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Effects of Major Fungal Pathogens on Growth and Yield of Improved and Local Sorghum Genotypes under Field Trials in Lower Eastern Kenya

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Authors' contributions

This work was carried out in collaboration among all authors. Authors MKR, INK and CO set up the experimental design and sourced for germplasms for the study. Author MKR and INK carried out the field experiments, collected data, performed statistical analysis and wrote the first draft of the manuscript. Authors BM, NE and CO supervised the study and offered technical advice. All authors read and approved the final manuscript.

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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. A study on the effects of major fungal diseases on sorghum growth and yield and identification of tolerant genotypes is

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critical for sustainable sorghum production. A total of 14 germplasms were analyzed under a two-seasonal field trial 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 was used for fungal inoculation. Ten plants randomly sampled and tagged from two inner rows in each plot, were used to asses 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 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≤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.

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 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 production regions in the semi-arid areas of Nyanza, Eastern and Coast [3]. The estimated area of sorghum cultivated at national level is 228,640 ha yielding 205,399 tonnes (0.9 t/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 ranges between 2 and 5 t/ha [5]. This can mainly be attributed to biotic factors namely: diseases, insect pests and weeds [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 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 a reduction in both grain and biomass 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 sorghum 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-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 study. Recently, Koima et al. [11] carried out a survey of 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. MATERIALS 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 (October to December) and the long rainy season (March to May) of 2021, concurrently. Ithookwe is located at an altitude of 1158 meters above sea level, latitude 01° 22′34″ S and longitude 037° 58′43″ E [12,13]. Average rainfall and temperatures range per annum 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 [14]. Annual temperatures range between 14.3°C – 35.1°C while rainfall is between 545 -629 mm (16). Although the two sites receive a bimodal rainfall pattern annually according to Muui [12], they are hotspots for plant fungal diseases and differ in agro-ecological zones [11,15].

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 to fungal diseases [9] while Kateng'u a common local landrace among farmers was used as a control for yield comparison [10,11]. Sorghum variety Sila 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 *Striga hermonthica*	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 resistant to shoot 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	-	-	ICRISAT
16	Wagiita	-	Susceptible to fungal diseases	ICRISAT

Source: Sheunda [32]

2.3 Experimental Design

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

2.4 Inoculation by Spreader Variety

Fungal inoculation on test varieties using the spreader variety technique as described by Pande et al. [16] was adopted. The rows of spreader variety (Wagiita) were sowed 21 days earlier than the test varieties, after which they were inoculated with fungal suspension that was prepared as described by Shekhar and Kumar [17]. Spraying was done on plant whorls on the 25th and 40th day during evening hours [18] when the conditions were ideal for fungal infection [19].

2.5 Weather Conditions During the Field Trial Seasons

Temperature and rainfall data of the research stations namely: Kiboko and Ithookwe was obtained from KALRO Kiboko station and Kenya Meteorological department, respectively for the period the experiments were done (Table 5 and 6).

2.6 Identification of Fungal Diseases

Fungal diseases in the field were identified based on visual symptoms and signs, aided through magnification by hand lenses [20] as well as sorghum fungal disease identification keys as described by Williams et al. [21] and other authors. The symptoms and signs used to identify various fungal diseases in this study are summarized in Table 2.

Table 2. Signs and symptoms used to identify various sorghum fungal diseases

Disease	Description of symptoms and signs	Source
Anthracnose	Small, circular, elliptical to elongated spots with straw-colored centers and margins that are dark, red or purple. 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. [21]; Thakur & Mathur, [22]
Leaf blight	Long elliptical necrotic lesions consisting of centers that are straw-colored. Lesions can coalesce displaying a burnt appearance. Moreover, a faint to grey bloom of conidiophores and conidia is produced on lesions.	Williams et al. [21]; Mathur et al. [23]
Rust	Scattered purple, tan, or red small 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 teleutosori, hence changing from a reddish brown to dark.	Williams et al. [21]; Thakur et al. [24]
Gray leaf spot	Rectangular shaped, dark red to purplish lesions in pigmented plants while lighter centers occur in tan plants and develop on either leaf blades or sheaths. These symptoms are majorly isolated but can develop into long stripes. A greyish-white bloom of conidia can also appear on lesions.	Williams et al. [21]
Ladder leaf spot	Lesions characterized by pale centers and dark margins appear like a ladder on the leaf.	Njoroge et al. [25]
Oval leaf spot	Small water-soaked spots emerge first and later develop 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 spots from anthracnose which is characterized by the production of black setae on the lesions.	Williams et al. [22]; Njoroge et al. [25]
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. [21]; Thakur et al. [26]

2.7 Disease Measurements

Fungal disease severity (FDS) data were collected 30 days after planting up to 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 [27] (Table 4).

2.8 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 [28], stay green (STG) or number of green leaves per plant [29,30], leaf area/plant leaf area [31], Days to 50% flowering [30], plant color [28], panicle length, panicle width and grain weight (g) [32]. Grain yield (GRY in t/ha) and dry matter yield (DMY in t/ha) were determined using formulae by Sheunda [32] as shown below:

$$\mathrm{GRY} = \frac{\mathrm{GW}}{100\mathrm{A}} \qquad \text{Formula (1)}$$

Where:

GW = grain weight in grams per net plot
A = area of net plot harvested (m^2) was determined by:

A = (R×I×L) Where;
R = No. of rows within the net plot
I = Space between rows (cm)
L = Length of the rows (cm)

$$\mathrm{DMY} = \frac{10\mathrm{DW}}{\mathrm{A}} \qquad \text{Formula (2)}$$

Where:

DW = Dry biomass per plot (kg)
A = area of net plot harvested (m^2) –see formula (1) above

2.9 Data Analysis

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

Table 3. Severity Scores for 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

Source: Ngugi et al. [7]

Table 4. Severity Scores for 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: Thakur [27]

3. RESULTS

3.1 Weather Data for the Experimental Sites

Weather elements showed variations during the experiemental period in both sites. For example mean rainfall of 3.4mm, average min. and max. temp. of 16.6°C and 31.7°C respectively were recorded in season one at KALRO Kiboko while the same elements averaged 1.1 mm rainfall, 15.1°C min. temp. and 30.2°C max. temp. in season two at the same site (Table 5). For KALRO Ithookwe, mean 121.9 mm rainfall, mean min. temp. 17.6°C and max. temp. 28.2°C were recorded in season one with season two showing 65.6 mm rainfall, 16.2°C and max. temp. 27.0°C (Table 6).

3.2 Major Fungal Diseases

The major fungal diseases diseases identified comprised of seven foliar diseases namely: anthracnose (Fig. 1A), leaf blight (Fig. 1B), leaf rust (Fig. 1C), gray 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.

3.3 Variations in Fungal Disease Severity and Incidence

KALRO Kiboko recorded higher fungal disease severity (FDS) scores and fungal disease incidences (FDI) compared to KALRO Ithookwe (Fig. 2 and Fig. 3). The mean FDS scores at KALRO Kiboko were descending in order: leaf blight, anthracnose, leaf rust, gray leaf spot, oval leaf spot, downy mildew, ladder leaf spot and covered Kernel smut, while at KALRO Ithookwe were in the order: leaf blight, anthracnose, leaf rust, downy mildew, gray leaf spot, oval leaf spot, ladder leaf spot and covered Kernel smut (Fig. 2). FDI highest ranking at KALRO Kiboko were in the order: leaf blight, leaf rust, anthracnose, ladder leaf spot, gray leaf spot, oval leaf spot, downy mildew and covered Kernel smut while at KALRO Ithookwe were in order: leaf blight, leaf rust, anthracnose, gray leaf spot, oval leaf spot, ladder leaf spot, downy mildew and covered Kernel smut (Fig. 3). Anthracnose, leaf blight and rust had significantly higher FDS and FDI in both sites compared to the other fungal diseases (Fig. 2 and Fig. 3).

3.4 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 other fungal diseases at both sites.

3.5 Sorghum Growth and Yield

Growth and yield data varied significantly (P≤0.001) between sorghum genotypes in both locations. For example, the range of days to 50% flowering (DF) at KALRO Kiboko was 56 to 72.9 with a mean of 65.6 (Table 7) while at KALRO

Table 5. Weather conditions at KALRO, Kiboko

Year/S1	Month	Min. Temp (°C)	Max. Temp (°C)	Rainfall (mm)
2020	October	16.6	32.7	0.2
2020	November	18.1	31.3	10.1
2020	December	17.0	30.8	1.6
2021	January	15.7	30.9	0.8
2021	February	15.8	32.9	4.5
	Mean	**16.6**	**31.7**	**3.4**
Year/S2	Month	Min. Temp (°C)	Max. Temp (°C)	Rainfall (mm)
2021	April	18.5	34.4	1.5
2021	May	16.2	30.4	4.2
2021	June	13.9	28.5	0
2021	July	13.0	28.2	0
2021	August	14.1	29.4	0
	Mean	**15.1**	**30.2**	**1.1**

Where: Min. Temp= Mean minimum temperature, Max. Temp= Mean maximum temperature; S1 = season one; S2 = season two

Table 6 Weather conditions at KALRO, Ithookwe

Year/S1	Month	Min. Temp (°C)	Max. Temp (°C)	Rainfall (mm)
2020	October	17.6	29.4	28.5
2020	November	18.4	27.5	506.6
2020	December	17.5	27.7	57.1
2021	January	16.7	27.2	11.8
2021	February	17.7	29.4	5.4
	Mean	**17.6**	**28.2**	**121.9**
Year/S2	**Month**	**Min. Temp (°C)**	**Max. Temp (°C)**	**Rainfall (mm)**
2021	April	19.0	29.3	270.5
2021	May	16.9	27.3	57.3
2021	June	15.7	25.6	0
2021	July	14.8	25.6	0
2021	August	14.6	27.2	0
	Mean	**16.2**	**27.0**	**65.6**

Where: Min. Temp= Mean minimum temperature, Max. Temp= Mean maximum temperature; S1 = season one; S2 = season two

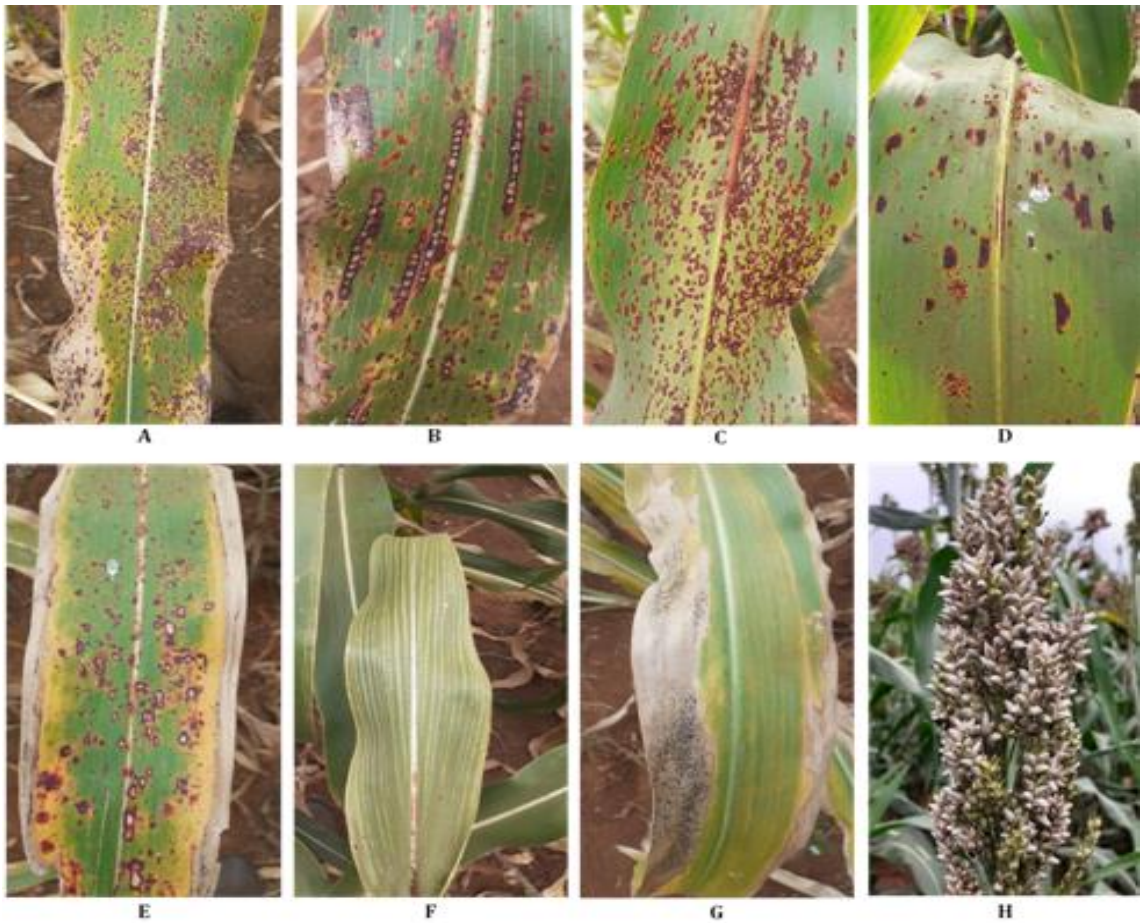

Fig. 1. Major fungal diseases identified during the field trials

A = Anthracnose; B = Laddder leaf spot; C = leaf rust; D = Gray leaf spot; E = Oval leaf spot; F = Downy mildew; G = Leaf blight; H = Covered kernel smut

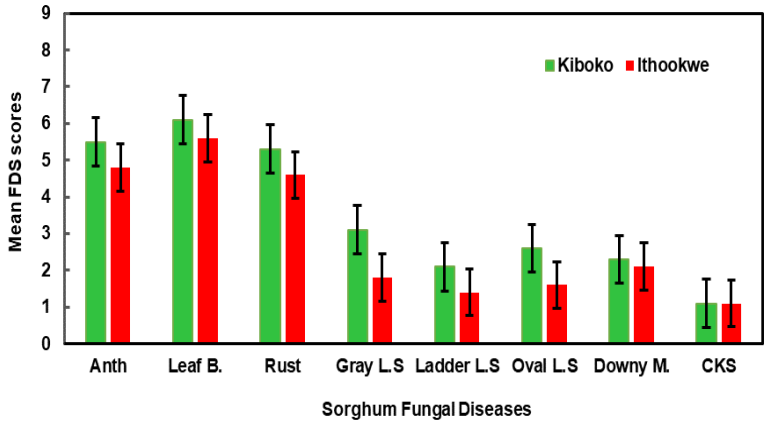

Fig. 2. Mean fungal disease severity (FDS) recorded at KALRO Kiboko and Ithookwe

Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Ladder L.S= ladder leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

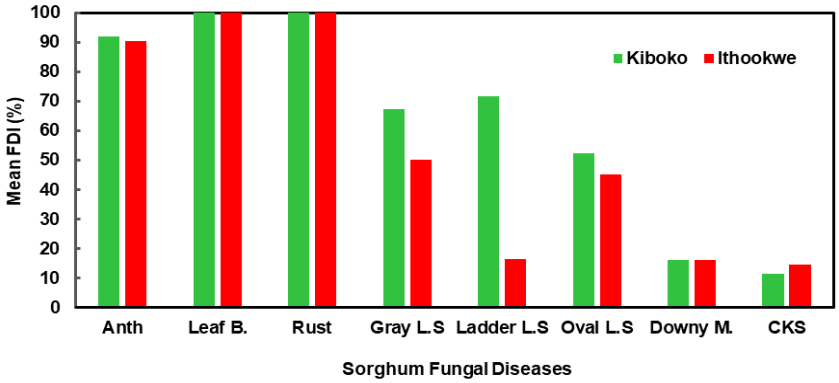

Fig. 3. Fungal disease incidence recorded at KALRO Kiboko and Ithookwe.

Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Ladder L.S= ladder leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

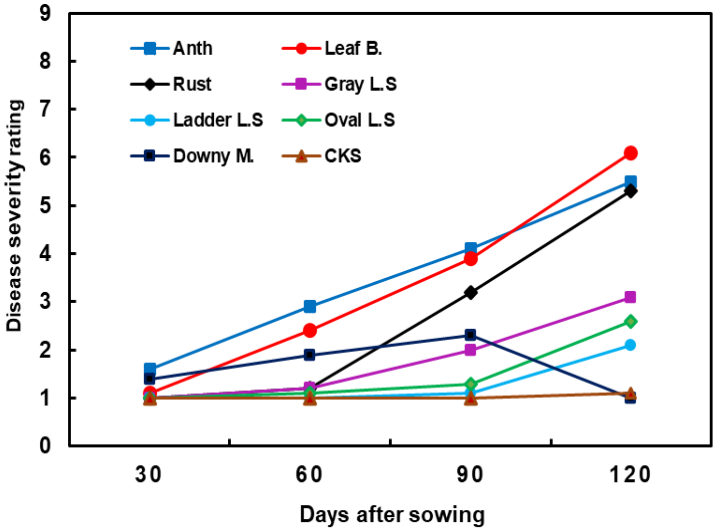

Fig. 4. Disease severity progression at KALRO Kiboko

Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Ladder L.S= ladder leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

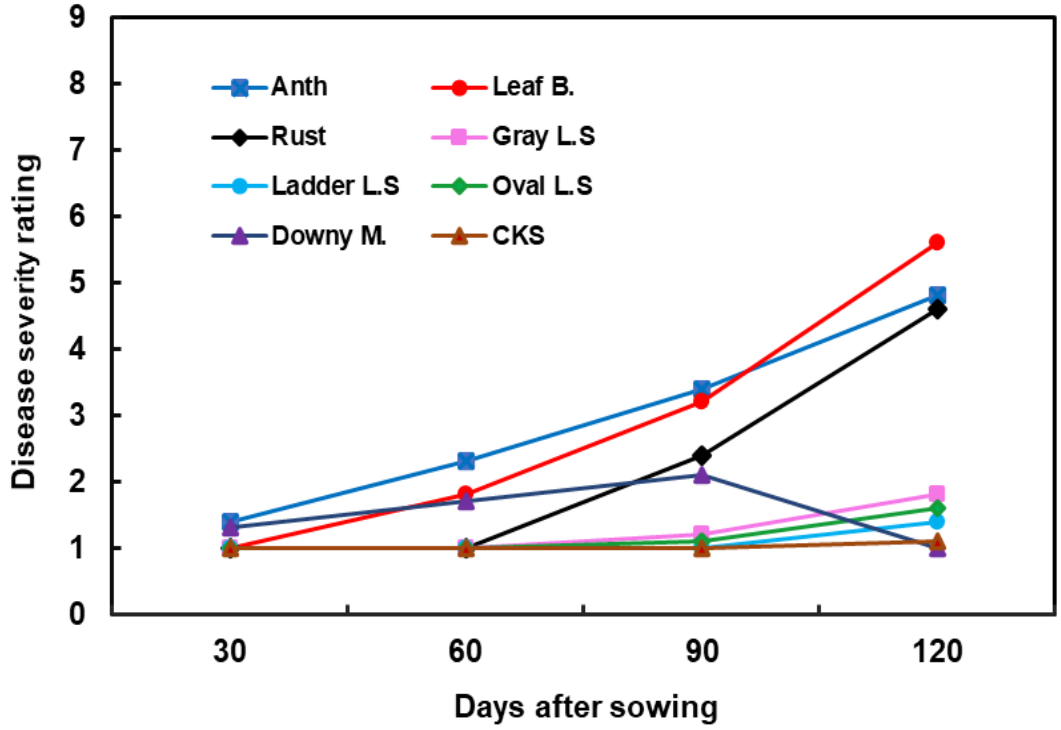

Fig. 5. Disease severity progress at KALRO Ithookwe

Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Ladder L.S= ladder leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

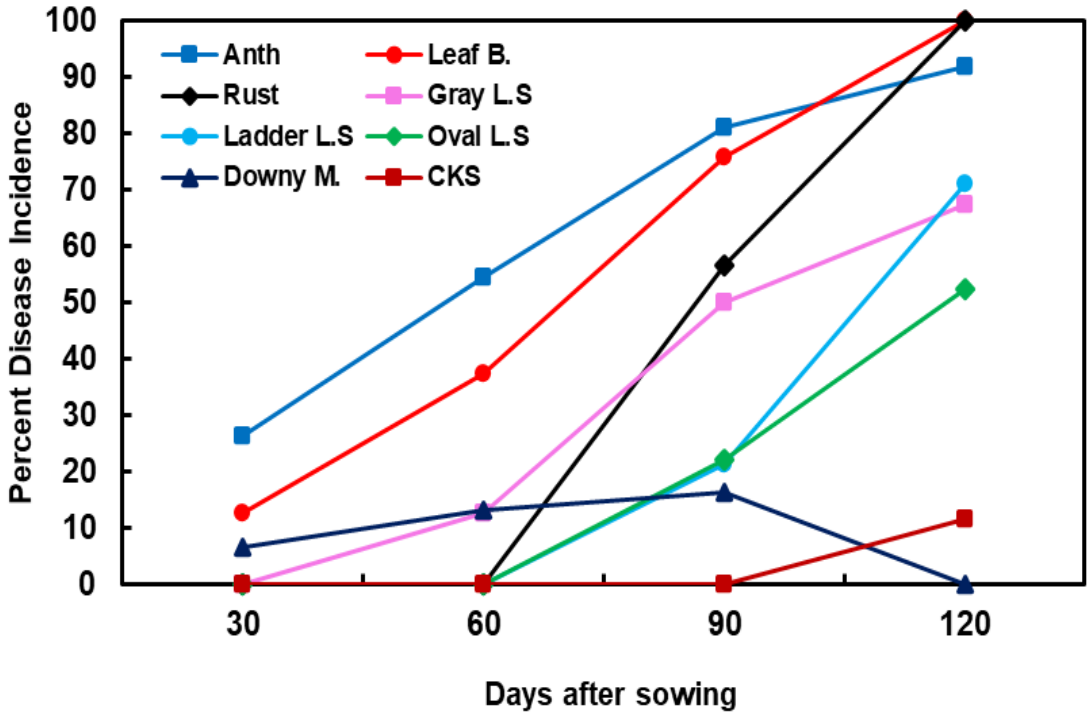

Fig. 6. Disease incidence progression at KALRO Kiboko

Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Ladder L.S= ladder leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

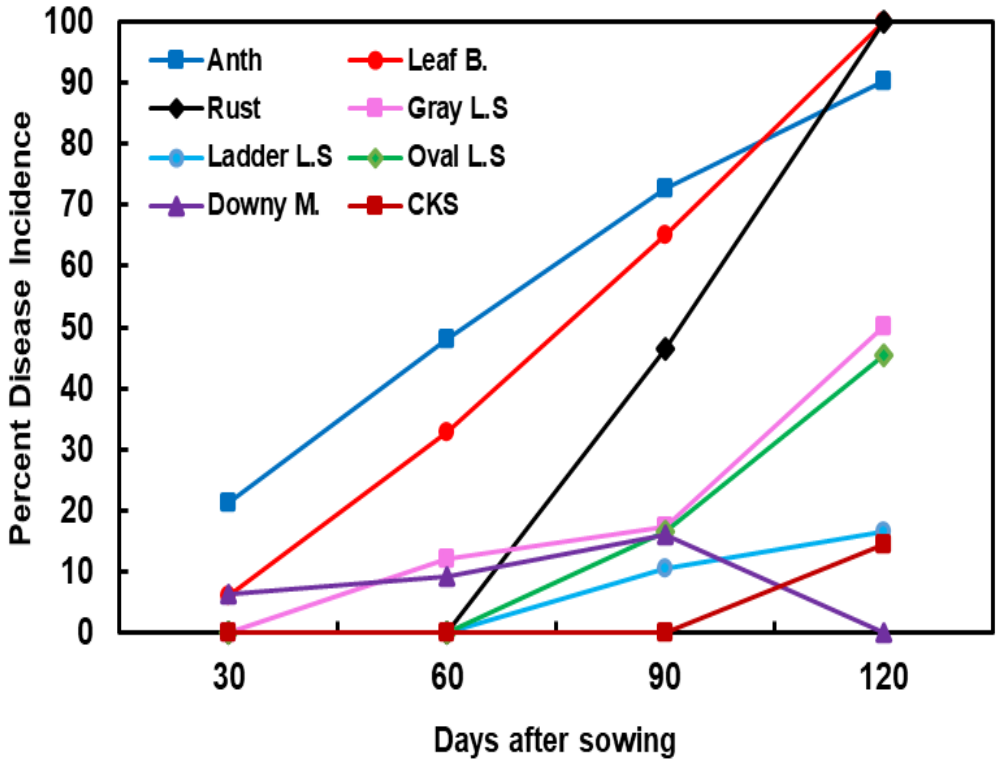

Fig. 7. Disease incidence progression at KALRO Ithookwe

Where: Anth = anthracnose; Leaf B. = leaf blight; Gray L.S =gray leaf spot; Ladder L.S= ladder leaf spot; Oval L.S = oval leaf spot; Downy M. = downy mildew; CKS = covered Kernel smut

Ithookwe was between 58.7 and 74.1 with a mean of 67.2 (Table 8). Local genotypes namely Kateng'u, Rasta and Kaguru were the earliest to flower at both sites (Table 7 and Table 8). Improved variety Marcia took the longest number of days to flowering at KALRO, Kiboko and Ithookwe. 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 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 highest leaf area at both sites while local landraces: Kateng'u and Rasta had the least leaf area at KALRO, Kiboko and Ithookwe respectively (Table 7 and Table 8).

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 recoreded highest panicle width, while shortest panicle width were revealed on local landrace Mugeta at both sites (Table 7 and Table 8). 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 7 and Table 8). Improved varieties namely; Makueni Local, Kiboko Local 2 and IESV 24029 SH recorded higher grain yield 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 7 and Table 8).

3.6 Correlations between Diseases, Growth and Yield Data

At KALRO Kiboko, fungal disease severity (FDS) was significantly negatively associated with days to 50% flowering ($r = -0.794$, $P \leq 0.001$), number of green leaves ($r = -0.692$, $P \leq 0.006$), leaf area ($r = -0.560$, $P \leq 0.037$) and (Table 9). Insignificant

Table 7. 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^{bcde}	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}	243ab	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}	370e	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}	192de	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
l.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≤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 8. 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^{a}	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**	**2.0**	**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≤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

negative correlation was recorded between fungal disease severity and dry matter yield (r = -0.392, P≥0.166), grain yield (r= -0.268, P≥0.355), grain weight (r = -0.293, P≥0.309), and panicle length (r = -0.163, P≥0.577) (Table 9). Fungal disease incidence (FDI) was also significantly negatively correlated with days to 50% flowering (r = -0.647, P≤0.012) and number of green leaves (r = -0.754, P≤0.002). Insignificant negative association was recorded between FDI with leaf area (r= -0.449, P≥0.107), dry matter yield (r = -0.224, P≥0.441), grain yield (r = -0.277, P≥0.337), grain weight (r = -0.405, P≥0.151) and panicle length (r = -0.097, P≥0.741) (Table 9). Plant height was insignificantly positively correlated with fungal disease severity (r = 0.457, P≥0.100) and incidence (r = 0.446, P≥0.110). Panicle width was also insignificantly positively correlated with FDS (r = 0.275, P≥0.076) and FDI (r = 0.280, P≥0.332) (Table 9).

Fungal disease severity (FDS) at KALRO, Ithookwe was only significantly negatively correlated with days to 50% flowering (r = -0.669, P≤0.009) and number of green leaves (r = -0.857, P≤0.001) (Table 10) while Insignificant negative assoiation was recorded between fungal disease severity and leaf area (r = -0.493, P≤0.07), dry matter yield (r = -0.282, P≥0.330), grain yield (r= -0.255, P≥0.379), grain weight (r = -0.164, P≥0.576), and panicle length (r = -0.207, P≥0.478) (Table 10). Fungal disease incidence (FDI) was also significantly negatively correlated with days to 50% flowering (r = -0.656, P≤0.010) and number of green leaves (r = -0.837, P≤0.001). Insignificant negative association was recorded between FDI with leaf area (r= -0.441, P≥0.114), dry matter yield (r = -0.227, P≥0.436), grain yield (r = -0.214, P≥0.464), grain weight (r = -0.137, P≥0.462) and panicle length (r = -0.207, P≥0.477) (Table 10). Plant height was insignificantly positively associated with fungal disease severity (r = 0.410, P≥0.146) and incidence (r = 0.445, P≥0.111). Panicle width was significantly positively correlated with FDS (r = 0.564, P≥0.036) and FDI (r = 0.600, P≥0.023) (Table 10). Generally most growth parameters (DF, NL, LA and PL) at both sites showed a signficant and positive correlations with yield parameters (DM, GY and GW) (Table 9 and Table 10).

3.7 Fungal Disease Tolerance

Most improved genotypes were classified as tolerant to fungal diseases compared to local land races that were mostly susceptible in both sites (Table 11 and Table 12). The improved genotypes had significantly higher yield (2.0 – 2.4t/ha) and relatively lower disease severities compared to local varieties that had low yield (1.0 – 1.5t/ha) and higher disease severities in Kiboko (Table 7). These improved genotypes included Makueni Local, Kiboko Local 2, IESV 24029 SH, Marcia, KARI Mtama 1, Seredo and Serena. 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 8). Two tan-colored improved genotypes (KARI Mtama 1 and Marcia) recorded least disease severities and higher yield compared to all germplasms in both sites (Table 11 and 12).

4. DISCUSSION

Three fungal diseases; leaf blight, anthracnose and rust showed higher disease severity and incidences. This is in agreement with findings of a study by Koima et al. [11] which also identified 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. 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 the suscetability of the genotypes under the study [11].

Higher fungal disease severity attained at KALRO Kiboko compared to KALRO Ithookwe maybe due to initial adequate pathogen inoculum and warmer temperatures accompanied with suplimentary irrigation which provided favourable conditions for disease development. This finding conforms with Thakur et al. (45) who listed weather variables and inoculumn density among factors that contribute to variation in disease severities. Moroever, this findings also corroborates with Tesso et al. [34] who suggested that high leaf blight and anthracnose severities manifests under elevated humidity that alternates with dry weather. 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 leaf spot, ladder leaf spot and oval leaf spot can be attributed to lower of initial inoculum build up [35], which with time,

Table 9 Pearson correlation coefficients (r) between fungal disease severity, incidence, growth and yield parameters at KALRO, Kiboko

	FDS	FDI	DF	PH	NL	LA	DM	GY	GW	PL	PW
FDS	1	0.951***	-0.794***	0.457	-0.692**	-0.560*	-0.392	-0.277	-0.405	-0.097	0.314
FDI	0.951***	1	-0.638*	0.446	-0.589*	-0.477	-0.241	-0.151	-0.332	-0.144	0.280
DF	-0.794***	-0.638*	1	-0.338	0.822***	0.800***	0.586*	0.617*	0.694**	0.100	-0.004
PH	0.457	0.446	-0.338	1	-0.237	-0.014	0.517*	0.012	-0.104	0.117	0.502
NL	-0.692**	-0.589*	0.822***	-0.237	1	0.731**	0.502	0.547*	0.660*	0.137	0.124
LA	-0.560*	-0.477	0.800***	-0.014	0.731**	1	0.683**	0.866***	0.914***	0.501	0.443
DM	-0.392	-0.241	0.586*	0.517*	0.502	0.683**	1	0.559*	0.493	0.201	0.296
GY	-0.277	-0.151	0.617*	0.012	0.547*	0.866***	0.559*	1	0.957***	0.657*	0.561*
GW	-0.405	-0.332	0.694**	-0.104	0.660*	0.914***	0.493	0.957***	1	0.639*	0.568*
PL	-0.097	-0.144	0.100	0.117	0.137	0.501	0.201	0.657*	0.639*	1	0.632*
PW	0.314	0.280	-0.004	0.502	0.124	0.443	0.296	0.561*	0.568*	0.632*	1

****Correlation is significant at P ≤ 0.001 level; **Correlation is significant at P ≤ 0.01 level; *Correlation is significant at P ≤ 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.*

Table 10. Pearson correlation coefficients (r) between fungal disease severity, incidence, growth and yield parameters at KALRO, Ithookwe

	FDS	FDI	DF	PH	NL	LA	DM	GY	GW	PL	PW
FDS	1	0.992***	-0.669*	0.410	-0.857***	-0.493	-0.282	-0.255	-0.164	-0.207	0.564*
FDI	0.992***	1	-0.656*	0.445	-0.837***	-0.441	-0.227	-0.214	-0.137	-0.207	0.600*
DF	-0.669**	-0.656*	1	-0.319	0.750**	0.766***	0.536*	0.713**	0.629*	0.097	-0.271
PH	0.410	0.445	-0.319	1	-0.387	0.007	0.516	0.062	0.062	-0.189	0.658*
NL	-0.857***	-0.837***	0.750**	-0.387	1	0.518*	0.342	0.303	0.203	0.045	-0.371
LA	-0.493	-0.441	0.766***	0.007	0.518*	1	0.770**	0.843***	0.787***	0.350	-0.068
DM	-0.282	-0.227	0.536*	0.516*	0.342	0.770**	1	0.638*	0.552*	-0.049	0.175
GY	-0.255	-0.214	0.713**	0.062	0.303	0.843***	0.638*	1	0.971***	0.409	0.218
GW	-0.164	-0.137	0.629*	0.062	0.203	0.787***	0.552*	0.971***	1	0.476*	0.300
PL	-0.207	-0.207	0.097	-0.189	0.045	0.350	-0.049	0.409	0.476*	1	-0.114
PW	0.564*	0.600*	-0.271	0.658*	-0.371	-0.068	0.175	0.218	0.300	-0.114	1

****Correlation is significant at P ≤ 0.001 level; **Correlation is significant at P ≤ 0.01 level; *Correlation is significant at P ≤ 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.*

Table 11. 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 12. 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.

develop appearing late in the season 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].

The significant negative correlations observed between fungal disease 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 [37,38]. These have a net negative effect on yield accumulation. The insignificant negative correlation between leaf area in KALRO, Ithookwe site, 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 to anthesis stages. This corroborates with findings of a study by Anitha et al. [39] which noted that crop losses vary with the critical stage which fungal diseases infect plants, genotype reaction to diseases and envrionmental condition at the time of infection.

Tan genotypes seemed to record lower disease severity than the pigmented and mixed genotypes. This maybe attributed to pigments called flavones [40] which include apigenin and luteolin [41]. In vitro assay by Du et al. [42] revealed the two flavones inhibitted *Colletotrichum sublineola* growth, with luteolin perfoming 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 exploited in breeding programs for enhanced sorghum production in the Arid and semi arid lands of Kenya. Local landraces namely Kateng'u, Rasta and Kaguru displayed susceptibility trait by not only registering high fungal disease severity and incidence but also lower yields than improved genotypes. These results corroborates findings by Njoroge et al. [25] who reported some local landraces being susceptible to fungal diseases than improved varieties..

The present study recorded three additional foliar fungal diseases namely; grey leaf spot, ladder leaf spot and oval leaf spot apart from those that were recorded by Koima et al. [11] when conducting a field survey in lower eastern Kenya. These diseases were also noted by Ngugi et al. (7) during a survey to assess the prevalence and severity of sorghum diseases in western Kenya. Gray 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 leaf spot symptoms included: rectangular shaped dark red lesions with lighter centers as described by Williams et al. [22] and ladder leaf spot was characterized by lesions rescembling ladder pattern, with darker margins and pale centers while oval leaf spot symptoms were small circular spots with tan centers as described by Njoroge et al. [25]. The timing of 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 maturtity resulted in low effect on final yield [43]. Although the three diseases exhibited lower diseases 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 [44].

5. CONCLUSION

In conclusion, leaf blight, anthracnose and rust showed higher severity compared to other dieases. Although fungal diseases greatly affected growth characters, yield loss was minimal due to variation in timing at which the disease infected the genotypes. Improved genotypes registered high growth and yields with lesser disease severity, hence considered potential sources of disease tolerance that could be incooperated in future crop improvement programs than local landraces that had low yield with high disease severities. The present study recommends testing of the improved genotypes in other agroecologies of arid and semi-arid lands to confirm tolerance stability before being exploited for sustainable sorghum production.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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