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Incidence, Severity, and Prevalence of Sorghum Diseases in the Major Production Regions in Niger

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Abstract

Sorghum ranks second to pearl millet as the most important cereal in Niger and is used primarily for food, feed, and other uses. During the 2022 growing season, 96 fields from the five major sorghum production regions of Dosso, Maradi, Tahoua, Tillabéri, and Zinder were surveyed for foliar and panicle diseases. In each field, 40 plants were assessed using a W-shaped pattern to cover the whole field. A total of 19 diseases, including leaf blight, anthracnose, long smut, zonate leaf spot, bacterial leaf stripe, oval leaf spot, and rough leaf spot were documented. Leaf blight (100%) was detected in all the fields surveyed. In the regions of Dosso and Zinder, anthracnose was found in all the surveyed fields while oval leaf spot was detected in all surveyed fields in Maradi and Zinder. The highest mean incidence of leaf blight (95%) was recorded in the regions of Tahoua and Zinder while oval leaf spot (80%), anthracnose (56%), and gray leaf spot (25%) were highest in Maradi region. The highest mean severities of leaf blight (30%), long smut (29%), grain mold (18%), and anthracnose (13%) were recorded in Maradi region. The severity of head smut was 100% in all the regions where the disease was observed. Fields with incidence of 90% and above identified during the survey are considered as 'hot spots' for disease resistance screening. This work is significant because the information generated by the study can be utilized by sorghum workers, students, funding agencies and government officials to prioritize research projects.

Keywords: sorghum, survey, sorghum diseases, incidence, prevalence, severity, Niger

1. Introduction

In Sub-Saharan Africa, sorghum [Sorghum bicolor (L.) Moench] supplies the daily caloric needs for millions of inhabitants (Frederickson & Odvody, 2000; Mundia et al., 2019; Pereira & Hawkes, 2022). Its uses include baked foodstuff, alcoholic beverages, fiber, starch, paper, syrup, biofuel, and in the health industry to combat or reduce the impact of various human maladies (Gonzalez et al., 2011; Araujo et al., 2017; Upadhyaya et al., 2017; Khalid et al., 2022). Sorghum is drought tolerant and often grown under marginal lands with low farm inputs, especially in several resource poor Countries (Gonzalez et al., 2011; Rooney et al., 2007, Chala et al., 2010; Ignacimuthu & Premkumar., 2014). In Niger, 3,519,085 ha were harvested, producing 1,207,237 metric tons during the 2021 season (FAOSTAT). Compared to other countries, including some in Africa, sorghum yield in Niger fluctuates from year to year but is still low, ranging from 193 kg/ha to a little over 406 kg/ha (Anonymous, 2021); Mundia et al., 2019; Hamidou et al., 2018; Anonymous, 2019). Globally, Africa produces the most sorghum and West Central African Countries are responsible for 90% of the production (Weltzien & Rattunde, 2022). Nevertheless, sorghum yield/ha in Niger and other African Countries in the drier tropics is still low and this is due to several factors such as lower farm inputs, the unpredictable weather patterns, type of sorghum cultivars/landraces used, demand from urban areas where people prefer the consumption of the other major cereals, wheat, maize, and rice, lack of research, pests and diseases (Pereira & Hawkes, 2022; Mundia et al., 2019; Kadi Kadi et al., 2005). In Niger, sorghum production ranks second to pearl millet in importance, and is

used primarily as a staple food and for animal feed, especially their stalks (Hamidou et al., 2018; Manssour et al., 2014; Ousmane et al., 2017). The world's population is projected to reach 9.1 billion by 2050 and is estimated that 3 billion tons increase of cereal for food and non-food purposes will be needed (Mundia et al., 2019; FAO, 2009). The projected increases in cereal production coupled with other factors such as climate change will likely increase fungal, bacterial, viral and other diseases. Some of these diseases can cause both yield and quality losses, and in addition, many of these pathogens have the capacity to produce mycotoxins that can negatively impact human and animal health (Sashidha et al., 1992; Leslie et al., 2005; Isakeit et al., 2008; Prom et al., 2011a; Funnell-Harris et al., 2013; Cuevas et al., 2016). As a result, an integrated effort, including disease management will be critical in ensuring food security and environmental resilience. To determine the relative importance of these diseases, four major sorghum producing regions in Niger were surveyed in Niger during the 2019 growing season (Prom et al., 2020). The 2019 survey did not include the second ranked sorghum production region of Zinder and severity of the various diseases, which is a critical component in estimating economic loss. This study was conducted to investigate the occurrence, distribution, and severity of foliar and panicle diseases affecting sorghum in farmers' fields from the top five major production regions of Niger and to validate the information gathered during the 2019 growing season.

2. Material and Methods

The five major sorghum production regions of Dosso, Maradi, Tahoua, Tillabéri, and Zinder in Niger were surveyed for foliar and panicle diseases during the 2022 growing season (Figure 1). Climatic condition for the four regions of Dosso, Maradi, Tahoua, and Tillabéri is Sahelian; however, northern Tahoua has a Sahelo-Saharian, while the southern of Gaya in Dosso region has a Sahelo-Sudanian type of climate. Zinder region has a dry subtropical climate while the northern part belongs to the Sahara Desert (Table 1) (Hamidou et al., 2018; Anonymous, 2019; Anonymous, 2021). The annual rainfall ranges from 435 mm in Tahoua with most of the rains falling in July and August to 700 mm (Dosso) and Gaya experiencing total rains primarily in June to September that exceed 800 mm. The soil type for the region of Zinder is Lithosols while the other regions have mainly Ferruginous tropical soil, with localities of Bengou and to a lesser degree Tara also having a hydromorphous soil type (Table 1) (Hamidou et al., 2018; Anonymous, 2019; Anonymous, 2021). During the rainy season, the maximum and minimum temperatures for the surveyed regions also are noted in table 1 (Hamidou et al., 2018; Anonymous, 2019; Anonymous, 2021). Table 2 shows the average yield, rank in term of annual sorghum production, and farming systems among the surveyed regions of Niger (Moussa, 2013; Anonymous, 2015; Anonymous, 2022). A total of 96 farmers' fields along paved and unpaved roads, including National and Secondary (RN1, RN2, RN3) were arbitrarily surveyed and plants at late flowering to hard dough stages of development were assessed for diseases to cover the whole field, a W-shaped pattern was used. Along the roads, stops were made at intervals of 30 km. At each stop, 2 - 5 fields (40 plants per field) were surveyed for disease incidence, severity, and prevalence. The formulae for incidence and prevalence noted below have been previously described by Prom et al. (2020).

$$\text{Prevalence rate} = \frac{\text{Number of fields with the disease}}{\text{Total number of surveyed fields}} \text{ x } 100$$

$$\text{Incidence} = \frac{\text{Number of plants with the disease in a field}}{\text{Number of plants assessed in a field.}} \text{ x } 100$$

Disease Severity scale: The surveyed fields were planted with landraces and advanced lines with different leaf sizes; as a result, a modified Horsfall-Barratt rating scale of 0 – 11 (Campbell & Madden, 1990) with Chala et al. (2007) range where 1 = 1-10, 2 = 11-20, 3 = 21-30, 4 = 31-40, 5 = 41-50, 6 = 51-60, 7 = 61-70, 8 =71-80, 9 = 81-90, 10 = 91-100, and 11 = 100 was employed. Their mid-points, where 1 = 5.5, 2 = 15.5, 3 = 25.5, 4 = 35.5, 5 = 45.5, 6 = 55.5, 7 = 65.5, 8= 75.5, 9 = 85.5, 10 = 95.5, and 11 = 100 were used to calculate the mean severity.

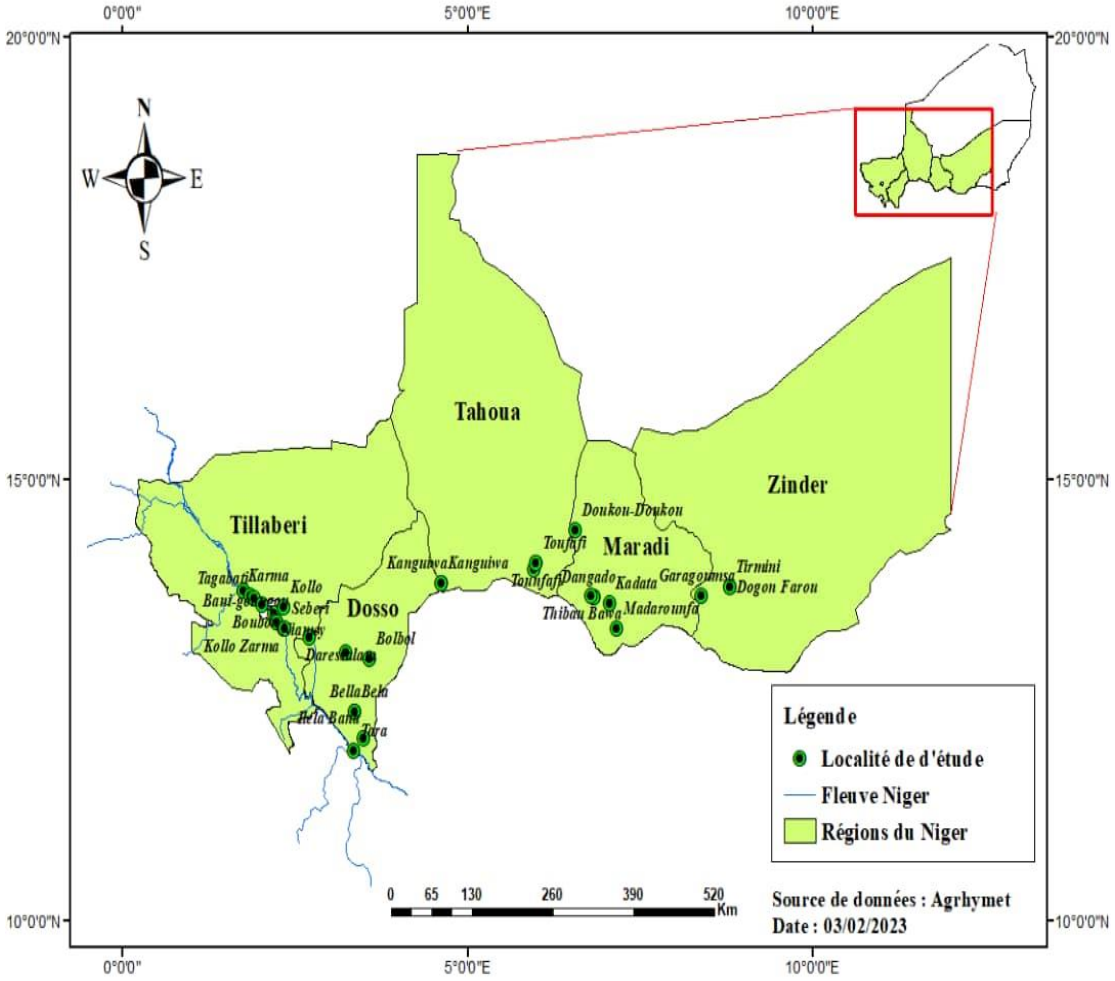

Figure 1. Regions and locations of the sorghum fields surveyed in 2022

Table 1. Weather parameters and soil types of the surveyed regions of Niger

	Regions				
Data	**Tillabéri**	**Tahoua**	**Dosso**	**Maradi**	**Zinder**
Annual rainfall	450 mm from Apr. to Oct. (66% in Jul. and Aug.).	Ave. Range 435 mm to 509 mm. In **Konni**, Apr.to Oct. (58% in Jul. and Aug.).	Ave. Range 700 mm to 814 mm. In **Gaya** from Mar. to Oct. (86% between Jun. to Sept).	Ave. 550 mm from Apr. to (66% in Jul. and Aug.)	Ave.450 mm from Jun. to Sept. (70% between Jul. to Aug.)
Climate	Sahelian	Sahelian climate. Northern part is Sahelo-saharian climate	Sahelian climate. Southern part is Sahelo-soudanian climate	Sahelian	Dry subtropical climate. Northern part belongs to the desert
Mean temperatures during the rainy season	Temperatures (Max: 28 ℃; Min: 23 ℃)	Temperatures (Max: 33 ℃; Min: 24 ℃)	Temperatures (Max: 33 ℃; Min: 24 ℃)	Temperatures (Max: 28 ℃; Min: 23 ℃)	Temperatures (Max : 33.9 ℃; Min: 22.3 ℃).
Soil type	Ferruginous tropical	Ferruginous tropical	Ferruginous tropical in the most part of this region, but Hydromorphous at **Bengou** and Less evoluted at **Tara** locality	Ferruginous tropical	Lithosols on poorly drained sandstones, poorly developed soils on sandy formations with highly individualized sesquioxides (Fe_2O_3), tropical ferruginous soils,

Information obtained from Moussa, 2013; Anonymous, 2015; Anonymous, 2022.

Table 2. Mean sorghum yield, rank in production, hectarage, yearly production, and farming practices in the five major growing regions of Niger

	Regions				
Data	**Tillabéri**	**Tahoua**	**Dosso**	**Maradi**	**Zinder**
Average sorghum yield	193 kg/ha	315 kg/ha	406 kg/ha	406 kg/ha	324 kg/ha
Rank in sorghum production within the 8 regions of the Niger:	5th	3th	4th	1nd	2nd
Quantity and hectarage	74,137 Metric Tonnes 384,010 ha	209,944 Metric Tonnes 625,607 ha	123,065 Metric Tonnes 303,345 ha	430,360 Metric Tonnes 105,9049 ha	361,024 Metric Tonnes 1,115,531 ha
Sorghum production systems	Monoculture; Association (Sorghum-Millet-Cowpea-Peanut)	Sorghum intercrop (Early and Late maturing varieties); -Association (Mil-Sorghum-Cowpea)	Association (Sorghum-Millet-Cowpea-Peanut)	Association (Millet-Sorghum-Cowpea-Hibiscus)	Association (Millet-Sorghum-Cowpea-peanuts)

Information by Hamidou et al., 2018; Anonymous, 2019; Anonymous, 2021.

Table 3. Prevalence of the various sorghum diseases observed across 96 production fields in Niger, West Africa, 2022

Disease	Fields with disease (%)
Anthracnose (*Colletotrichum Sublineola*)	82
Bacterial Leaf Stripe (*Burholderia Andropogonis*)	7
Long Smut (*Sporisorium Ehrenbergii*)	46
Oval Leaf Spot (*Ramulispora Sorghicola*)	71
Leaf Blight (*Exserohilum Turcicum*)	100
Target Leaf Spot (*Bipolaris Sorghicola*)	36
Bacterial Leaf Streak (*Xanthomonas Campestris* Pv. *Holcicola*)	5
Sooty Stripe (*Ramulispora Sorghi*)	23
Covered Smut (*Sporisorium Sorghi*)	16
Rough Leaf Spot (*Ascochyta Sorghina*)	71
Downy Mildew *(Peronosclerospora Sorghi*)	1
Head Smut (*Sporisorium Reilianum*)	27
Maize Dwarf Mosaic Virus	1
Crazy Top (*Sclerophthora Macrospora*)	15
Gray Leaf Spot (*Cercospora Sorghi*)	38
Bacterial Leaf Blight (*Acidovorax Avenae Subsp. Avenae*)	8
Grain Mold (Various Fungal Genera)*	8
Zonate Leaf Spot (*Gloeocercospora Sorghi*)	43
Ladder Leaf Spot (*Cercospora Fusimaculans*)	7

Sorghum fields from the major sorghum growing regions of Dosso, Maradi, Tahoua, Tillabéri, and Zinder were surveyed. A total of 96 fields across regions were surveyed.

*The lower prevalence of grain mold may be attributed to the fact that some of the surveyed plants were ta the late flowering early soft dough stage of development.

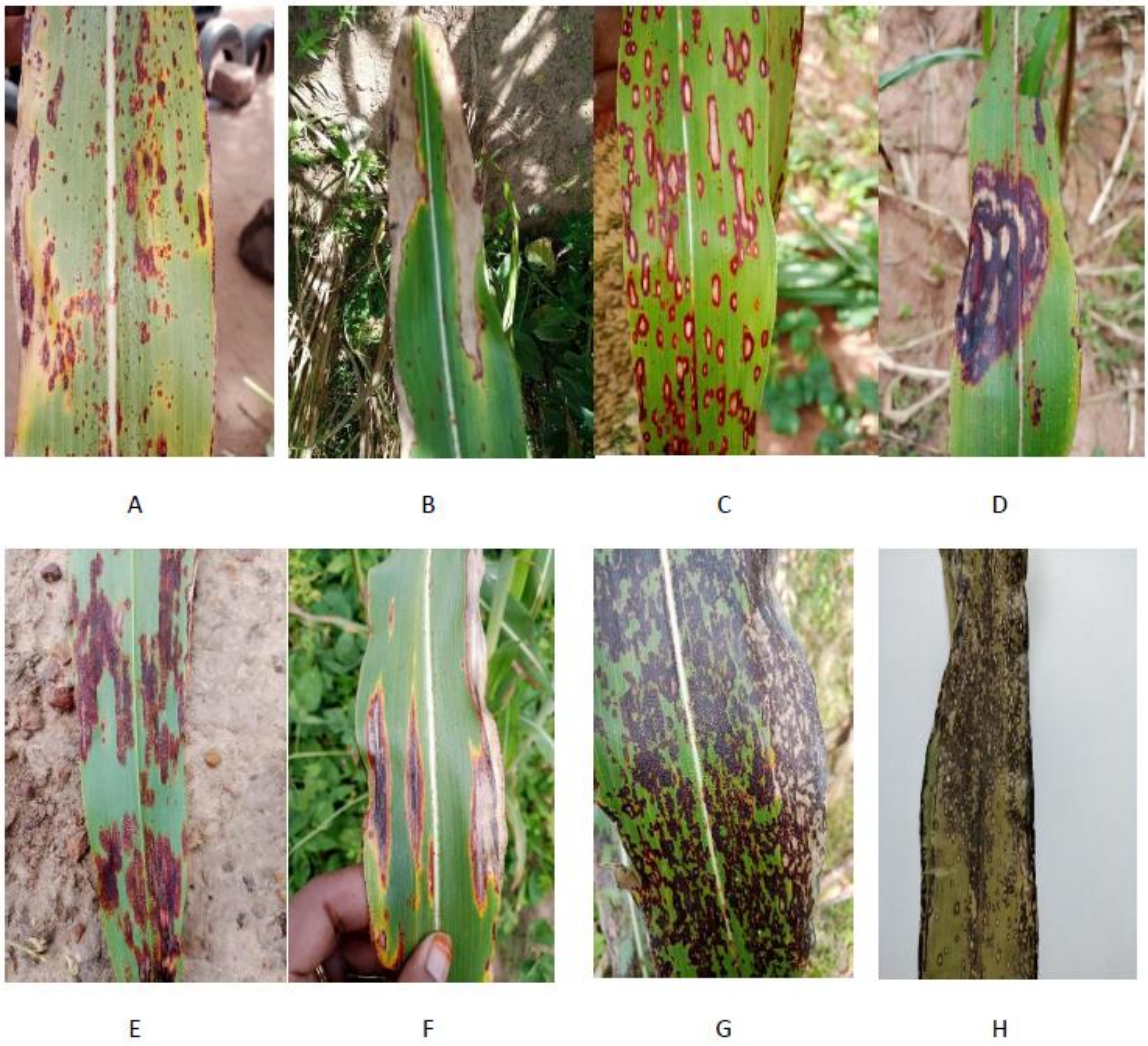

Figure 2. (a-h): (a) Anthracnose; (b) Leaf blight; (c) Oval leaf spot; (d) Zonate leaf spot; (e) Rough leaf spot; (f) Sooty stripe; (g) target leaf spot; (h) Scalariform lesions of ladder leaf spot

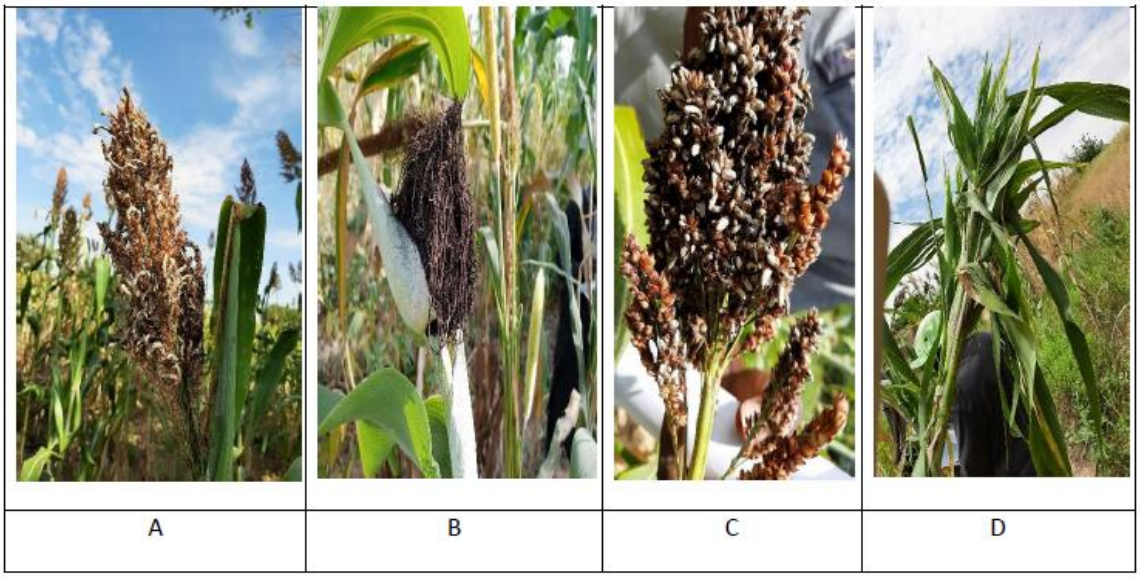

Figure 3. (a-d): (a) Long smut; (b) Head smut; (c) Covered kernel smut; and (d) Crazy top

Table 4. Percent prevalence of sorghum diseases observed in the five regions surveyed during the 2022 growing season in Niger, West Africa

Disease	Dosso	Maradi	Tahoua	Tillabéri	Zinder
Anthracnose	100	90	71	55	100
Leaf blight	100	100	100	100	100
Grain mold	0	20	5	15	0
Zonate leaf spot	91	50	43	5	0
Bacterial leaf blight	13	0	10	15	0
Oval leaf spot	74	100	76	15	100
Bacterial leaf stripe	26	0	5	0	0
Rough leaf spot	74	60	67	65	92
Bacterial leaf streak	9	0	0	15	0
Sooty stripe	43	15	24	15	8
Maize dwarf mosaic virus	4	0	0	0	0
Target leaf spot	70	45	33	0	25
Downy mildew	0	5	0	0	0
Long smut	26	40	57	90	0
Gray leaf spot	65	45	38	15	8
Covered smut	13	20	24	15	0
Ladder leaf spot	0	15	0	0	33
Head smut	13	70	38	5	0
Crazy top	35	5	0	25	0

Number of surveyed fields in each region: Dosso = 23 fields; Maradi = 20 fields; Tahoua = 21; Tillabéri = 20 fields and Zinder = 12 fields. In each field, 40 plants were evaluated using a W-shaped pattern

Table 5. Percent mean incidence and severity of sorghum diseases observed across production fields during the 2022 growing season in Niger, West Africa

Region	AN		LB		Zon		Ols		Rls		Soot		Tar		LS		CS		HS	
	Inc[2]	Sev[3]	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev
Dosso	43	10	80	20	50	10	44	8	42	13	20	11	29	8	17	11	9	17	26	100
Maradi	56	13	90	30	10	7	80	18	30	14	5	6	11	6	18	29	8	24	18	100
Tahoua	35	10	95	28	47	14	39	12	45	12	16	13	54	16	40	22	13	24	10	100
Tillaber	22	8	74	16	8	6	10	6	17	6	10	6	0	0	25	8	16	18	8	100
Zinder	55	8	95	18	0	0	68	11	35	11	3	6	3	6	0	0	0	0	0	0

Region	GM		BL		Bsp		Bsk		Mdm		DM		Gls		LD		Craz	
	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev	Inc	Sev
Dosso	0	0	4	11	4	14	4	6	10	46	0	0	19	7	0	0	35	6
Maradi	19	18	0	0	0	0	0	0	0	0	3	66	25	6	9	6	3	6
Tahoua	15	14	8	5	3	6	0	0	0	0	0	0	8	8	0	0	0	0
Tillabèri	4	7	3	6	0	0	17	9	0	0	0	0	4	12	0	0	5	6
Zinder	0	0	0	0	0	0	0	0	0	0	0	0	8	9	13	17	0	0

Number of surveyed fields in each region: Dosso = 23 fields; Maradi = 20 fields; Tahoua = 21; Tillabéri = 20 fields and Zinder = 12 fields. In each field, 40 plants were evaluated using a W-shaped pattern. AN=Anthracnose; LB=Leaf blight; ZON=Zonate leaf spot; Ols=Oval leaf spot; Rls=Rough leaf spot; Soot=Sooty stripe; Tar=Target leaf spot; LS=Long smut; CS=Covered kernel smut; HS=Head smut; GM=Grain mold; BL=Bacterial leaf blight; Bsp=Bacterial leaf stripe; Bsk=Bacterial leaf streak; Mdm= Maize dwarf mosaic virus; DM= Downy mildew; Gls=Gray leaf spot; LD=Ladder leaf spot ; and Craz=Crazy top.

Table 6. Regions and selected location of fields with 90% or above percent incidence (‘hot spots’) of leaf blight

Region	Field #	Location
Dosso	1*	Tara
	7*	Bela
	21	Bela
	22*	Bolbol
	23*	Bolbol
Maradi	2	Kadata
	4	Kadata
	5	Kadata
	6	Dan boudouk (Dan gado)
	14	Kadata
	16	Dan gado
	17*	Dan gado
Tahoua	5*	Tounfafi
	7*	Tounfafi
	9	Kadadowa
	10*	Dogueraoua
	11*	Dogueraoua
	17*	Tounfafi
Tillabèri	2*	Tondi Banda
	6	Karma
	8*	Boubon
	16*	Ndounga Tarey
Zinder	1*	Gargoumsa
	2*	Gargoumsa

In each field, 40 plants were evaluated using a W-shaped pattern.

*Fields with 100% incidence.

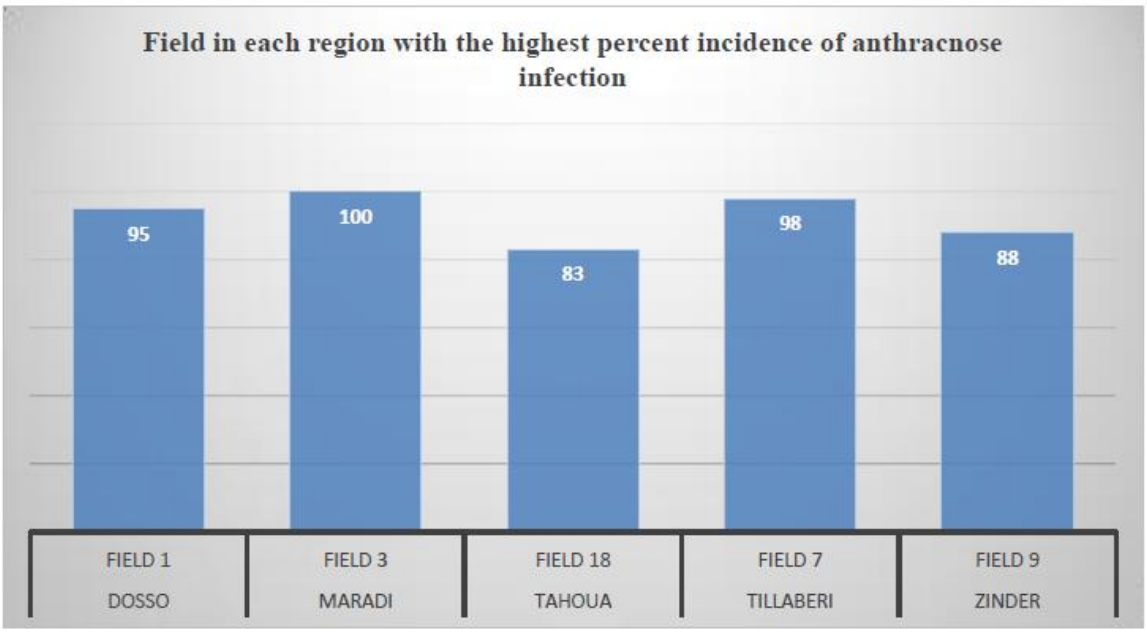

Figure 4. Anthracnose ‘hot spot’ in each of the five surveyed regions: Dosso (Field 1, location: Tara), Maradi (Field 3, location: Kadata), Tahoua (Field 18, location: Dogueraoua), Tillabèri (Field 7, location: Tagabati), Zinder (Field 9, location: Tirmini) in Niger, 2022

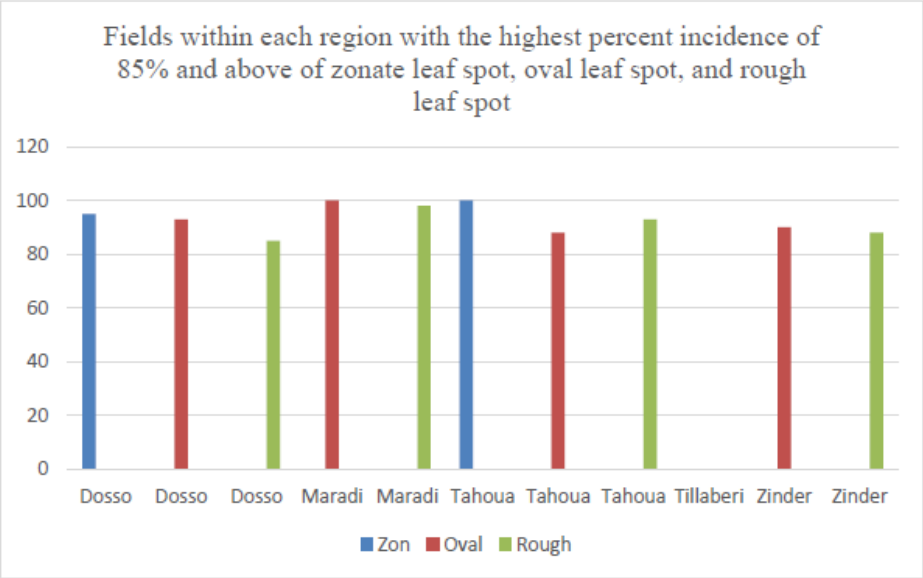

Figure 5. Zonate leaf spot (Zon), (Region: Dosso, Field 4, location: Tara), (Region: Tahoua, Field 11, location: Dogueraoua); Oval leaf spot (Oval) (Region: Dosso, Field 14, location: Tara), (Region: Maradi, Field 7, location: Dan gado), (Region: Tahoua, Field 15, location: Tounfafi), (Region: Zinder, Field 12, location: Tirmin); and Rough leaf spot (Rough) (Region: Dosso, Field 20, location: Bella), (Region: Maradi, Field 9, location: Dan Gado) (Region: Tahoua, Field 14, location: Kanguiwa) and (Region: Zinder, Field 1, location: Gargoumsa) 'hot spots' in the surveyed regions, Niger, 2022

3. Results

During the 2022 growing season, 96 farmers' fields from five major sorghum producing regions of Dosso, Maradi, Tahoua, Tillabèri, and Zinder were surveyed for foliar and panicle diseases. Most of the fields evaluated were planted with different landraces with a few exceptions that were planted with improved varieties released by the National Institute of Agricultural Research of Niger. The fields surveyed ranged in size from 0.2 to 1 ha and were mostly reasonably maintained by regular hand hoeing. The cropping systems used by the vast majority of sorghum producers in the surveyed regions were pure sorghum stands and intercropping with early and late varieties, millet-sorghum-cowpea, millet-cowpea-peanut, millet-sorghum-cowpea-hibiscus (Table 2).

3.1 Disease Incidence, Severity, and Prevalence

In each surveyed field, 40 plants were assessed using a W-shaped pattern to cover the whole field. Across the 96 fields surveyed, 19 diseases anthracnose, gray leaf spot, grain mold, zonate leaf spot, bacterial leaf stripe, long smut, oval leaf spot, leaf blight, bacterial leaf blight, target leaf spot, bacterial leaf streak, sooty stripe, covered smut, rough leaf spot, downy mildew, head smut, maize dwarf mosaic virus, ladder leaf spot, and crazy top were documented (Table 2). Figure 2 shows 8 of the different diseases observed: 2a shows anthracnose infected leaf, 2b leaf blight infected leaf, 2c oval leaf spot, 2d zonate leaf spot, 2e rough leaf spot, 2f sooty stripe, 2g target leaf spot, and 2h scalariform lesions of ladder leaf spot. The smuts and crazy top observed during the 2022 survey are presented in figure 3, with 3a long smut, 3b head smut, 3c covered kernel, and 3d crazy top. All the fields surveyed had plants that were infected with leaf blight (Table 3). Out of the 96 production fields surveyed, 85 fields had anthracnose, 74 fields were infected with oval leaf spot, and rough leaf spot, respectively. The prevalence of long smut was (46%), zonate leaf spot (43%), and gray leaf spot (38%), and target leaf spot (36%). Out of the 96 fields surveyed, downy mildew and maize dwarf mosaic virus were observed in one field. In the regions of Dosso and Zinder, anthracnose was found in all the surveyed fields while oval leaf spot was detected in all surveyed fields in Maradi and Zinder (Table 4). Among the regions, the highest prevalence of zonate leaf spot (91%), target leaf spot (70%), gray leaf spot (65%), sooty stripe (43%), and crazy top (35%) was recorded in the region of Dosso. Out of the 20 fields assessed in region Tillabèri, long smut was found in 18 fields whereas rough leaf spot (92%) was most prevalent in Zinder region (Table 4).

The highest mean incidence of leaf blight (95%) was recorded in the regions of Tahoua and Zinder (Table 5). Higher mean incidence of Target leaf spot (54%), rough leaf spot (45%), and long smut (40%) was noted in the

region of Tahoua while oval leaf spot (80%) anthracnose (56%), and gray leaf spot mean incidences were highest in Maradi region (Table 5). Compared to other regions, the highest mean severities of leaf blight (30%), long smut (29%), grain mold (18%), and anthracnose (13%) were recorded in Maradi region (Table 5). Ladder leaf spot (17%) was more severe in the region of Zinder while plants surveyed in the region of Tahoua had more severe target leaf spot infection. The severity of head smut was 100% where the entire panicles were replaced with teliospres (Figure 3B) in all the regions where the disease was observed. The highest severity of covered kernel smut (24%) was noted in the regions of Maradi and Tahoua. Table 6 shows selected locations in Dosso region that can be considered as 'hot spot' for leaf blight resistance screening. Other locations such as Dan gado in Maradi, Tounfafi and Dogueraoua in Tahoua region, Tondi Banda and Karma in Tillabèri, and Gargoumsa in the region of Zinder also can be considered as 'hot spot' for leaf blight resistance evaluation sites. In all surveyed regions, there are sites where anthracnose resistance evaluations can be conducted (Figure 4). Except for the region of Tillabèri, sites were identified with incidence of 85% and above of zonate leaf spot, oval leaf spot and rough leaf spot in Dosso, Maradi, Tahoua, and Zinder regions where sorghum germplasm can be evaluated for resistance (Figure 5). The lower prevalence and incidence of grain mold was expected because the majority of the plants were assessed at late flowering to early hard dough stages.

4. Discussion

The multi-uses of sorghum and its adaptability in marginal agro-ecological zones makes it indispensable for people and animals living in drier tropics (Frederiksen & Odvody, 2000; Pereira & Hawkes, 2022; Kangama, 2017; Prom et al., 2020). Global population is projected to increase to 9.1 billion by 2050 which will require increases in cereal production, including sorghum to around 3 billion tons for food, feed and other uses (FAO, 2009). Future increases in cereal production will likely increase diseases that will impact yield and quality for both food, feed, and non-food use (Prom, 2017; Prom et al., 2020).

In this study, 96 farmers' fields in the five major sorghum producing regions of Dosso, Maradi, Tahoua, Tillabèri and Zinder in Niger were surveyed for incidence, prevalence, and severity of various diseases during the 2022 growing season. Across, the regions, leaf blight, incited by *Exserohilum turcicum* was the most prevalent (100%) disease followed by anthracnose (81%), oval leaf spot (72%) and rough leaf spot (68%). Beshir et al. (2015) detected leaf blight in all 45 sorghum fields surveyed in Central Sudan. In Niger, 121 fields were surveyed in 2019 to determine the distribution of sorghum diseases and the results revealed that anthracnose (99%) was the most prevalent disease followed by leaf blight (89%), long smut (76%), and rough leaf spot (67%) (Prom et al., 2020). Out of 384 fields surveyed for the presence of sorghum diseases in lower eastern Kenya, 272 fields were infected with anthracnose and 270 fields exhibited leaf blight infection (Koima et al., 2022). In Western Kenya, anthracnose, leaf blight, gray leaf spot, and zonate leaf spot were the most dominant diseases noted in sorghum fields (Ngugi et al., 2002). The prevalence of anthracnose (93.7%) and leaf blight (84.8%) were reported by Teferi & Wubshet, (2015) after inspecting 76 fields in South Tigray, Ethiopia, while Tsedaley et al. (2016) surveyed 117 fields in Southwestern and Western Ethiopia and noted the presence of anthracnose in all the fields. Pande et al. (1993) noted that anthracnose, oval leaf spot, sooty stripe, and gray leaf spot were the most prevalent diseases across fields in four major growing climatic zones in Nigeria. Surveys conducted in 37 fields in Tanzania and 134 fields in Uganda revealed that leaf blight and rust were more prevalent in Tanzania while anthracnose and zonate were more frequently observed in Uganda (Njoroge et al., 2018).

The current survey in Niger validated the information that was gathered during the 2019 survey. There were many similarities between the surveys conducted in 2019 and 2022 in Niger, with few exceptions. In 2019, a total of 21 diseases were observed and the most prevalent disease was anthracnose (99%) followed by leaf blight (89%) (Prom et al., 2020) while in the current 2022 survey, 19 diseases were detected with leaf blight (100%) found in all fields followed by anthracnose with 81% prevalence. In the 2019 survey, maize mosaic virus, loose smut, and bacterial leaf spot were observed in low frequency (Prom et al., 2020) but absent during the 2022 survey. Ladder leaf spot was noted in the 2022 survey but not observed during the 2019 survey. In both surveys conducted in Niger in 2019 and 2022, anthracnose, leaf blight, long smut, oval leaf spot, zonate leaf spot, rough leaf spot, head smut, and target leaf spot were the most prevalent diseases found in sorghum production fields. There was a major difference between the 2019 and 2022 surveys. In the 2022 survey, severity of the sorghum diseases observed was recorded but not in 2019. Disease severity which has a direct impact on yield is one of the critical components in estimating the relative economic losses due to plant diseases. In this survey, the highest severities of leaf blight, anthracnose, and long smut were noted in the region of Maradi. Head smut severity was 100% in the region where the disease was detected (Table 5). In covered kernel smut and long smut infections (Figure 3a and 3c), individual ovules and spikelets are replaced by smut sori while other ovules and spikelets within the same panicle develop normal seeds (Frederiksen, 2000; Kollo, 2000). In contrast to head smut

infection, symptoms may vary from sterile panicles to entire panicles been replaced with teliospores (Prom et al., 2011b) so that grain losses can be directly predicted from the percent infected plants.

5. Conclusion

In conclusion, this study confirmed the distribution of sorghum diseases and sites "hot spot" for leaf blight, anthracnose, oval leaf spot, rough leaf spot and zonate leaf spot for resistance evaluations in the major production regions in Niger. This work also is significant because the information generated on the incidence, severity, farm sizes are vital components that can be utilized by scientists, producers, funding agencies, and government officials to estimate relative economic impact of these various sorghum diseases in Niger.

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Reference

Anonymous. (2015). *Regional Council of Zinder*. Regional Development plan. (RDP). Retrieved from https://www.migration-spccm.ne

Anonymous. (2019). Direction of Statistics. Assessment report of the 2018 winter agricultural campaign and Food Outlook 2018/2019. *Ministry of Agriculture and Livestock*, Republic of Niger, April 2019. pp. 45. Retrieved from https://duddal.org/files/original/35edc6c393ec3fee947403b9f666a10b59bfae15.pdf

Anonymous. (2021). *Ministry of Agriculture of Niger*. Final results for the 2021 crop year by region and department. Retrieved from https://reca-niger.org/IMG/pdf/rapport_definitif_des_resultats_de_l_eper_2021.pdf

Anonymous. (2022). *Climatsetvoyages. Climat-Zinder, Niger*. Retrieved from https://www.climatsetvoyages.com/climat/niger/zinder

Araújo, K., Mahajan, D., Kerr, R., & da Silva, M. (2017). Global Biofuels at the Crossroads: An overview of technical, policy, and investment complexities in the sustainability of biofuel development. *Agriculture, 7,* 32. https://doi.og/10.3390/agriculture7040032

Beshir, M. M., Ahmed, N. E., Mukhtar, A., Babiker, I. H., Rubaihayo, P., & Okori, P. (2015). Prevalence and severity of sorghum leaf blight in the sorghum growing areas of Central Sudan. *Journal of Agricultural Research, 4*, 54-60. Retrieved from https://repository.ryforum.org/sites/default/files/beshiretal_2015wudpeker journal.pdf

Campbell, C. L., & Madden, L. V. (1990). *Introducing to Plant Disease Epidemiology*. John Wiley & Sons, Inc. New York. pp. 532.

Chala A., Brurberg, M. B., & Tronsmo, A. M. (2010). Incidence and severity of sorghum anthracnose in Ethiopia. *Plant Pathology Journal, 9*, 23-30. https://doi.org/10.3923/ppj.2010.23.30

Chala, A., Tronsmo, A. M., & Brurberg, M. B. (2007). Prevalence and intensity of sorghum anthracnose in Ethiopia. *Journal of SAT Agricultural Research, 5*, 1-3.

Cuevas, H. E., Prom, L. K., Isakeit, T., & Radwan, G. (2016). Assessment of sorghum germplasm from Burkina Faso and South Africa to identify new sources of resistance to grain mold and anthracnose. *Crop Protection, 79*, 43-50. https://doi.org/10.1016/j.cropro.2015.10.007

FAO. (2009). Retrieved from https://www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agricculture.pdf

FAOSTAT. (2023). Retrieved from http://www.fao.org/faostat/en/#data/QCL

Frederiksen, R. A. (2000). Covered Kernel Smut. In R. A. Frederiksen, & G. N. Odvody (Eds.), *Compendium of Sorghum Diseases* (pp. 22), The American Phytopathological Society. St. Paul, MN, USA.

Frederiksen, R. A., & Odvody, G. N. (Eds). (2000). *Compendium of Sorghum Diseases*. The American Phytopathological Society. St. Paul, MN, USA. pp. 78.

Funnell-Harris, D. L., Prom, L. K., Sattler, S. E., & Pedersen, J. F. (2013). Response of near-isogenic sorghum lines, differing at the P locus for plant colour, to grain mould and head smut fungi. *Annals of Applied Biology, 163*, 91-101. https://doi.org/10.1111/aab.12037

Gonzalez, R., Phillips, R., Saloni, D., Jameel, H., Abt, R., Pirraglia, A., & Wright, J. (2011). Biomass to energy in the Southern United States: Supply chain and delivered cost. *BioResources, 6*, 2954-2976. Retrieved from https://bioresources.cnr.ncsu.edu/BioRes_06/BioRes_06_3_2954_Gonzalez_PJAPSW_Biomass_Energy_S_US_Chain_Cost_1711.pdf

Hamidou, M., Souley, A. K M., Kapran, I., Soulemane, O., Danquah, E. Y., Ofori, K., Gracen, V., & Ba, M. N. (2018). Genetic Variability and Its Implications on Early Generation Sorghum Lines Selection for Yield, Yield Contributing Traits, and Resistance to Sorghum Midge. *International Journal of Agronomy,* 10. Article ID 1864797. https://doi.org/10.1155/2018/1864797

Ignacimuthu, S., & Premkumar, A. (2014). Developmet of transgenic S*orghum bicolor* (L.) Moench resistant to the Chilo partellus (Swinhoe) through *Agrobacterium*-mediated transformation. *Molecular Biology & Genetic Engineering, 2,* 1. https://doi.org/10.7243/2053-5767-2-1

Isakeit**,** T., Prom, L. K., Wheeler, M., Puckhaber, L., & Liu, J. (2008). Mycotoxigenic potential of ten *Fusarium* species grown on sorghum and *in vitro*. *Plant Pathology. Journal, 7*, 183-186. https://doi.org/10.3923/ppj.2008.183.186

Kadi Kadi, H. A., Kapran, I., & Pendleton, B. B. (2005). Identification of sorghum genotypes resistant to sorghum midge in Niger. *International Sorghum and Millets Newsletter, 46*, 57-59.

Kangama, C. O. (2017). Importance of Sorghum bicolor in African's cultures. *Journal of Agricculture & Environmental Sciences, 6,* 134-137. https://doi.org/10.15640/jaes.v6n2a16

Khalid, W., Ali, A., Arshad, M. S., Afzal, F., Akram, R., Siddeeg, A., Kousar, S., Rahim, M. A., Aziz, A., Maqbool, Z., & Saeed, A. (2022). Nutrients and bioactive compounds of *Sorghum bicolor* L. used to prepare functional foods: a review on the efficacy against chronic disorders. *International Journal of Food Properties, 25*, 1045-1062. https://doi.org/10.1080/10942912.2022.2071293

Koima, I. N., Kilalo, D. C., Orek, C. O., Wagacha, J. M., & Nyaboga, E. N. (2022). Survey of fungal foliar and panicle diseases in smallholder sorghum cropping systems in different agro-ecologies of lower Eastern Kenya. *Microbiology Research, 13*, 765-787. https://doi.org/10.3390/microbiolres13040055

Kollo, A. I. (2000). Long Smut. Pages 22-23 In R. A. Frederiksen, & G. N. Odvody (Eds.), *Compendium of Sorghum Diseases* (pp. 22-23), The American Phytopathological Society. St. Paul, MN, USA.

Leslie, J. F., Zeller, K. A. Lamprecht, S. C. Rheeder J. P., & Marasas, W. F. (2005). Toxicity, pathogenicity, and genetic differentiation of five species of fusarium from sorghum and millet. *Phytopathology, 95*, 275-283. https://doi.org/10.1094/PHYTO-95-0275

Manssour A. M., Alzouma M. Z., Dan-Lamso N., Elhadji S. D., & Ambouta J. M. K. (2014). Productivity of the cultivation of sorghum (*Sorghum bicolor*) in *Acacia Senegal* (L.) Willd. based agroforestry system in Niger. *Journal of Applied Biosciences, 82*, 7339-7346. https://doi.org/10.4314/jab.v82i1.2

Moussa, S. (2013). Situation of soils in Niger: Constraints and needs. *Global Soil Partnership (GSP) in West Africa*, 24. Retrieved from https://pt.slideshare.net/FAOoftheUN/situation-des-sols-au-niger-contraintes-et-besoins-salou-moussa-inranniger

Mundia, C. W., Secchi, S., Akamani, K., & Wang, G. (2019). A regional comparison of factors affecting global sorghum production: The case of North America, Asia, and Africa's Sahel. *Sustainability, 11*, 2135. https://doi.org/10.3390/su11072135

Ngugi, H. K., King, S. B., Abaya, G. O., & Reddy, Y. V. R. (2002). Prevalence, incidence, and severity of sorghum diseases in Western Kenya. *Plant Disease, 86*, 65-70. https://doi.org/10.1094/PDIS.2002.86.1.65

Njoroge, S. M., Takan, J. P., Letayo, E. A., Okoth, P. S., Ajaku, D. O., Rathore, A, Ojulong, H., & Manyasa, E. (2018). Survey of fungal foliar and panicle diseases of sorghum in important agroecological zones of Tanzania and Uganda. *Plant Health Progress, 19*, 265-271. https://doi.org/10.1094/PHP-04-18-0013-S

Ousmane, S. D., Niaba, T., Mamadou, A., Abdoul-Kader, M., Garba, S., & Tongoona, P. (2017). Survey on Crop Residues for Cattle Feeding in Niger. *Journal of Agriculture & Food Technology, 7*, 7-15. Retrieved from https://www.textroad.com/pdf/JAFT/J.%20Agric.%20Food.%20Tech.,%207(8)7-15,%202017.pdf

Pande, S., Harikrishnan, R., Alegbejo, M. D., Mughogho, L. K., Karunakar, R. I., & Ajayi, O. (1993). Prevalence of sorghum diseases in Nigeria. *International Journal of Pest Management, 39*, 297-303. https://doi.org/10.1080/09670879309371809

Pereira, L. M., & Hawkes, C. (2022). Leveraging the potential of sorghum as a healthy food and resilient crop in the South African food system. *Frontier in Sustainable Food Systems, 6*, 786151. https://doi.org/10.3389/fsufs.2022.786151

Prom, L. K. (2017). The role of plant pathology and plant pathology journals in future food security. *Research Journal of Plant Pathology, 1*, 01.

Prom, L. K., Haougui, A., Adamou, I., Abdoulkadri, A. A., Karimou, I., Ali, O. B., & Magill, C. (2020). Survey of the prevalence and incidence of foliar and panicle diseases of sorghum across production fields in Niger. *Plant Pathol. J., 19*, 106-113. https://doi.org/10.3923/ppj.2020.106.113

Prom, L. K., Isakeit, T., Perumal, R., Erpelding, J. E., Rooney, W., & Magill, C. W. (2011a). Evaluation of the Ugandan sorghum accessions for grain mold and anthracnose resistance. *Crop Protection, 30*, 566-571. https://doi.org/10.1016/j.cropro.2010.12.025

Prom, L. K., Perumal, R., Erattaimuthu, S. R., Erpelding, J. E., Montes, N., Odvody, G. N., Greenwald, C., Jin, Z., Frederiksen, R. A., & Magill, C. W. (2011b). Virulence and molecular genotyping studies of *Sporisorium reilianum* isolates in sorghum. *Plant Disease, 95*, 523-529. https://doi.org/10.1094/PDIS-10-10-0720

Rooney, W. L., Blumenthal, J., Bean, B., & Mullet, J. E. (2007). Designing sorghum as a dedicated bioenergy *feedstock, Biofuels, Bioproducts. Biorefining, 1*, 147-157. https://doi.org/10.1002/bbb.15

Sashidha, R. B., Ramakrishna, Y., & Bhat, R.V. (1992). Moulds and mycotoxins in sorghum stored in traditional containers in India. *The Journal of Stored Products, 28*, 257-260. https://doi.org/10.1016/0022-474X(92)90006-C

Teferi, T. A., & Wubshet, M. L. (2015). Prevalence and intensity of economically important fungal diseases of sorghum in South Tigray, Ethiopia. *Journal of Plant Sciences, 3*, 92-98. https://doi.org/10.11648/j.jps.20150302.18

Tsedaley, B., Adugna, G., & Lemessa, F. (2016). Distribution and importance of sorghum anthracnose (*Colletotrichum sublineolum*) in Southwestern and Western Ethiopia. *Plant Pathology. Journal, 15*, 75-85. https://doi.org/10.3923/ppj.2016.75.85

Upadhyaya, H. D., Reddy, K. N., Vetriventhan, M., Ahmed, M. I., Krishna, G. M., Reddy, M. T., & Singh, S. K. (2017). Sorghum germplasm from West and Central Africa maintained in the ICRISAT genebank: Status, gaps, and diversity. *The Crop Journal, 5*, 518-532. https://doi.org/10.1016/j.cj.2017.07.002

Weltzien, E., & Rattunde, F. (2022). Research and development for sorghum and millets in Sub-Saharan Africa: What have we learned? *Outlook on Agriculture, 51*, 435-447. https://doi.org/10.1177/00307270221133127