anthracnose

Table 6: Pearson correlation coefficients between weather conditions and sorghum disease prevalence at 5% significance level

	RainF[1]	MaxT[2]	MinT[3]	LBL[4]	LSM	TAR	ANTH	ZONA	OVL	RLS	Sooty	GLS	GM
RainF	1.00000	0.00064	0.24976	0.8071	-0.46106	-0.20034	0.12901	-0.21604	-0.36774	-0.16215	-0.58401	-0.21379	0.01136
		0.9989	0.5891	0.0282*	0.2978	0.6667	0.7828	0.6417	0.4170	0.7283	0.1686	0.6453	0.9807
Max. T	0.00064	1.00000	0.77723	0.1899	-0.33923	-0.10670	-0.38126	-0.34550	-0.75306	0.03436	0.16948	0.31840	0.30065
	0.9989		0.0397	0.6834	0.4567	0.8199	0.3988	0.4478	0.0507*	0.9417	0.7164	0.4864	0.5123
Min. T	0.24976	0.77723	1.00000	0.56218	-0.20110	-0.07871	-0.45043	-0.31936	-0.62765	-0.27323	0.04822	0.61171	0.04639
	0.5891	0.0397		0.189	0.6655	0.8668	0.3105	0.4851	0.1313	0.5533	0.9182	0.1444	0.9213

[1]RainF: Annual rainfall in millimeters. [2]MaxT: mean maximum temperature during the growing season (June to October). [3]MinT: mean minimum temperature during the growing season (June to October). [4]Sorghum diseases: LBL: Leaf blight, LSM: Long smut, TAR: Target leaf spot, ANTH: Anthracnose, ZONA: Zonate leaf spot, OVL: Oval leaf spot, RLS: Rough leaf spot, Sooty: Sooty stripe, GLS: Gray leaf spot and GM: Grain mold. *Significant at the 5% probability level

Table 7: Pearson correlation coefficients between weather conditions and sorghum disease incidence significant at the probability levels of 1, 5 and 10%

	RainF	Max. T	Min. T	LBL	LSM	TAR	ANTH	ZONA	OVL	Sooty	RLS	GLS	GM
RainF	1.00000	0.00064	0.24976	0.87651	-0.40704	0.77783	0.52063	-0.28552	0.28552	-0.40169	-0.44072	0.01864	-0.56925
		0.9989	0.5891	0.0096***	0.3648	0.0395**	0.2309	0.5348	0.5348	0.3717	0.3223	0.9684	0.1823
Max. T	0.00064	1.00000	0.77723	-0.05111	0.18534	0.22563	-0.04454	-0.04781	0.15860	-0.66409	0.04746	0.69814	0.47017
	0.9989		0.0397	0.9133	0.6907	0.6266	0.9245	0.9189	0.7341	0.1038	0.9195	0.0811*	0.2870
Min. T	0.24976	0.77723	1.00000	-0.05415	0.09176	0.49469	-0.17364	-0.03832	0.50405	-0.43351	-0.08210	0.21390	0.22790
	0.5891	0.0397		0.9082	0.8449	0.2591	0.7096	0.9350	0.2487	0.3312	0.8611	0.6451	0.6231

[1]RainF: Annual rainfall in millimeters. [2]MaxT: Mean maximum temperature during the growing season (June to October). [3]MinT: Mean minimum temperature during the growing season (June to October). [4]Sorghum diseases: LBL: Leaf blight, LSM: Long smut, TAR: Target leaf spot, ANTH: Anthracnose, ZONA: Zonate leaf spot, OVL: Oval leaf spot, RLS: Rough leaf spot, Sooty: Sooty stripe, GLS: Gray leaf spot and GM: Grain mold. ***,**,*Designated as significant at the probability levels of 1, 5 and 10%

in higher prevalence of leaf blight (Table 6). A significant negative correlation (p = -0.75306, r = 0.0507) between maximum temperature and oval leaf spot also was noted during the 2019 growing season. Similarly, there was a highly positive significant correlation (p = 0.87651, r = 0.0096) between rainfall and leaf blight incidence, indicating that higher rainfall results in a higher incidence of leaf blight (Table 7). Also, a positive significant correlation (p = 0.77783,

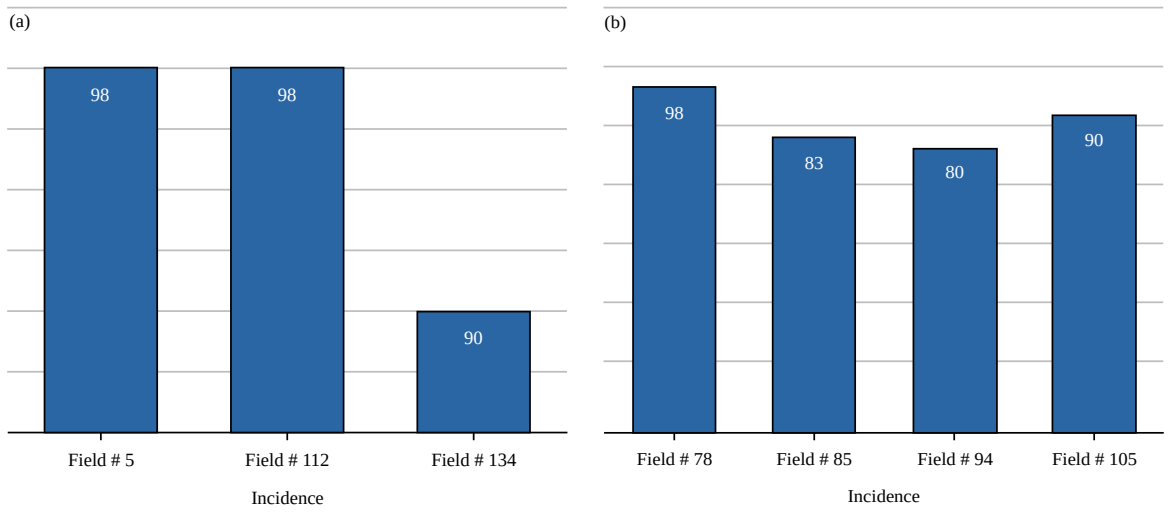

Fig. 3(a-b): (a) Sooty stripe 'hotspots' field # 5 (Region: Thies, Location: Pointe Sarene), Field # 112 (Region: Kaffrine, Location: Fass Bamba) and Field # 134 (Region: Kaolack, Location: Keur Kory) and (b) Zonate leaf spot hotspots-field # 78 (Region: Tambacounda, Location: Djinkore); Field # 85 (Region: Tambacounda, Location: Djinkore); Field # 94 (Region: Tambacounda, Location: Taliboulou) and Field # 105 (Region: Tambacounda, Location: Damantang)

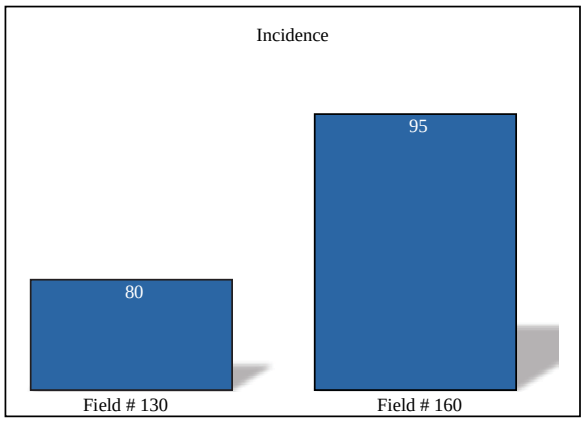

Fig. 4: Hotspots for Rough leaf spot-field # 130 (Region: Kaolack, Location: Thiawando) and Field # 160 (Region: Kaffrine, Location: Keur Ismaila)

r = 0.0395) between rainfall and the incidence of target leaf spot was noted. A non-significant positive correlation between rainfall and anthracnose and a non-significant negative association between rainfall and long smut were observed (Table 6 and 7).

DISCUSSION

The ability to increase yield and garner profit for farmers in rainfed cultivation of sorghum in Senegal and other arid and semi-arid sorghum growing regions are hampered by many challenges, including lower farm inputs, low soil fertility, weather pattern and biotic stresses[3,8,18]. For food security and the expected global increase in population to around 9.1 billion by 2050, increase in annual cereal production, including sorghum will be required[10]. Increases in sorghum production coupled with climate change will likely increase diseases caused by fungal, bacterial and viral micro-organisms[11]. In Senegal, there is little or no information on the occurrence and distribution of sorghum diseases in farmers' fields. In addition, sound management strategy will require knowledge of the occurrence, distribution and relative economic importance of each disease across major sorghum growing regions in Senegal. Thus, this is the first time that an extensive survey of sorghum foliar and panicle diseases in production fields was conducted.

In this survey, leaf blight was the most prevalent disease in all the 7 regions surveyed and in three of the regions Kolda, Kaolack and Fatick, the prevalence was 100%. Out of the 51 fields surveyed in the region of Kolda, 20 fields exhibited 100% of leaf blight. Beshir *et al.*[19], also noted the presence of sorghum leaf blight in all 45 fields surveyed in Central Sudan with incidence ranging from 65-100%. In Niger, the prevalence of leaf blight was 89% across farmers' fields surveyed in four major sorghum-growing regions[11]. Survey conducted by Njoroge *et al.*[17] on sorghum grown across different agroecological zones in Tanzania and Uganda, revealed that leaf blight was the most prevalent disease in Tanzania. The prevalence of leaf blight was 84.8% on sorghum fields surveyed in South Tigray, Ethiopia in 2015[20]. However, survey

conducted in three climatic zones (Sudan, northern and southern Guinea Savanna) in major sorghum-growing regions in Ghana, revealed low frequency of leaf blight[21]. This is not surprising due to the different weather patterns, farming systems and different landraces that are planted in different regions and Countries in West Africa. In Senegal, anthracnose was the second most frequently documented disease with 68% prevalence. Tsedaley *et al.*[22] observed the presence of anthracnose in all fields surveyed in Southwestern and Western Ethiopia. Similarly, Eshte *et al.*[23], recorded 100% incidence of anthracnose in three districts of South Omo and Segen People zones in Ethiopia. while Prom *et al.*[11], noted the presence of anthracnose in 120 out of 121 fields surveyed in four major sorghum growing regions of Niger. In the current survey, 7 fields out of 51 surveyed in the region of Kolda had 100% incidence of anthracnose. In some Countries of West Africa, anthracnose infected foliage can result in yield loss of up to 46%[24]. During the survey in Senegal, other diseases such as zonate leaf spot, rough leaf spot, sooty stripe, target leaf spot covered kernel smut, gray leaf spot, oval leaf spot and long smut were also documented, while bacterial leaf streak, bacterial leaf blight, grain mold and maize mosaic virus were observed in low frequency. In Senegal, one of the primary priorities involves the development of high yielding hybrids with resistance or tolerance to grain mold[9]. However, Denis and Girard[25] reported that location was a significant factor in grain mold severity and the concentration of grain molding fungi such as *Fusarium* and *Curvularia* in the kernel. In this study, the low frequency of grain mold observed can also be attributed to the fact that some of the surveyed field did not reach physiological maturity. Nevertheless, where it occurred in the regions of Tambacounda and Diourbel in this survey, grain mold was more severe in improved varieties released by ISRA/CNRA with compact shaped panicles. The landraces (loose panicles) planted in farmers' fields during the survey were mainly from the Guinea race. In Puerto Rico, Cuevas *et al.*[26] evaluated 158 accessions from the Senegalese germplasm collection maintained by the USDA National Plant Germplasm, Georgia and reported that Guinea race population favors resistance to anthracnose and grain mold. Anthracnose, oval leaf spot, sooty stripe and gray leaf spot were the most prevalence diseases documented in farmers' fields surveyed across four major sorghum-growing climatic zones in Nigeria[27]. In Western Kenya, anthracnose, leaf blight, gray leaf spot and zonate leaf spot were found to be the most frequently observed diseases in farmers' fields[28]. In Niger, West Africa anthracnose, leaf blight, oval leaf spot, rough leaf spot and long smut were the most prevalence diseases found in farmers' field across four regions[11]. In this study, similar diseases with different frequencies were also documented in farmers' fields in Senegal. Rainfall is vital for plant growth, pathogen spore germination, infection, disease development, severity and spread[8,29-35]. The annual rainfall was highest in the region of Kolda which is located in the southern part of the Country (Table 1). In Kolda, 20 fields and 7 fields exhibited 100% incidence of leaf blight and anthracnose, respectively. These two diseases also were the most prevalent during the survey. In this survey, significant positive correlation between rainfall and leaf blight prevalence and highly significant association between rainfall and leaf blight incidence were noted, indicating that rainfall has an influence in the development of leaf blight. However, Hennessy *et al.*[36] observed that high leaf blight severity was associated with minimum temperature between 14 and 16°C and average temperature of 20.8-22.2°C, but that rain was not as critical in determining the severity of leaf blight as temperature. In the sorghum/ergot pathosystem, Montes-Garcia *et al.*[29] reported that ergot infection was enhanced by high humidity provided by rain or drizzles during the morning or afternoon. In the current survey, non-significant positive correlation was noted between rainfall and the prevalence and incidence of anthracnose. However, Chala *et al.*[30] and Prom *et al.*[31] noted significant positive association between total rainfall and anthracnose development. A positive significant correlation between rainfall and the incidence of target leaf spot was also noted in this study. Long smut of sorghum is most severe during drought and low soil moisture conditions[37] and in this survey, non-significant negative correlation between rainfall and long smut was noted.

CONCLUSION

This survey showed that leaf blight was the most prevalence sorghum disease, followed by anthracnose, zonate leaf spot, rough leaf spot and sooty stripe. The work is significant because for the first time this information was documented and can be utilized as a guide by researchers such as Plant Pathologists, students, government and funding agencies and producers, on occurrence, distribution and relative importance of each sorghum disease in major sorghum-growing regions in Senegal, West Africa. During this survey "hot spots" for leaf blight, anthracnose, zonate leaf spot, sooty stripe and rough leaf spot were identified. These locations can be used to screen sorghum germplasm for resistance against the pathogens inciting the aforementioned diseases. With the global population increases coupled with climate change, the proliferation of crop diseases constitutes a direct threat to food security and an indirect threat to

the economy, to human and animal health and to the environment. Integrated disease management, especially providing farmers with genetically resistant sources to diseases that of economic importance in the arid and semi-arid sorghum producing Countries or regions, including Senegal will be critical in ensuring food security, current interactions with farmers on disease identification, control methods and importance of planting resistant sources during the survey will facilitate the acceptance of new technology in improving farming in these regions.

SIGNIFICANCE STATEMENT

Sorghum leaf blight, anthracnose, zonate leaf spot, rough leaf spot, sooty stripe and target leaf spot were the most widely distributed diseases in major production regions of Senegal.

"Hot spots" for resistance evaluation of diseases such as leaf blight, anthracnose, sooty stripe, zonate leaf spot and rough leaf spot were identified. This is the first extensive survey of sorghum diseases in major production regions of Senegal. This document will serve as a guide for present and future sorghum workers, especially sorghum pathologists.

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