

Effects of major fungal pathogens on growth and yield of improved and local sorghum genotypes under field trials in lower Eastern Kenya.

Comment [CdM1]: Suggest: Effects of phytopathogenic fungi on growth and yield of sorghum genotypes in Eastern Kenya.

ABSTRACT

Sorghum is a climate-resilient cereal that offers food and nutrition security for ~~the~~ arid and semi-arid lands (ASALs). ~~Its production potential is however limited by fungal diseases~~ Fungal diseases however limit its production potential. A study on ~~the~~ effects of major fungal diseases on sorghum growth and yield and identification of tolerant genotypes is critical for sustainable sorghum production. ~~A total of~~ 14 germplasms were analyzed under a two-seasonal field trials laid out in Randomized Complete Block Design with four replications at two different agro-ecological zones within Kenya's ASALs. A spreader row technique using a highly susceptible variety and natural infections ~~were was~~ used for fungal inoculation. Ten plants, randomly sampled and tagged from two inner rows in each plot, were used to collect data on plant growth, yield and diseases. Diseases were identified using identification keys, visual symptoms and signs, and effects scored through disease severity (DS) and disease incidence (DI). Identified diseases included anthracnose, leaf blight, rust, ~~gray-grey~~ leaf spot, ladder leaf spot, oval leaf spot, downy mildew and covered kernel smut. Higher DS (>7.0) and DI (>50%) were recorded in anthracnose, leaf blight and leaf rust across most genotypes. The significant ($P \leq 0.01$) negative correlations between DS and days to 50% flowering, number of green leaves, leaf area and panicle width indicated potential disease inhibition of sorghum growth. Correlations between DS and dry biomass, grain yield and grain weight were also negative but insignificant ($P > 0.05$), implying no disease effects on sorghum yield. Improved genotypes had ~~the~~ least foliar and panicle infections and produced significantly higher grain yield (>2.0 t/ha) compared to local varieties with lower yield (<1.5t/ha) and higher foliar and panicle symptoms. The improved genotypes were thus classified as tolerant to fungal diseases and could be used to support resistance breeding programs as a sustainable management strategy for improved sorghum production in ASALs of Kenya.

Keywords: Sorghum; fungal diseases; growth; yield; tolerance; ASALs.

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1. INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench) originated in the tropics of Africa, with ancient evidence of cultivation tracing back to 300BC in Egypt [1]. Globally, it is a significant food security crop, especially in ~~the~~ arid and semi-arid lands (ASALs). Its diversified uses include food for human consumption, feeds for livestock, and raw materials in industrial brewing [2]. In Kenya, sorghum ranks fourth in cereal production after maize, rice and wheat, with ~~main~~ principal production regions in the semi-arid areas of Nyanza, Eastern and Coast [3]. The national estimated area of sorghum cultivated is at 228,640 ha yielding 205,399 tonnes (0.9t/ha) [4]. In lower eastern Kenya, sorghum production ~~stands at~~ 0.5 t/ha [4]. However, both estimated national and regional production is below the potential yield that range

between 2 to 5 t/ha [5]. This can mainly be attributed to biotic factors, namely diseases caused by insect pests, weeds and various fungal pathogens [6].

Major fungal diseases that infect sorghum include anthracnose (*Colletotrichum sublineolum*), leaf blight (*Exserohilum turcicum*), leaf rust (*Puccinia purpurea*), ladder leaf spot (*Cercospora fusimaculans*), ~~gray-grey~~ leaf spot (*Cercospora sorghi*), oval leaf spot (*Ramulispora sorghicola*), zonate leaf spot (*Gloeocercospora sorghi*), covered kernel smut (*Sporisorium sorghi*), head smut (*Sporisorium reilianum*) and loose smut (*Sporisorium cruenta*) [7]. These diseases can appear in multiple infections or singular on different parts of the plant at various growth stages, contributing to the reduction in yield. Although previous studies in Kenya by Ngugi et al. [7, 8] and Ogolla et al. [9] have examined the prevalence, incidence, severity, and distribution of fungal diseases in different regions, there is limited extensive and quantitative data on the effect of fungal diseases on growth and yield in lower eastern Kenya. Further, most ~~open-open~~-pollinated elite and improved sorghum genotypes have been evaluated for drought tolerance but not disease tolerance [10]. There is also no published information on the evaluation of disease tolerance among the local landraces that were screened in the present ~~the~~ study. Recently, Koima et al. [11] ~~carried out a survey of surveyed~~ fungal foliar and panicle diseases in smallholder sorghum cropping systems in different agro-ecologies of lower Eastern Kenya. However, they did not analyze the effect of these diseases on sorghum growth and yield. Thus, the present study aimed at screening for major fungal diseases, their effect on growth and yield, and potential sources of tolerance among both local and improved varieties under field trials in lower Eastern Kenya.

2. MATERIAL AND METHODS

2.1 Field Trial Sites

The study was conducted at two Kenya Agricultural and Livestock Research Organizations (KALRO) research stations (Kiboko and Ithookwe) during the short rainy season of 2020 and the long rainy season of 2021. Ithookwe is located at an altitude of 1158 meters above sea level, latitude 01° 22'34" S and longitude 037° 58'43" E [12, 15]. Average rainfall and temperatures range ~~is~~ between 835-1079 mm and 16-34°C, respectively [12]. Kiboko site is ~~at an altitude of~~ 975 meters above sea level, longitude 37.7235°E and latitude 2.2172°S [16]. Temperatures range between 14.3°C – 35.1°C. Although the two sites receive a bimodal rainfall pattern annually, according to Muui [12], they are hotspots for plant fungal diseases and differ in agroecological zonation [11, 13].

2.2 Sorghum Germplasms

Fourteen sorghum germplasms, including eight improved genotypes from International Crops Research Institute for Semi-Arid Tropics (ICRISAT) such as Gadam, Marcia, IESV 24029 SH, KARI Mtama 1, Kiboko Local 2, Makueni Local, Serena and Seredo and six local landraces from farmers (Kateng'u, Kauwi, Rasta, Mugeta, Kaguru and Dark Red) were used as test varieties for this study (Table 1). Kaguru was used as a positive control because it's highly ~~susceptible-susceptible~~ to fungal diseases [9], while Kateng'u a common local landrace among farmers, was used as a control for yield comparison [10, 11]. Sila variety was grown as guard rows while the highly susceptible variety called Wagiita was sowed as a spreader.

Table 1: Sorghum germplasms subjected to field trials in lower Eastern Kenya

No.	Germplasm	Parents	Trait(s) / characteristics	Source
1	Kiboko Local 2	Landraces from Kiboko	-Bred for drought tolerance	ICRISAT
2	Makueni Local	Landraces from Makueni	Bred for short duration, drought tolerance and resistance to bird damage.	ICRISAT
3	IESV 24029SH	Gadam x IS 8193	Bred for grain yield and resistance to <i>Striga hermonthica</i>	ICRISAT
4	Marcia	F3A-115-2 / M91057	Bred for high grain yield, stay green and dual purpose	ICRISAT
5	KARI Mtama 1	KAT 83/KAT 369, Open pollinated (pure line) variety	Bred for food, baking and brewing qualities and adaptation to short and long rain seasons	ICRISAT
6	Serena	Swazi P1207 x Dobbs, Open pollinated (pure line) variety	Bred for early to medium maturity, suitable for food uses and <u>resistance resistant</u> to shoot <u>fly</u> flies.	ICRISAT
7	Seredo	Serena x CK60, Open pollinated (pure line) variety	Bred for utilization as food and adaptation to sub-humid and dry lowland areas	ICRISAT
8	Gadam	Selection from IS 7055	Bred for food and brewing qualities, adaptation to dry lowlands and drought tolerance	ICRISAT
9	Kateng'u	-	Widely grown by local farmers.	Local
10	Kauwi	-	-	Local
11	Rasta	-	-	Local
12	Mugeta	-	-	Local
13	Kaguru	-	Susceptible to fungal diseases	Local
14	Dark Red	-	-	Local
15	Sila	-	-	Local
16	Wagiita	-	Susceptible to fungal diseases	Local

Source: Sheunda [14].

2.3 Experimental Design

The field experimental design was laid in a Randomized Complete Block Design (RCBD) with four replications. Each plot consisted of 8 rows measuring 3.0m by length, intra-row spacing of 20cm, 60cm inter-row spacing and 1m for paths between plots and blocks. The two outer rows in each plot were of the spreader variety (Wagiita), while six middle rows were sowed test varieties. Supplemental irrigation was done up to the grain-grain-filling stage at Kiboko, while Ithookwe was mainly rain-fed. Standard management practices were applied in raising healthy plant stand. The study was carried for two seasons, short rainy

~~season of 2020 (October – December) and~~ out for two seasons: the short rainy season of 2020 (October – December) and the long rainy season of 2021 (March – May).

2.4 Inoculation by Spreader Variety

Fungal inoculation on test varieties using spreader variety technique as described by Pande et al. [17] was adopted. The rows of spreader variety (Wagiita) were sowed 21 ~~days~~ days earlier than the test varieties, after which they were inoculated with fungal suspension ~~that was prepared as described by~~ prepared as Shekhar and Kumar prepared as Shekhar and Kumar described [18]. Spraying was done on plant whorls on the 25th and 40th day during evening hours [19] when the conditions were ideal for fungal infection [20].

2.5 Identification of Fungal Diseases

Fungal diseases in the field were identified based on visual symptoms and signs, aided through magnification by hand lenses [21] ~~as well as~~ sorghum fungal disease identification keys as described by Williams et al. [22] and other authors. The symptoms and signs used to identify various fungal diseases in this study are summarised in table 2 below.

Table 2: Symptoms and signs used to identify of various sorghum fungal diseases

Disease	Description of symptoms and signs	Source
Anthrachnose	Small, circular, elliptical to elongated spots with straw-colored centers and margins that are dark, red or purple dark, red or purple margins. Spots may enlarge to coalesce all over the leaf. When magnified with a hand lens, black hair-like structures (setae) can be seen protruding from fruiting bodies (acervuli).	Williams et al. [22]; Thakur & Mathur, [23]
Leaf blight	Long elliptical necrotic lesions consisting of centers that are straw straw-colored. Lesions can coalesce displaying a burnt appearance. Moreover, a faint grey bloom of conidiophores and conidia is produced on lesions.	Williams et al. [22]; Mathur et al. [24]
Rust	Scattered purple, tan, or red small tiny flecks first appear on leaves. Rust pustules or uredosori then develop under the leaf surface, rupturing to release uredospores (reddish powder). Teliospores later develop either in the old uredosori, or in the old uredosori or teleutosori, hence changing from a reddish brown to dark.	Williams et al. [22]; Thakur et al. [25]
Gray leaf spot	Rectangular Rectangular-shaped, dark red to purplish lesions in pigmented plants while lighter centers occur in tan plants and develop on either on leaf blades and leaf blades or sheaths. These symptoms are majorly isolated but can develop into long stripes. A greyish greyish-white bloom of conidia can also appear on lesions.	Williams et al. [22]
Ladder leaf spot	Lesions characterized by pale centers centres and dark margins appear like a ladder on the leaf.	Njoroge et al. [26]

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Oval leaf spot	Small water-soaked spots emerge first, and later develop later developing into small circular lesions with lighter centers in which small black sclerotia are generated and dark red to brown margins. A land lens is used in distinguishing oval leaf spot from anthracnose which isto distinguish oval leaf spot from anthracnose , characterized by production of black setae on the lesions.	Williams et al. [22]; Njoroge et al. [26]
Downy mildew	Leaves appear light green and abundant white spores (conidia and conidiophores) are produced nocturnally under the leaf surface. Subsequent leaves display parallel green and white stripes which shredding may occur when the interveinal tissue die.	Williams et al. [22]; Thakur et al. [27]
Covered kernel smut	Conical to oval-oval -shaped smut sori, enclosed by a tough silver-silver -white or cream to light brown skin, replaces individual grains on the panicle. When smut sori ruptures, brownish to black smut spores are visible.	Williams et al. [22]; Thakur [28]

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2.6 Disease measurements

Fungal disease severity (FDS) data was collected ~~on monthly basis~~ every month upto physiological maturity using a severity scale of 1-9 as described by Ngugi et al. [7] for foliar diseases (Table 3), while severity for panicle diseases, were scored on a scale of 1-9 as described by Thakur [28] (Table 3.a).

Table 3.: Foliar diseases

Score	Area of foliage infected
1	No disease
2	1 to 4% area of top 5 leaves
3	5 to 9%
4	10 to 19%
5	20 to 29%
6	30 to 44%
7	45 to 59%
8	60 to 75%
9	>75% of leaf area affected

Table 3.a: Panicle diseases

Score	Area of panicle infected.
1	< 1%
2	1 - 5%
3	6 - 10%
4	11 - 20%
5	21 - 30%
6	31 - 40%
7	41 - 50%
8	51 - 75%
9	76 - 100%

Source: Ngugi et al. [7]. Source: Thakur [28]

2.7 Growth and Yield Data

Growth and yield data were taken on a random sample of 10 tagged plants from two inner rows in each plot for: plant height [29], stay-green (STG) or ~~the~~ number of green leaves per plant [30, 31], leaf area ~~+/~~ plant leaf area [32], Days to 50% flowering [31], plant colour [29], panicle length, panicle width and grain weight (g) [14]. Grain yield (GRY in t/ha) and dry matter yield (DMY in t/ha) were determined using formulae by Sheunda [14] as below:

Formula (1):
$$GRY = \frac{GW}{100A}$$

Where:

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GW = grain weight in grams per net
A = area of net plot harvested (m²) determined by:
A = (R×l×L) Where;
R = No. of rows within the net plot
l = Space between rows (cm)
L = Length of the rows (cm)

Formula (2): $DMY = \frac{10DW}{A}$

Where:

DW = Dry biomass per plot (kg)

A = area of net plot harvested (m²) – see formula (1) above

2.7 Data Analysis

Data recorded on FDS, FDI, and all agro-morphological and yield parameters were subjected to analysis of variance (ANOVA) using Genstat version 15 [33]. Differences between groups of means were separated by Fischer's LSD ($\alpha=0.05$) procedure. Pearson correlation coefficient (r) was used to determine the relationships between fungal disease severity and fungal disease incidence with the growth and yield of sorghum genotypes and varieties. Yield and severity data were used to determine the level of tolerance among germplasms.

3. RESULTS AND DISCUSSION

3.1 Major Fungal Diseases

The major fungal ~~diseases~~ diseases identified comprised of seven foliar diseases, namely: Aanthracnose (Fig. 1a), leaf blight (Fig. 1b), leaf rust (Fig. 1c), gray-grey leaf spot (Fig. 1d), ladder leaf spot (Fig. 1e), oval leaf spot (Fig. 1f) and downy mildew (Fig. 1g). Covered kernel smut was the only panicle disease identified (Fig. 1h). The diseases were identified based on their distinct symptoms as described in Table 2. For example, leaf foliage displayed lesions that are ~~were~~ small, circular to elliptical, with centers ~~centres~~ that were straw in colour surrounded by purple margins typical of Aanthracnose (Fig. 1a); lesions with a ladder like ~~a~~ pattern were used to identify ladder leaf spot (Fig. 1b); dense red to tan coloured pustules of rust were used to identify leaf rust (Fig. 1c); gray leaf spot (Fig. 1d) showed isolated purple-like rectangular lesions; oval leaf spot (Fig. 1e) showed small oval lesions with lighter centers ~~centres~~ and dark red margins; downy mildew (Fig. 1f) showed bleaching of the leaf in streaks; leaf blight (Fig. 1g) had coalescing ~~to coalesce~~ of lesions resulting in a burnt appearance on leaf consisting of a grey bloom of conidia, and sorghum grains were replaced by cream cone shaped smut sori indicating covered kernel smut (Fig. 1h).

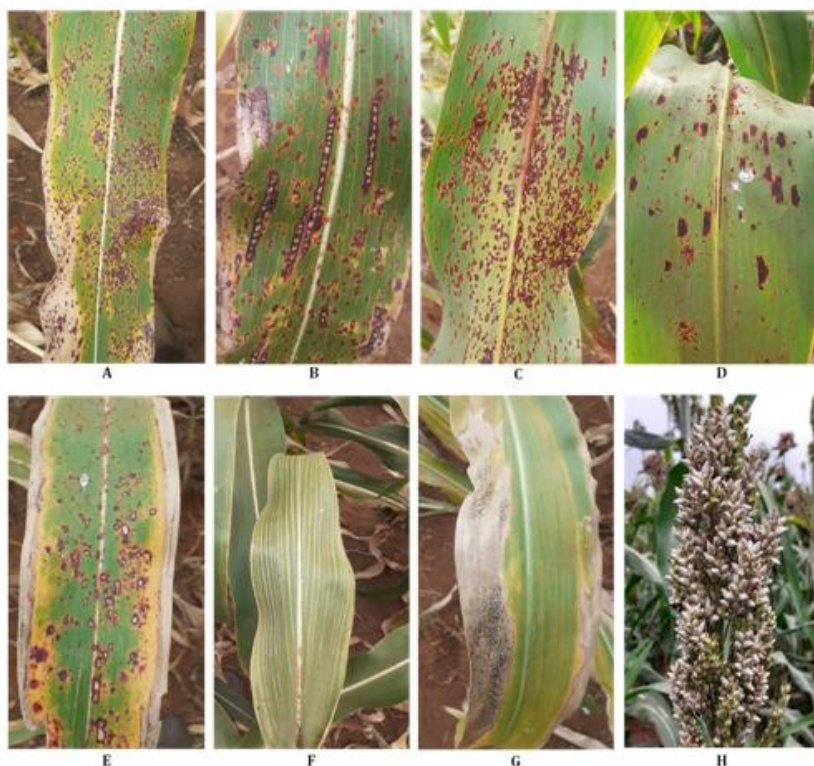


Fig. 1. Major fungal diseases identified during the field trials: A = Anthracnose; B = Ladder leaf spot; C = leaf rust; D= Gray leaf spot; E = Oval leaf spot; F = Downy mildew; G= Leaf blight; H = Covered kernel smut.

3.2 Variations in Fungal Disease Severity and Incidence

KALRO Kiboko recorded higher fungal disease severity (FDS) scores ~~compared to~~ than KALRO Ithookwe. The mean FDS scores of leaf blight, ~~A~~anthracnose, leaf rust, ~~gray-grey~~ leaf spot, ladder leaf spot, oval leaf spot, downy mildew and covered Kernel smut at KALRO Kiboko were 6.1, 5.5, 5.3, 3.1, 2.1, 2.6, 2.3 and 1.1 respectively while at KALRO Ithookwe were; 5.6, 4.8, 4.6, 1.8, 1.4, 1.6, 2.1 and 1.1 respectively (Fig. 2). Anthracnose, leaf blight and rust had significantly higher FDS in both sites compared to the other diseases (Fig. 2). Generally all the fungal diseases showed higher FDS scores in Kiboko compared to Ithookwe (Fig. 2).

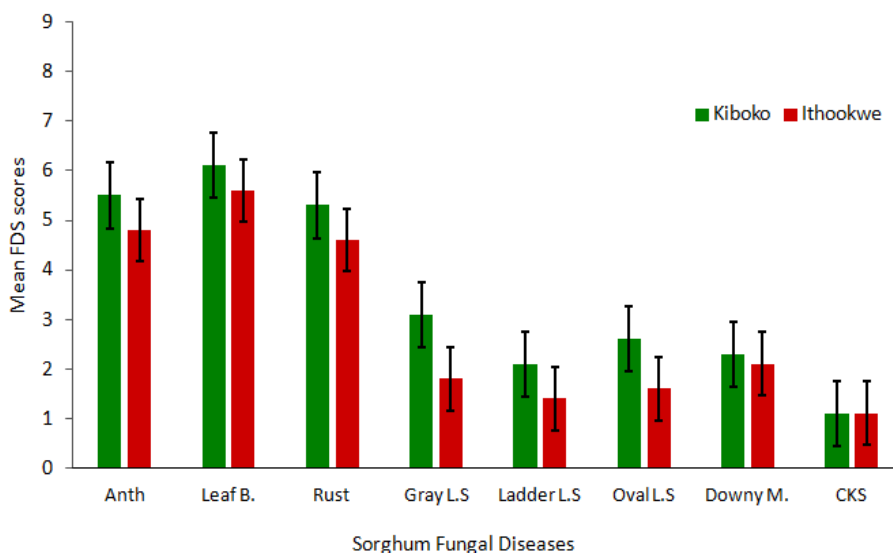


Fig. 2. Mean fungal disease severity (FDS) recorded at KALRO Kiboko and Ithookwe. Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S = gray leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

Percent (%) fungal disease incidence (FDI) also varied between the two sites (Fig. 3). FDI at KALRO Kiboko for: Anthracnose, leaf blight, leaf rust, gray leaf spot, ladder leaf spot, oval leaf spot, downy mildew and covered Kernel smut were: 91.8, 100, 100, 67.2, 71.7, 52.4, 16.1 and 11.4 while at KALRO Ithookwe were: 90.3, 100, 100, 50.1, 16.5, 45.0, 16.1 and 14.6 (Fig. 3). Similar to FDS, Anthracnose, leaf blight and the rust showed higher FDI in both sites compared to the other diseases (Fig. 3). Generally most of the fungal diseases showed higher FDI in Kiboko than in Ithookwe (Fig. 3).

3.3 Disease Progression

Overtime, KALRO Kiboko showed higher or rapid disease progression compared to KALRO Ithookwe. Disease progression were determined through diseases severity ratings (Fig. 4; Fig. 5) or disease incidence (Fig. 6; Fig. 7). Among diseases, anthracnose, leaf blight and leaf rust recorded higher disease progression compared to as determined through disease severity ratings (Fig. 4; Fig. 5) or disease incidence (Fig. 6; Fig. 7). Among diseases, anthracnose, leaf blight and leaf rust recorded higher disease progression than other fungal diseases at both sites.

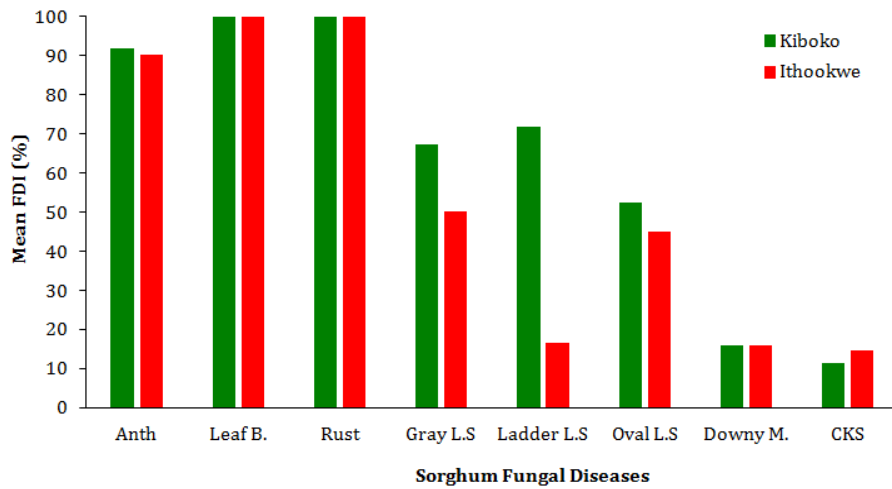


Fig. 3. Fungal disease incidence recorded at KALRO Kiboko and Ithookwe. Where: *Anth* = anthracnose; *Leaf B.* = leaf blight; *Gray L.S* =gray leaf spot; *Oval L.S* = oval leaf spot; *Downy M.* = downy mildew; *CKS* = covered Kernel smut

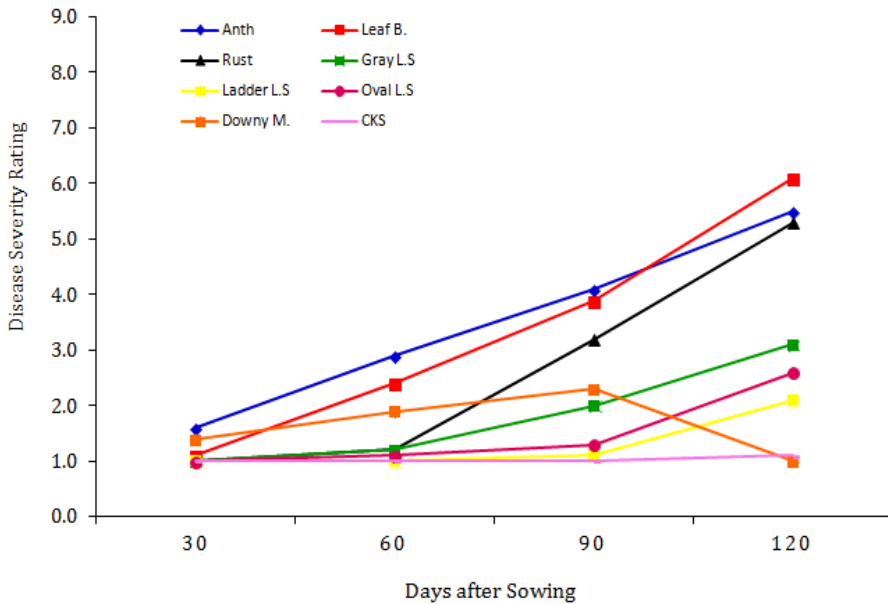


Fig. 4. Disease severity progression at KALRO Kiboko. Where: *Anth* = anthracnose; *Leaf B.* = leaf blight; *Gray L.S* =gray leaf spot; *Oval L.S* = oval leaf spot; *Downy M.* = downy mildew; *CKS* = covered Kernel smut

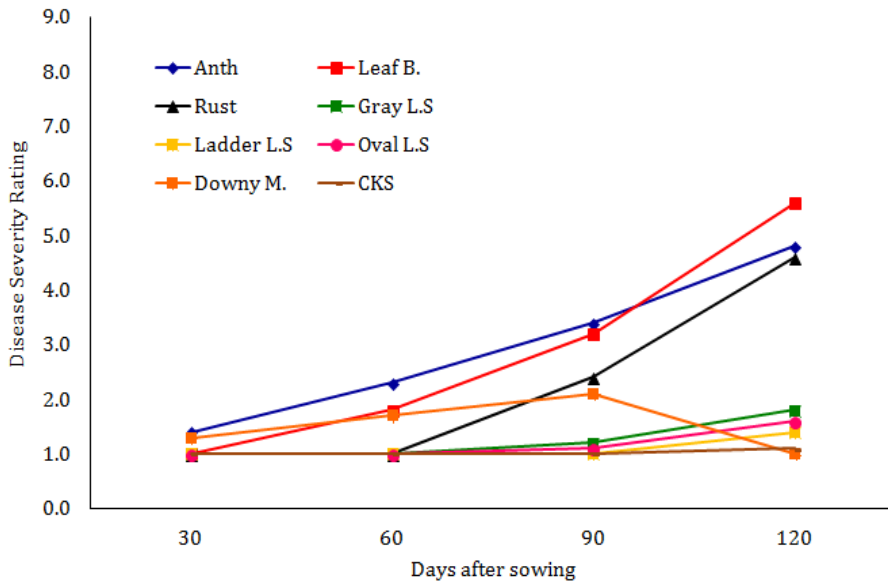


Fig. 5. Disease severity progress at KALRO Ithookwe. Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

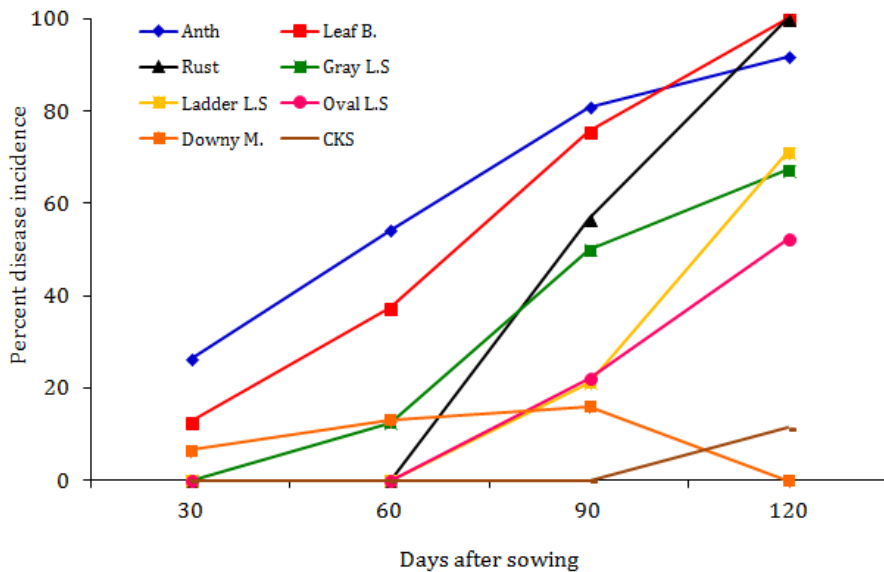


Fig. 6. Disease incidence progression at KALRO Kiboko. Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

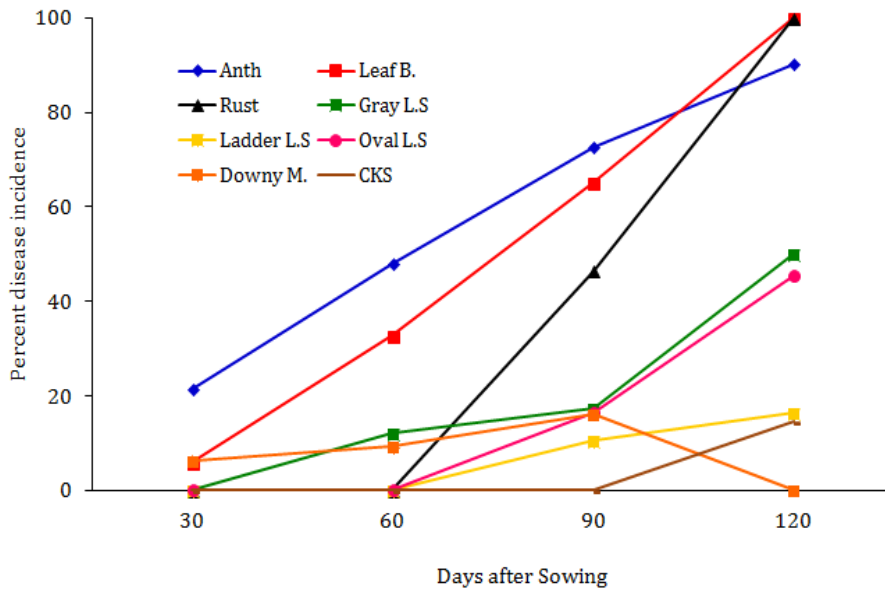


Fig. 7. Disease incidence progression at KALRO Ithookwe. Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S = gray leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

3.4 Growth and Yield

Growth and yield data varied significantly ($P \leq 0.001$) between sorghum genotypes in both locations. For example, the range of days to 50% flowering (DFL) at KALRO Kiboko was 56 to 72.9 with a mean of 65.6, while at KALRO Ithookwe was between 58.7 and 74.1 with a mean of 67.2 (Table 4). Local genotypes, namely Kateng'u, Rasta and Kaguru were the earliest to flower at both sites (Table 4 and Table 4.a). Improved variety Marcia took the longest-most extended number of days to flowering at KALRO, Kiboko (72.9 days) and Ithookwe (74.1 days). Mean plant height ranged between 137 to 233cm and 115 to 240cm at KALRO Kiboko and Ithookwe, respectively. Improved genotypes Makueni Local and Kiboko Local 2 were the tallest genotypes, while Marcia, recorded the least plant height at both sites. Leaf area ranged between 236.8 to 373 at KALRO Kiboko and 234.4 to 444 at KALRO Ithookwe. Improved varieties; Makueni Local, Kiboko Local 2, KARI Mtama 1, and IESV 24029 SH recorded the highest leaf area at both sites, while local landraces: Kateng'u (237cm^2) and Rasta (234.4cm^2) had the least-most minor leaf area at KALRO, Kiboko and Ithookwe respectively (Table 4 and Table 4.a). The mean panicle length range was 13.3 to 26.1 and 12.4 to 25.4cm at KALRO Kiboko and KALRO Ithookwe, respectively.

Improved variety Kiboko local 2 had the longest panicle while the shortest panicles were recorded on local landrace Dark Red at both sites. Panicle width was between 6.3 to 10.8cm at KALRO Kiboko, and 6.5 to 16.6 cm at KALRO Ithookwe. Improved variety Makueni local 2 recorded the highest panicle width, while the shortest panicle width were revealed on

local landrace Mugeta at both sites (Table 4 and Table 4.a). Grain yield ranged between 1.0 to 2.4 t/ha with a mean of 1.8 t/ha at KALRO Kiboko while KALRO Ithookwe was 1.1 to 2.8 t/ha with a mean of 2.0 t/ha (Table 4 and Table 4.a). Improved varieties, namely; Makueni Local, Kiboko Local 2 and IESV 24029 SH recorded higher grain yields while the least grain yield was recorded in local genotypes, namely; Mugeta Dark Red, Kateng'u, Rasta and Kaguru. Significantly more dry matter yield was recorded in Makueni Local and Kiboko Local 2 at both sites (Table 4 and Table 4.a).

Table 4: Mean growth and yield data of sorghum germplasms at KALRO Kiboko

Genotype	DF	PH	LA	NL	PL	PW	DMY	GY	GW
Gadam	63.6 ^b	137 ^{ab}	249 ^{abc}	2.9 ^{bcd}	20.1 ^{bc}	6.6 ^{ab}	5.3 ^{abc}	1.5 ^{bcd}	355.8 ^{ab}
Kateng'u	56.1 ^a	207 ^{ef}	237 ^a	2.3 ^a	23.2 ^{de}	8.9 ^{def}	4.9 ^a	1.5 ^{abc}	352.4 ^{ab}
Marcia	72.9 ^f	127 ^a	332 ^{bcde}	4 ^f	26 ^{fg}	8.8 ^{def}	5.8 ^{abcd}	2.0 ^{def}	568.7 ^d
IESV 24029 SH	69.8 ^{de}	143 ^{ab}	337 ^{cde}	3.6 ^{ef}	23.1 ^{dde}	7.6 ^{bc}	6.1 ^{abcd}	2.2 ^f	525.9 ^d
Kauwi	62.9 ^b	198 ^e	267 ^{abcd}	2.7 ^{abc}	21.5 ^{bcd}	6.4 ^a	7.3 ^d	1.6 ^{bcd}	364 ^{abc}
KARI Mtama 1	70.1 ^e	157 ^{abc}	373 ^e	3.3 ^{de}	23.5 ^{def}	8.1 ^{cd}	6.7 ^{cd}	2.1 ^{ef}	560.8 ^d
Kiboko Local 2	70.6 ^e	229 ^f	359 ^e	3.3 ^{de}	26.1 ^g	9.5 ^f	9.3 ^e	2.3 ^f	533.4 ^d
Rasta	56 ^a	206 ^{ef}	243 ^{ab}	2.3 ^a	22.9 ^{de}	8.8 ^{def}	5.1 ^{ab}	1.4 ^{abc}	356.9 ^{ab}
Makueni Local	70.7 ^e	233 ^f	370 ^e	3.4 ^{def}	23.8 ^{defg}	11 ^g	9.1 ^e	2.4 ^f	587 ^d
Serena	67.8 ^{cd}	144 ^{ab}	315 ^{abcde}	2.4 ^{ab}	24 ^{efg}	8.3 ^{cde}	5.7 ^{abc}	1.9 ^{cdef}	468.9 ^{bcd}
Mugeta	64.8 ^b	182 ^{cde}	253 ^{abc}	2.7 ^{abc}	20 ^b	6.3 ^a	6.4 ^{bcd}	1.0 ^a	260.6 ^a
Seredo	67.5 ^c	154 ^{abc}	283 ^{abcde}	2.4 ^{ab}	23.6 ^{def}	7.6 ^{bc}	6.0 ^{abcd}	2.1 ^f	492.6 ^{cd}
Kaguru	56.2 ^a	192 ^{de}	245 ^{ab}	2.3 ^a	22.6 ^{cde}	9.4 ^{ef}	4.9 ^{ab}	1.4 ^{abc}	368.6 ^{cd}
Dark Red	69.7 ^{de}	166 ^{bcd}	264 ^{abc}	3.2 ^{cde}	13.3 ^a	6.6 ^{ab}	6.3 ^{abcd}	1.3 ^{ab}	341.6 ^{ab}
Means	65.6	177	295	2.9	22.4	8.1	6.3	1.8	438.4
FPr	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
I.s.d.	2	30.5	92.1	0.6	2.5	1.1	1.5	0.5	130.3
CV%	3.1	17.4	31.5	20.2	11.1	14	24	29.5	30

Means within each column (agromorphological and yield characters) that are not followed by the same letter are significantly different ($P \leq 0.05$), while those followed by the same are insignificantly different at ($P > 0.05$). Where: DF= Days to 50% flowering, PH = plant height (cm), LA = Leaf area, NL = number of leaves, PL= Panicle length, PW= Panicle width, DMY= Dry Matter yield (t/ha), GY=Grain Yield (t/ha) GW= Grain weight per 10 sampled plants.

Table 4.a: Mean growth and yield data of sorghum germplasms at KALRO Ithookwe

Genotype	DF	PH	LAI	NL	PL	PW	DMY	GY	GW
Gadam	64.9 ^c	115.1 ^a	318.3 ^{cd}	3.6 ^{de}	19.2 ^c	8.1 ^{ab}	5.8 ^{abc}	1.6 ^{bc}	374.4 ^{bc}
Kateng'u	58.7 ^a	203.7 ^g	247.3 ^a	2.4 ^{ab}	19.8 ^{cd}	13.1 ^d	5.0 ^e	1.7 ^{bc}	376.4 ^{bc}
Marcia	74.1 ^g	121.1 ^{ab}	340.2 ^{de}	5.3 ^f	23.8 ^{fg}	9.5 ^{bc}	6.0 ^{abc}	2.3 ^{de}	483.2 ^{cd}
IESV 24029 SH	72.3 ^{fg}	127.4 ^{bc}	410.6 ^{fg}	3.8 ^e	22.4 ^{ef}	8.0 ^{ab}	6.3 ^{bcd}	2.6 ^{ef}	518.2 ^d
Kauwi	64.1 ^{bc}	194.9 ^g	347.7 ^{de}	3.5 ^{de}	20.4 ^{cd}	7.0 ^a	8.1 ^e	1.9 ^c	377.5 ^{bc}
KARI Mtama 1	72.6 ^{fg}	155.4 ^e	385.7 ^{ef}	3.8 ^e	21.4 ^{de}	8.8 ^b	7.1 ^d	2.3 ^{de}	531.9 ^d
Kiboko Local 2	71.2 ^{ef}	234.5 ^h	444.0 ^g	3.5 ^{cde}	25.4 ^{cd}	11.0 ^c	10.0 ^{ab}	2.7 ^f	580.9 ^d
Rasta	59.0 ^a	200.6 ^g	234.4 ^a	2.3 ^a	20.1 ^{cd}	13.4 ^d	5.0 ^a	1.6 ^{bc}	392.8 ^{bc}
Makueni Local	72.5 ^{fg}	240.6 ^h	385.9 ^{ef}	3.8 ^e	15.1 ^b	16.6 ^e	10.0 ^{ab}	2.8 ^f	553.2 ^d
Serena	69.8 ^{de}	137.0 ^{cd}	329.3 ^d	3.0 ^f	23.1 ^f	8.8 ^b	5.6 ^{ab}	2.2 ^d	474.3 ^{cd}
Mugeta	62.4 ^b	180.8 ^f	239.7 ^a	3.5 ^{de}	19.5 ^c	6.5 ^a	5.3 ^{ab}	1.1 ^a	227.9 ^a

Seredo	69.1 ^d	141.9 ^d	299.3 ^{bcd}	2.8 ^{abc}	22.3 ^{ef}	7.8 ^{ab}	5.9 ^{abc}	2.4 ^{def}	517.5 ^d
Kaguru	58.9 ^a	201.0 ^g	252.0 ^{ab}	2.4 ^{ab}	20.4 ^{cd}	14.9 ^{de}	5.1 ^a	1.6 ^{bc}	392.9 ^{bc}
Dark Red	71.1 ^{ef}	158.2 ^e	278.5 ^{abc}	3.8 ^e	12.4 ^a	6.8 ^a	6.7 ^{cd}	1.4 ^b	304 ^{ab}
Means	67.2	172	322	3.4	20.4	10	6.6	2	436.1
FPr	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
l.s.d.	2	10.2	49.1	0.7	1.7	1.8	1	0.3	117.6
CV%	3	6	15.3	19.9	8.2	18.1	16	16.9	27.2

Means within each column (agromorphological and yield characters) that are not followed by the same letter are significantly different ($P \leq 0.05$), while those followed by the same are insignificantly different at ($P > 0.05$). Where: DF= Days to 50% flowering, PH = plant height (cm), LA = Leaf area, NL = number of leaves, PL= Panicle length, PW= Panicle width, DMY= Dry Matter yield (t/ha), GY=Grain Yield (t/ha) GW= Grain weight per 10 sampled plants.

3.5 Correlations between Diseases, Growth and Yield Data

Fungal disease severity (FDS) was significantly negatively associated with days to 50% flowering ($r = -0.741$, $P \leq 0.002$), number of green leaves ($r = -0.813$, $P \leq 0.001$), leaf area ($r = -0.543$, $P \leq 0.045$) and panicle width ($r = -0.567$, $P \leq 0.043$) (Table 5). Insignificant-An insignificant negative correlation was recorded between fungal disease severity and dry matter yield ($r = -0.338$, $P \geq 0.237$), grain yield ($r = -0.268$, $P \geq 0.355$), grain weight ($r = -0.293$, $P \geq 0.309$), and panicle length ($r = -0.163$, $P \geq 0.577$) (Table 5). Fungal disease incidence (FDI) was also significantly negatively correlated with days to 50% flowering ($r = -0.647$, $P \leq 0.012$) and number of green leaves ($r = -0.754$, $P \leq 0.002$). Insignificant-An insignificant negative association was recorded between FDI with leaf area ($r = -0.449$, $P \geq 0.107$), dry matter yield ($r = -0.224$, $P \geq 0.441$), grain yield ($r = -0.175$, $P \geq 0.550$), grain weight ($r = -0.236$, $P \geq 0.417$) and panicle length ($r = -0.185$, $P \geq 0.528$) (Table 5). Plant height was insignificantly positively correlated with fungal disease severity ($r = 0.434$, $P \geq 0.121$) and incidence ($r = 0.507$, $P \geq 0.116$). Panicle width was also insignificantly positively correlated with FDI ($r = 0.490$, $P \geq 0.076$) (Table 5). Generally, most growth parameters (DF, NL, LA and PL) showed a significant and positive correlations with yield parameters (DM, GY and GW) (Table 5).

Table 5: Pearson correlation coefficients (r) between fungal disease severity, incidence, growth and yield parameters.

	FDS	FDI	DF	PH	NL	LA	DM	GY	GW	PL	PW
FDS	1	0.977**	-0.741**	0.434	-0.813**	-0.543*	-0.338	-0.268	-0.293	-0.163	-0.567*
FDI	0.977**	1	-0.647*	0.439	-0.754**	-0.449	-0.224	-0.175	-0.236	-0.185	0.490
DF	-0.741**	-0.647*	1	-0.330	0.821**	0.809**	0.557*	0.671**	0.672**	0.117	-0.220
PH	0.434	0.439	-0.330	1	-0.339	0.008	0.523	0.040	-0.016	-0.039	0.627*
NL	-0.813**	-0.754**	0.821**	-0.339	1	0.647*	0.429	0.415*	0.449	0.068	-0.211
LA	-0.543*	-0.449	0.809**	0.008	0.647*	1	0.748**	0.879**	0.863**	0.424	0.100
DM	-0.338	-0.224	0.557*	0.523	0.429	0.748**	1	0.609*	0.532*	0.083	0.203
GY	-0.268	-0.175	0.671**	0.040	0.415*	0.879**	0.609*	1	0.977**	0.556*	0.331
GW	-0.293	-0.236	0.672**	-0.016	0.449	0.863**	0.532*	0.977**	1	0.585*	0.369
PL	-0.163	-0.185	0.117	-0.039	0.068	0.424	0.083	0.556*	0.585*	1	0.225
PW	-0.567*	0.490	-0.220	0.627*	-0.211	0.100	0.203	0.331	0.369	0.225	1

**Correlation is significant at $P \leq 0.01$ level; *Correlation is significant at $P \leq 0.05$ level; FDS= Fungal disease severity, FDI= Fungal disease incidence, DF= Days to 50% flowering, PH= plant height (cm), NL= number of green leaves, LA= Leaf area, DM= Dry Matter yield (t/ha), GY=Grain Yield (t/ha) GW= Grain weight per 10 sampled plants(g), PL= Panicle length, PW= Panicle width.

3.6 Fungal Disease Tolerance

~~Classification of sorghum genotypes or varieties into tolerant or susceptible categories~~
~~wa~~Sorghum genotypes or varieties were classified into tolerant or susceptible categories based on yield and fungal disease severity scores or incidences. Most improved genotypes were classified as tolerant to fungal diseases compared to local landraces that were ~~mostly~~ primarily susceptible in both sites (Table 6 and Table 6.a). The improved genotypes had significantly higher yields (2.0 – 2.4t/ha) and relatively lower disease severities compared to local varieties that had low yields (1.0 – 1.5t/ha) and higher disease severities in Kiboko (Table 6). These improved genotypes included Makueni Local, Kiboko Local 2, IESV 24029 SH, Marcia, KARI Mtama 1, Seredo and Serena. Relatively similar observations were made in KALRO Ithookwe, where improved genotypes yielded 2.2 – 2.8t/ha compared to local varieties with 1.1 – 1.6t/ha (Table 6.a). Two ~~tan-tan~~-colored improved genotypes (KARI Mtama 1 and Marcia) recorded ~~least disease severities and higher yield compared to the~~ least disease severities and higher yield than all germplasms in both sites (Table 6 and 6.a).

Table 6: Classification of germplasms based on mean disease severity scores and yield (t/ha) at KALRO Kiboko

Germplasms	Type	PC	AN	LB	RT	GLS	LLS	OLS	DM	CKS	YLD	DR
Makueni local	Improved	Pigmented	6.3	6.1	5.2	3.1	1.9	2.8	1.0	1.0	2.4	Tolerant
Kiboko local 2	Improved	Pigmented	6.3	6.1	5.1	3.1	2.0	2.8	1.0	1.0	2.3	Tolerant
IESV 4029 SH	Improved	Pigmented	5.9	6.0	4.7	3.0	1.7	2.2	2.4	1.0	2.2	Tolerant
KARI Mtama 1	Improved	Tan	1.0	6.6	4.0	2.2	1.0	1.5	2.9	1.0	2.1	Tolerant
Seredo	Improved	Pigmented	6.2	6.1	5.0	2.9	1.9	2.3	3.0	1.0	2.1	Tolerant
Marcia	Improved	Tan	1.0	6.5	3.9	2.0	1.0	1.0	1.0	1.0	2.0	Tolerant
Serena	Improved	Pigmented	6.2	6.1	5.0	3.1	1.8	2.1	3.0	1.0	1.9	Tolerant
Kateng'u	Local	Pigmented	8.1	5.7	7.4	4.4	3.5	4.5	3.7	1.0	1.5	Susceptible
Rasta	Local	Pigmented	8.1	5.7	7.4	4.3	3.5	4.5	3.3	1.0	1.4	Susceptible
Kaguru	Local	Pigmented	8.1	5.7	7.4	4.3	3.6	4.5	3.5	1.0	1.4	Susceptible
Dark Red	Local	Pigmented	6.1	5.8	5.0	3.0	1.9	2.6	3.8	1.0	1.3	Susceptible
Mugeta	Local	Mixed	3.3	6.6	4.2	2.4	1.4	1.7	1.0	1.0	1	Susceptible
Gadam	Improved	Pigmented	6.2	5.9	5.5	2.9	1.8	2.3	1.0	1.0	1.5	Susceptible
Kauwi	Local	Mixed	3.7	6.6	4.7	2.8	1.8	2.1	1.0	1.1	1.6	Susceptible

Where: PC = Plant color; AN = anthracnose; LB. = leaf blight; RT = rust; GLS =gray leaf spot; LLS = ladder leaf spot; OLS = oval leaf spot; DM. = downy mildew; CKS = covered Kernel smut; YLD = yield (t/ha); DR = disease reaction.

Table 6.a: Classification of germplasms based on mean disease severity scores and yield (t/ha) at KALRO Ithookwe

Germplasms	Type	PC	AN	LB	RT	GLS	LLS	OLS	DM	CKS	YLD	DR
Makueni local	Improved	Pigmented	5.7	5.7	4.3	1.9	1.3	1.6	1.0	1.0	2.8	Tolerant
Kiboko local 2	Improved	Pigmented	5.8	5.9	4.3	1.8	1.4	1.6	1.0	1.0	2.7	Tolerant
IESV 4029 SH	Improved	Pigmented	5.1	5.6	4.0	1.5	1.2	1.3	2.0	1.0	2.6	Tolerant
KARI Mtama 1	Improved	Tan	1.0	6.0	3.7	1.4	1.0	1.1	2.2	1.0	2.3	Tolerant
Seredo	Improved	Pigmented	5.4	5.5	4.2	1.7	1.3	1.3	3.1	1.0	2.4	Tolerant
Marcia	Improved	Tan	1.0	6.0	3.7	1.4	1.0	1.0	1.0	1.0	2.3	Tolerant
Serena	Improved	Pigmented	5.4	5.6	4.2	1.7	1.3	1.3	2.9	1.0	2.2	Tolerant
Kateng'u	Local	Pigmented	7.1	4.8	6.4	2.4	1.8	2.7	3.2	1.0	1.7	Susceptible
Rasta	Local	Pigmented	7.1	4.9	6.4	2.4	1.9	2.8	3.3	1.0	1.6	Susceptible
Kaguru	Local	Pigmented	7.1	4.9	6.4	2.5	1.9	2.8	3.1	1.0	1.6	Susceptible
Dark Red	Local	Pigmented	5.5	5.5	4.3	1.8	1.3	1.6	3.5	1.0	1.4	Susceptible
Mugeta	Local	Mixed	2.3	6.0	3.8	1.4	1.2	1.2	1.0	1.0	1.1	Susceptible
Gadam	Improved	Pigmented	5.4	5.6	4.9	1.7	1.3	1.3	1.0	1.0	1.6	Susceptible
Kauwi	Local	Mixed	3.0	6.1	4.2	1.6	1.3	1.3	1.0	1.1	1.9	Susceptible

Where: PC = Plant color; AN = anthracnose; LB. = leaf blight; RT = rust; GLS = gray leaf spot; LLS = ladder leaf spot; OLS = oval leaf spot; DM. = downy mildew; CKS = covered Kernel smut; YLD = yield (t/ha); DR = disease reaction.

4. DISCUSSION

Previous A previous survey by Ogolla et al. [9] in eastern Kenya noted that although fungal diseases played a key role in limiting the attainment of sorghum production potential, there was limited information on their effects on the growth and yield of this cereal. Ngugi et al. [7], while carrying out a surveysurveying in Western Kenya, established a complex of fourteen foliar diseases and six panicle diseases affecting sorghum production. Recently, Koima et al. [11] confirmed six foliar and one panicle fungal diseases infecting sorghum through a field survey in lower eastern Kenya. All these studies provided little or no information on the effect of these diseases on the growth and yield of sorghum. Further, non of these studies compared the performance of improved and local varieties under disease infections that could lead to the identification of genotypes with sources of fungal tolerance. The present study recorded three additional foliar fungal diseases—namely; grey leaf spot, ladder leaf spot and oval leaf spot that which were previously never reported in the study area.

Fungal diseases identified among sorghum genotypes under field trials included; leaf blight, Anthracnose, rust, gray-grey leaf spot, ladder leaf spot, oval leaf spot, downy mildew and covered kernel smut. However, three fungal diseases; leaf blight, Anthracnose and rust, showed higher disease severity and incidences. Koima et al. [11] equally listed the three diseases as most prevalent, with Anthracnose recording higher incidence and prevalence. The present study established leaf blight with higher disease severity among the three. Furthermore, higher disease incidence was recorded in leaf blight and rust, followed by

anthracnose in all sites the trials were done. The dominance of these diseases can be linked to conducive weather conditions ~~which ranged between moderate to high temperatures and humidity during the field trials, and also ranging between moderate to high temperatures and humidity during the field trials, and~~ the susceptibility of the genotypes under the study [11]. Higher fungal disease severity attained at KALRO Kiboko compared to KALRO Ithookwe maybe due to warmer temperatures ~~accompanied with supplementary supplementary~~ irrigation. This finding are in line with Tesso et al. [34] who suggested that high leaf blight and anthracnose severities manifests under elevated humidity that alternates with dry weather. Furthermore, Koima et al. [11] listed warm and humid conditions, and moderate temperatures as important for high rust severity unlike cold temperatures and dry weather ~~patterns~~ that significantly reduce its development. Slower disease severity and incidence progress of ~~gray-grey~~ leaf spot, ladder leaf spot and oval leaf spot can be attributed to ~~a~~ lack of initial inoculum buildup [35], which later in the season appears briefly at maturity. Almost all of the foliar diseases attained maximum severities at maturity due to ~~the~~ limited ability of plants to fight off these fungal pathogens, which rapidly penetrate ~~into~~ plants [36].

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The significant negative correlations observed between fungal diseases severities or incidences with days to 50% flowering, number of green leaves, panicle width and leaf area suggests the role fungal diseases play in limiting sorghum growth. The diseases reduce plant growth and yield by affecting both vegetative and reproductive stages. For example, ~~by affecting the green leaf area through wilting and defoliation, plant physiological processes such as photosynthesis are inhibited~~ plant physiological processes such as photosynthesis are inhibited by affecting the green leaf area through wilting and defoliation [37, 38]. These have a net negative effect on yield accumulation. The insignificant negative correlation between dry matter yield, grain yield, grain weight, panicle length and fungal disease severity observed in this study, may be due to lower fungal disease infection during the first three months from vegetative ~~stage~~ to anthesis stages. This ~~is in agreement~~ agrees with a study by Anitha et al. [39], who acknowledged that crop losses rely at the critical stage which fungal diseases infect plants, ~~the~~ genotype reaction to diseases and ~~envrionmental~~ environmental conditions at the time of infection.

Tan genotypes ~~seemed to record~~ recorded lower disease severity than the pigmented and mixed genotypes. This may ~~be~~ attributed to pigments called flavones [40] which include apigenin and luteolin [41]. In vitro assay by Du et al. [42] revealed ~~the two flavones inhibited Colletotrichum sublineola growth, with luteolin performing better~~ at the two flavones inhibited *Colletotrichum sublineola* growth, with luteolin performing better when its concentration was increased than apigenin. Improved varieties also registered higher yields except Gadam variety. ~~This traits are useful sources of host plant resistance which can be incooperated in breeding programs for enhanced sorghum production in the Arid and semi arid lands of Kenya~~ traits are useful sources of host plant resistance which can be incooperated in breeding programs for enhanced sorghum production in Kenya's Arid and semi arid lands. Local landraces ~~namely Kateng'u, Rasta and Kaguru displayed susceptibility trait by not only registering high fungal disease severity and incidence but also,~~ namely Kateng'u, Rasta and Kaguru, displayed susceptibility trait by registering high fungal disease severity and incidence and lower yields than improved genotypes. These results

confirm ~~the~~ findings by Njoroge et al. [26], who also reported some local landraces being more susceptible than improved varieties to fungal diseases.

The present study confirms presence of gray leaf spot, ladder leaf spot and oval leaf spot diseases that ~~had not been identified by previous studies in lower eastern Kenya~~ previous studies in lower eastern Kenya had not identified. ~~Gray-Grey~~ leaf spot development is caused by *Cercospora sorghi* Ellis & Everh [43] while ladder leaf spot and oval leaf spot is caused by *Cercospora fusimaculans* and *Ramulispora sorghicola* respectively [7]. ~~Gray Grey~~ leaf spotsymptoms included: rectangular shaped dark red lesions with lighter centers as described by Williams et al.[22], and ladder leaf spot was characterized by lesions resembling ladder pattern, with darker margins and pale ~~centers-centres~~ while oval leaf spot symptoms were small circular spots with tan ~~centers-centres~~ as described by Njoroge et al. [26]. The timing of ~~the~~ gray leaf spot, ladder leaf spot and oval leaf spot to develop before or several days after anthesis and slowly progress to attain maximum severity at maturity resulted in a low effect on final yield [43]. Although the three diseases exhibited lower disease severity scores and incidences, implying they showed the least foliar and panicle symptoms or infections in the present study, appropriate management strategies should be considered to suppress their rapid expansion.

5. CONCLUSION

In conclusion, leaf blight, anthracnose and rust showed higher severity ~~compared to~~ than other diseases. Although fungal diseases greatly affected growth characters, yield loss was minimal due to variations in ~~the~~ timing at which the disease infected the genotypes. When assessing the ~~performance in terms of reaction to fungal diseases and yield performance among the test varieties, improved genotypes registered high growth and yields with lesser disease severity than local landraces that had reaction to fungal diseases and yield performance among the test varieties, improved genotypes registered high growth and yields with lesser disease severity than local landraces with~~ low yield with high severities. Therefore improved genotypes were considered potential sources of disease tolerance that could be incooperated in future crop improvement programs. The present study recommends testing ~~of the improved genotypes in other agroecologies of arid and semi-arid lands before they are exploited~~ the improved genotypes in other agroecologies of arid and semi-arid lands before exploiting them for sustainable sorghum production.

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