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Response of sorghum genotypes for turcicum leaf blight [*Exserohilum turcicum* (Pass.) Leonard and Suggs] and agronomic performances in southern Ethiopia

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Abstract

A field study consisting of fourteen sorghum genotypes was conducted to determine turcicum leaf blight (TLB) intensity, resistant reactions, and agronomic performance of sorghum genotypes at Arba Minch and Derashe, southern Ethiopia. The study was carried out during the 2018 cropping year (March to July). A significant ($P < 0.05$ to < 0.0001) variations were observed in the magnitude of TLB intensity, resistant reactions and agronomic parameters among the evaluated sorghum genotypes as well as locations. The results indicated broad ranges of difference in disease progress rate with 0.0138 (Seredo) to 0.0392 (Rara) units day^{-1} at Arba Minch and 0.0138 (Kentera) to 0.0392 (Rara) units day^{-1} at Derashe were observed on the evaluated genotypes. The results also showed wide ranges of variations in incidence (71.15–83.51%) on average for the two locations. The highest mean severity (59.80 and 83.60%) and area under the disease progress curve (AUDPC) (988.65 and 1261.38%-days) were noticed from genotype Rara at Arba Minch and Derashe, respectively. The lowest mean severity and AUDPC were noted from genotype Gambella with 7.97 and 13.64% and 132.66 and 214.84%-days at Arba Minch and Derashe, respectively. Based on TLB mean severity score, sorghum genotypes were categorized as 42 and 29% resistant, 35 and 35% moderately resistant, and 23 and 28% susceptible at Arba Minch and Derashe, respectively. In addition, significant genotypic differences were observed for crop phenology, growth, yield, and yield-related parameters. The genotypes, 76TI#23 (4444.44 kg ha^{-1}) and Melkam (4444.44 kg ha^{-1}) (at Arba Minch) and Dekeba (1333.33 kg ha^{-1}) (at Derashe) showed the highest grain yields as compared to the other genotypes in the two locations. Various association degrees were observed between disease scores and crop parameters. Overall results pointed out that genotypes such as 76TI#23, Meko-1, Seredo, and Gambella-1107 exhibited consistent resistance reaction to TLB, although they showed variable grain yield potential across the locations. The genotype 76TI#23 is suggested to the producers with appropriate field management practices for sorghum production, and Gambella-1107, Seredo, 76TI#23, and Meko-1 used as a source of parental material for TLB resistance development in a future breeding program.

Keywords: AUDPC; Grain yield; Resistance reaction; Severity; Sorghum genotype; Turcicum leaf blight

1. Introduction

Sorghum (*Sorghum bicolor* L.) is one of the major cereal crops produced in arid and semi-arid environments worldwide [1, 2 and 3]. It ranks 5th next to wheat, maize, rice, and barley [3 and 4] globally and 2nd after maize in Sub-Saharan Africa [1, 5 and 6]. In Ethiopia, sorghum production is ranked 4th and 5th cereal crop grown next to tef, maize and wheat, and maize, tef, wheat, and barley in the country and Southern Nations, Nationalities, and Peoples' region (SNNPR),

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respectively [7]. The crop is a main staple food crop in East African countries, including Ethiopia, for most food insecure people where areas are characterized by arid and semi-arid conditions [1, 5 and 8]. The crop is cultivated in a wide range of agro-ecologies conditions and farming systems, including intercropping, mixed cropping, and drought-stressed areas in Ethiopia [7, 9, 10, 11 and 12].

According to the report of USDA [3], global production of sorghum was 68.28 million tons of grain yield with a productivity of 1.60 t ha^{-1} in 2021/2022. In Ethiopia, sorghum is potentially produced in the regional state of Oromiya, Amara, SNNPR, Tigray, and Gambella [7 and 10]. Sorghum production was covered with more than 1.68 million ha of land and production of more than 4.52 million tons of grains with a productivity of 2.69 t ha^{-1} during the 2020/2021 cropping season in the country [7]. Likewise, the crop covered more than 62.92 thousand ha of land and contributed to more than 1.62 million tons of grains with a productivity of 2.57 t ha^{-1} in SNNPR. In the study areas (Arba Minch and Derashe), sorghum production mean coverage was 4460.03 ha of land and production of more than 112,300 tons of grains with a productivity of 2.52 t ha^{-1} in the 2020/2021 cropping season [7].

The crop is appreciated for its essential nutrients supplies in the day-to-day human diet, source of raw material for industries, and beef production because they encompass a key livestock feed in sorghum producing countries of the world, including Ethiopia [10 and 13]. Despite being an important food, feed (forage crop), and source of raw material for industries, sorghum production and productivity is encumbered by abiotic, biotic, socioeconomic, and those related to crop management [11, 14, 15 and 16]. The authors reported that diseases caused by fungus are regarded as one of the foremost limiting biotic factors in sorghum-producing countries of the world, including Ethiopia, and cause significant yield losses. Due to this, sorghum mean productivity in the country is lower (2.69 t ha^{-1}) [7] than the crop potential (> 3.0 t ha^{-1}) [10], even if it is greater than the world's productivity (1.60 t ha^{-1}) [3]. Similarly, sorghum mean productivity in SNNPR (2.57 t ha^{-1}) in general and in the study areas (2.52 t ha^{-1}) in particular is low as compared to the national mean grain yield (2.69 t ha^{-1}) [7].

Among fungal diseases, turcicum leaf blight (TLB) incited by *Exserohilum turcicum* (Synonyms: *Helminthosprium turcicum (Pass.)* is one of the major economically important fungal diseases next to anthracnose disease in sorghum producing countries of the world, including Ethiopia [10, 17, 18, 19 and 20]. The disease is widely distributed and problematic in both extensive and subsistence sorghum-producing communities in the producing countries of the world. In Ethiopia as well as the study areas, sorghum is dominantly produced under mono-cropping systems year after year [9, 10, 11 and 19]. *Exserohilum turcicum* is able to overwinter season to season as sclerotia or mycelia or chlamydospores on infected sorghum or maize debris/residues or in the soil [21, 22, 23 and 24]. The disease epidemic development is favored by high precipitation and relative humidity, mild temperatures (20-28 °C), and the existence of huge amounts of inocula [23, 25 and 26]. However, severe epidemic development can arise, even under sub-optimal conditions, where greatly pathogenic TLB strains infect vulnerable host genotypes [22 and 23]. In this situation, the disease can cause significant yield losses in sorghum production [17 and 18]. In addition, loss of yield due to TLB of sorghum may be noteworthy depending on the severity and host susceptibility together with the time of disease onset. Yield loss due to TLB of sorghum was not estimated in the study areas as well as the country (Ethiopia). However, yield losses of 50 to 70% have been reported somewhere else on highly susceptible sorghum genotypes for TLB [28 and 29]. To this, effective TLB management alternatives should be focused on consideration of the pathosystem elements.

Efforts have been brought in characterizing TLB epidemic development as a way to make available for required information in designing and developing better management strategies for the disease as resumed by [17 and 18]. A number of TLB management approaches have been reported, including the use of high-quality seeds or disease-free seeds, removal of infected debris/residues, cultivation of resistant genotypes, crop rotations, and fungicide applications as seed treatments and foliar sprays [30, 31 and 32]. Among management options, the most beneficial way for the management of TLB is the development and use of resistant sorghum genotypes with help of good agricultural practices [18, 29, 33 and 34]. Therefore, the development and deployment of resistant genotypes are the most cost-effective means to manage TLB when it is combined with appropriate agronomic practices to provide efficient protection against the disease. However, little efforts have been made regarding TLB disease management using resistance genotypes for maize crops. However, no resistance breeding research in sorghum genotypes improvement has been done so far for TLB under Ethiopian conditions [10].

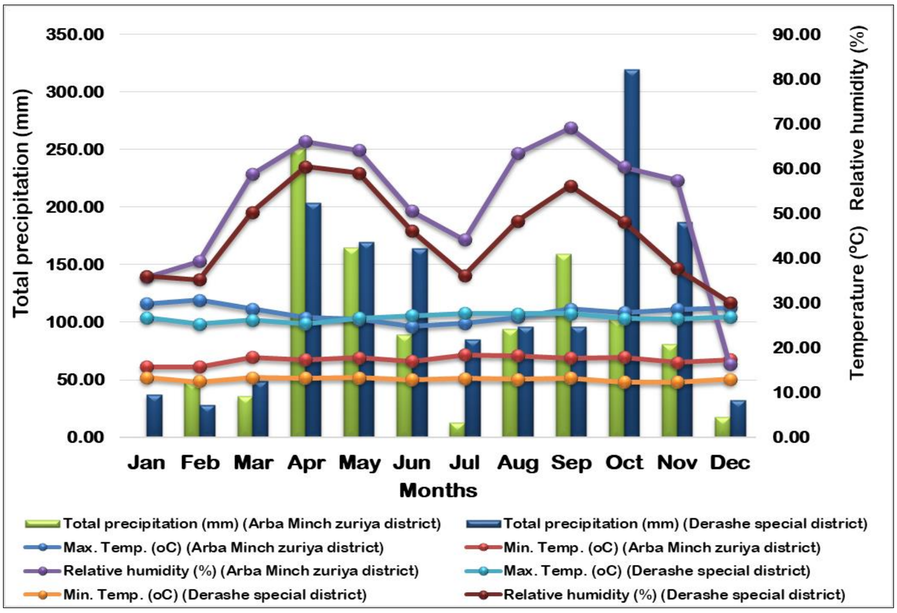
In this regard, developing resistance genotype takes a long time, and it cannot be an immediate solution for the farming communities under Ethiopian conditions. Hence, testing of existing released sorghum varieties and landraces is an urgent need for TLB response along with agronomic performance for the study areas and the country as well. Empirical research under such conditions has not been conducted in the study areas. Evaluating sorghum genotypes for TLB resistance and agronomic performance in areas where the environmental condition is conducive for disease development and yield response of genotypes can be a useful approach to determine the success of the selection process.

The objectives of the study were to determine TLB intensity and resistant reactions of sorghum genotypes under field conditions and to evaluate sorghum genotypes for agronomic performance under field conditions in southern Ethiopia.

2. Material and methods

2.1. Experimental sites

Evaluation of sorghum genotypes for TLB and agronomic performance were conducted in Arba Minch and Derashe special districts, southern Ethiopia, during the 2018 cropping year (March to July). Arba Minch experimental site is located at geographic coordinates of 06° 06’ 841’’ N-latitude and 037° 35’ 122’’ E-longitude and an altitude of 1216 meters above sea levels (m.a.s.l). Derashe special district is located at the geographic coordinates of 05° 31’ 31’’ N-latitude and 037° 25’ 46’’ E-longitude and at an altitude of 1253 m.a.s.l. A bimodal precipitation pattern is a characteristic feature of the two locations where the short rainy season (autumn, locally called *Belg*) occurs March and April months and the main rainy season (summer, locally called *Meher*) falls in August and November. Arba Minch areas and Derashe special districts receive mean annual precipitation of 750 and 810 mm and temperatures of 27.50 and 25.70 °C for the last 10 years, in the given order. Weather data for the study period (during 2018) were confronted in Figure 1. Furthermore, the soil physicochemical properties were characterized as moderately alkaline (pH = 6.8) and low organic contents (1.05%) with black sandy-loam at Arba Minch experimental site. Whereas, moderately alkaline (pH = 6.6) and high organic content (8.82%) with black clay-loam are the distinctive features of Derashe special district experimental site [35].



Source: National Meteorology Agency, Hawassa branch (2018).

Figure 1 Total precipitation (mm), mean monthly minimum and maximum temperatures (°C), and relative humidity (%) for Arba Minch zuriya and Derashe special in southern Ethiopia during the 2018 cropping year

2.2. Experimental materials, design, and procedures

The study was consisting of 14 sorghum genotypes to evaluate the genotypes' response to TLB reaction and agronomic performances under field conditions. Sorghum genotypes are composed of nine released varieties obtained from Melkassa Agricultural Research Center and five landraces collected from farmers' saved seeds. These genotypes were not tested for their TLB reaction together with agronomic performances in the study areas and Ethiopian as well. The genotype Rara (landrace) was cast off as a susceptible check. Details of the genotypes agro-ecological requirements, agronomic characters, and other related information are depicted in Table 1.

The trial was arranged in a randomized complete block design with three replications for both locations. A unit plot size of 3.0 m width x 2.4 m length with a gross plot size of 114.0 m width x 53.1 m length was utilized at each location. A space of 1.5 m and 2.5 m was applied between plots and adjacent replications, respectively. Each plot consisted of five rows with a spacing of 0.75 m between rows. Sowing was achieved with the recommended seed rates (10 kg ha^{-1}) on 18 March 2018 at both locations. The seeds were drilled along the rows and thinned with 0.15 m to keep the space between plants on 21-days after seedling emergence. A Nitrogen, Phosphorus, and Sulfur based blended fertilizer was applied based on recommended rates of 100 kg ha^{-1} as a basal application at the time of sowing in each location. While Nitrogen fertilizer at the rates of 100 kg ha^{-1} (Arba Minch) and 50 kg ha^{-1} (at Derashe) was added with the split application (1/3rd of it as a basal application at the time of sowing and 2/3rd of it as a top dressing on 35-days after planting). In addition, all other necessary agronomic practices were performed uniformly for all treatments as recommended by MoARR and EATA [10].

Table 1 Agro-ecological conditions*, agronomic characters, and releasing center of evaluated sorghum genotypes in Arba Minch and Derashe, southern Ethiopia, during the 2018 cropping season

Sorghum genotypes	Accession code/Pedigree	Year of Release	Releasing Center	Flowering dates	Maturity date	Plant height (cm)	Productivity kg ha^{-1}	
							Under research	Under farmer
Arghiti	WSV387/P9403	2016	MARC/EIAR	79	125	190-200	3780	-
Dekeba	ICSR24004	2012	MARC/EIAR	75	119	136	3700-4500	2600-3700
Melkam	WSV387	2009	MARC/EIAR	76-82	118	151	3700-5800	3500-4300
Teshale	3443-2-OP	2002	MARC/EIAR	65-76	100-120	196	2600-5200	-
Gobiye	P9410	2000	MARC/EIAR	83	100-120	110-140	1900-2700	-
Meko 1	M36121	1997	MARC/EIAR	61-92	120-130	132	2200-3300	1700
Seredo	Seredo	1986	MARC/EIAR	60-70	90-120	150-200	3000-5000	-
76TI#23	954062x73pp9	1979	MARC/EIAR	60-70	90-120	120-140	2500-4500	-
Gambella	Gambella1107	1976	MARC/EIAR	80-90	150-200	150-200	3000-5000	-
Landraces	-	-	-	-	-	-	-	-

MARC = Melkassa Agricultural Research Center; EIAR = Ethiopian Institute of Agricultural Research. *The suitable agro-ecology for the sorghum genotypes are dry lowland with an altitude of < 1600 m.a.s.l., the range of temperature of 27 to 32 ^{0}C, and annual total rainfall of 25 to 1170 mm; Source: Data were sourced and organized from MoARR and EATA [10] and MoANR [36].

2.3. Disease assessment

Disease monitoring was executed every week during the growing period at both locations. During the study, TLB symptom was first observed on released varieties of Arghiti and Dekeba and landrace (Rara) on 54 (at Arba Minch) and 60 (at Derashe) days after sowing time. Thus, the TLB score was carried out in every 10-days interval and ceased with the majority of sorghum genotypes were showed senescence, physiologically matured [37 and 38]. Totally five assessments per location were carried out during the epidemic period. Turcicum leaf blight incidence and severity were noticed. Afterward, the area under disease progress curve (AUDPC) and disease progress rate (DPR) was reckoned to estimate sorghum genotypes resistance reaction to TLB. For TLB incidence, the whole plants in the middle rows within the plot were considered, and it was determined as the average percentage of the number of diseased plants due to TLB per total number of sorghum plants following the formula mentioned by Wheeler [39] and Campbell and Madden [40].

$$\text{Disease incidence (\%)}=\frac{\text{Number of plants showing disease symptoms}}{\text{Total number of plants sampled and rated}}\text{X }100$$

Fifteen sorghum plants per plot were randomly selected from the middle rows and starred for severity score. Turcicum leaf blight severity was rated using a scale of 0, 3, 5, 10, 25, 50, and >75% leaf area affected/damaged as described by [37]. Average values of TLB severity obtained from 15 assessed plants of each plot were used for data analysis. The AUDPC, which means the TLB development and workup of disease on the entire leaves or part of the leaves during epidemic periods, was figured out from TLB severity data noted at various days after sowing for each plot using the formula suggested by Campbell and Madden [40].

$$\text{AUDPC}=\sum_{i=1}^{n-1} 0.5\ (X_i+X_{i+1})\ (t_{i-1} - t_i)$$

Where *n* is the total number of disease assessments, t_i is the time of the *i^th^* assessment in days from the first assessment date and x_i is the disease severity of FHB at the i^{th} assessment. AUDPC value was expressed in %-days because severity (x) is expressed in percent and time (t) in days.

Turcicum leaf blight type of resistance reactions was determined from the averages of severity scores for each sorghum genotype per plot during the growing period at both locations. In this regard, TLB severity scores up to 50% of sorghum plants began to fill the seeds in the panicle were used for determining sorghum genotypes into reaction types as suggested by Adipala et al. [37] and Ramathani [38]. According to the authors, the reaction type of sorghum genotypes was grouped as 0-10% resistance, 10.1–25% moderately resistance, 25.1-50% susceptible, and > 50.1% highly susceptible.

2.4. Phenology, growth, yield, and yield characters assessment

The phenology characters including 50% days to emergence (50% DoE), 50% days to heading (50% DoH), and 90% days to physiological maturity (90% DoPM) were considered in the present study. Growth characters such as plant height (PH), stand count (SC), number of productive tillers (NPT), panicle length (PL) were noted during the study. Whereas, thousand seed weight (TSW) and grain yield (GY) were considered for yield and yield-related characters. During the study, 50% DoE, 50% DoH, and 90% DoPM were noted by enumeration of the number of days after sowing when 50% of the sorghum plants per plot were reached to emergence and heading. Whereas, 90% DoPM was noted by counting the number of days taken for 90% of sorghum plants per plot physiologically matured.

The number of productive tillers and SC were determined as counting of productive tillers and all plants that existed within the three middle rows of each plot, respectively. Plant height (cm) and PL (cm) have assessed at 90% DoPM of the crop from the middle rows of randomly selected five plants and panicles, respectively. Average values for each of them were used for data analysis. To determine GY, the three middle rows were considered and it was registered on a plot basis. And then, the harvested GY was transformed into t ha-1. The harvested GY was adjusted to 12.50% based on the storable moisture content of the grain following the procedure mentioned by Taran et al. [41]. Thousand seed weight was appraised from sample grains randomly taken from the total storable grains of each plot.

2.5. Data analysis

The collected data were subjected to analysis of variance (ANOVA) using the SAS GLM procedure [42]. Mean separation between and among sorghum genotypes was achieved using Fisher's protected least significant difference (LSD) at 5% probability levels [43]. Separate data analyses were performed for each location. Spearman correlation studies were executed to observe the associations among and between disease scores and agronomic characters. Epidemiological models such as Logistic [ln (y/1-y)] [44] and Gompertz [-ln (-ln(y))] [45] were compared to decide which model is suitable to determine the DPR of TLB from the linear regression line for individual treatment considered [44]. Coefficient of determination (R^2) and residuals standard error values were used to determine the fitness of the two models [40]. Accordingly, the Logistic epidemiological model exhibited a greater coefficient of determination and lesser residuals standard error values than the Gompertz epidemiological model for both locations. As a result, TLB rates of progression were assessed using a Logistic epidemiological model for both locations.

3. Results and discussion

3.1. Analysis of variance

Mean square results for combined ANOVA of all study parameters exhibited various levels of distinctions between the locations, sorghum genotypes, and their interactions between and among the locations and sorghum genotypes (Table 2). Combined ANOVA revealed that significant variations of $P < 0.05$ (AUDPC and DPR) to $P < 0.001$ (disease verity, DS_f) between mean squares of disease scores were detected for the two locations. Very highly significant ($P < 0.0001$) differences between the mean square of agronomic characters across the locations. Likewise, the mean square of all study parameters, except DPR, showed very highly significant ($P < 0.0001$) differences between and among the evaluated sorghum genotypes. The mean square value of DPR significantly varied at $P < 0.05$ for the tested sorghum genotypes. No significant ($P > 0.05$) variations were perceived for the mean squares of all study parameters (except for 90% DoPM, SC, NPP, and GY) between and among the interaction effects of locations and sorghum genotypes (Table 2). Overall, combined ANOVA of the tested sorghum genotypes exhibited the highest mean squares for most of the study parameters across the locations. The higher or lower mean square values indicated that the tested sorghum genotypes for TLB intensity and agronomic characters responded similarly or differently to the two locations, respectively (Table 2).

Table 2 Results of mean square values obtained from combined ANOVA for disease assessment, phenology, growth, and yield-related parameters of sorghum genotypes evaluated in Arba Minch and Derashe districts, southern Ethiopia, during the 2018 *Belg* cropping season

Source of variations	**DF**	**DI_f (%)**	**DS_f (%)**	**AUDPC (%-days)**	**DPR (units day^{-1})**	**MTLBS (%)**	**50% DoE**	**50% DoH**
Replication (within the location)	4	9.24^{ns}	83.67^{ns}	20528.11^{ns}	2.31 x 10^{-5ns}	32.27^{ns}	0.15^{ns}	13.30^{ns}
Location	1	3211.03**	2209.73***	376557.51*	9.93 x 10^{-4}*	660.53**	86.01****	2283.86****
Genotype	13	3627.77****	1876.72****	528027.19****	2.68 x 10^{-4}*	839.48****	23.04****	740.30****
Genotype * Location	13	351.58^{ns}	42.92^{ns}	4877.76^{ns}	1.59 x 10^{-5ns}	10.53^{ns}	0.01^{ns}	40.52^{ns}
Pooled Error	52	392.84	116.65	21469.09	1.01 x 10^{-4}	21.58	2.41	9.23
Pooled F-value		2.99***	4.39****	2.46***	0.70*	3.14***	2.95**	23.92****
Standard error		3.3257	2.1492	37.0320	1.24 x 10^{-3}	1.4461	0.2594	1.3563
Grand mean		77.33	29.82	467.23	2.77 x 10^{-2}	18.94	12.51	73.24
CV (%)		25.63	36.22	31.36	36.23	24.53	12.42	4.15

Table 2. *Continued…*

Source of variations	**DF**	**90% DoPM**	**PH (cm)**	**SC**	**NPP**	**PL (cm)**	**TSW (g)**	**GY (kg ha^{-1})**
Replication (within the location)	4	7.11^{ns}	100.55^{ns}	603.80ns	69.88^{ns}	3.83^{ns}	25.88^{ns}	1825176.54^{ns}
Location	1	1701.00****	2899.66****	18452.68****	7581.01****	46.50****	1262.17****	52508700.53****
Genotype	13	1301.06****	5157.10****	2458.20****	2010.21****	31.00****	358.58****	7125890.85****
Genotype x Location	13	3889*	6.92^{ns}	401.93****	561.55****	0.05ns	95.85ns	3789888.88****
Pooled Error	52	17.04	79.18	71.74	50.10	2.09	18.69	61803.88
Pooled F-value		19.93****	15.85****	14.98****	29.74	4.20****	14.20****	6.83****
Standard error		1.6853	3.2484	3.0086	2.5015	0.2817	1.0925	180.9160
Grand mean		114.71	160.47	86.42	60.93	18.85	21.76	1492.22
CV (%)		3.60	5.55	9.80	11.46	7.66	19.44	16.66

DF = Degree of freedom; DI_i = Disease incidence at final assessment date; DS_f = Disease severity at final assessment date; AUDPC = Area under disease progress curve assessed in %-day; DPR = Disease progress rate in unit day^{-1}; MTLBS = Mean turcicum leaf blight severity for reaction type determinations (%); 50% DoE = Days to 50% emergence; 50% DoH = Days to 50% heading; 90% DoPM = Days to 90% physiologically matured; PH = Plant height measured in cm; PL = Panicle length measured in cm; SC = Stand count assessed in counting of all stand plants within the central rows; NPP = Number of productive plants per plot; TSW = Thousand seed weight measured in gram; GY = Grain yield in kg ha^{-1}; Genotype * Location = Interaction effect of sorghum genotypes and location; *SE* = Standard error; * = Significance difference at $P < 0.05$; ** = Significance difference at $P < 0.01$; *** = Significance difference at $P < 0.001$; **** = Significance difference at $P < 0.0001$; ns = Not significant ($P > 0.05$); and CV = Coefficients of variation (%)

3.2. Turcicum leaf blight epidemics

3.2.1. Rates of disease progression

Mean TLB rates of progression was significantly ($P < 0.05$) varied between and among the tested sorghum genotypes at both study locations in 2018 (Table 2 and 3). At Arba Minch, the highest mean (0.0392 units day^{-1}) DPR was estimated from Rara, followed by Dekeba (0.0301 units day^{-1}, R^2 = 91.50%), Arghiti (0.0280 units day^{-1}, R^2 = 90.40%) and Melkam (0.0272 units day^{-1}, R^2 = 90.3%). Conversely, the lowest mean (0.0138 units day-1, R^2 = 91.80%) DPR was computed from Seredo, subsequent by Gambella-1107 (0.0172 units day^{-1}, R^2 = 90.60%) and Meko-1 (0.0185 units day^{-1}, R^2 = 89.50%) at Arba Minch (Table 3). Released varieties such as Seredo, Gambella-1107 and Meko-1 reduced DPR by 64.80, 56.12, and 52.81% compared with Rara at Arba Minch, respectively. Nearly analogous trends were observed at Derashe. Comparatively, the genotype Kentera (0.0187 units day^{-1}, R^2 = 86.70%), Seredo (0.0205 units day^{-1}, R^2 = 86.80%), Gambella-1107 (0.007 units day^{-1}, R^2 = 90.90%) and Melkam (0.0209 units day^{-1}, R^2 = 87.40%) showed the lowest mean DPR at Derashe. Similar to Arba Minch, Rara (0.0489 units day^{-1}, R^2 = 84.20%), Dekeba (0.0452 units day^{-1}, R^2 = 92.40%) and Arghiti (0.0421 units day^{-1}, R^2 = 92.30%) exhibited the highest mean DPR at Derashe (Table 3). At Derashe, the genotype Kentera lowered DPR by 61.76% as compared to Rara genotype.

Table 3 Mean rates of disease progression and parameter estimates of turcium leaf blight of sorghum genotypes appraised under field conditions in Arba Minch and Derashe, southern Ethiopia, during the 2018 *Belg* cropping season

Sorghum genotypes	Disease progress rate (*r-units day^{-1}*) in Arba Minch [a]				Disease progress rate (*r-units day^{-1}*) in Derashe [a]			
	Disease progress rate	SE of rate	SE of intercept	R^2 (%)	Disease progress rate	SE of rate	SE of intercept	R^2 (%)
76TI#23	0.0256	0.0027	0.0197	91.60	0.0324	0.0024	0.1598	88.60
Melkam	0.0272	0.0043	0.0322	90.30	0.0209	0.0038	0.0998	87.40
Teshale	0.0223	0.0044	0.0343	91.50	0.0293	0.0054	0.2399	92.70
Meko 1	0.0185	0.0048	0.0268	89.50	0.0301	0.0027	0.0304	93.20
Arghiti	0.0280	0.0051	0.0112	90.40	0.0391	0.0091	0.0141	92.30
Gobiye	0.0222	0.0038	0.0106	94.80	0.0332	0.0042	0.1529	89.80
Dekeba	0.0301	0.0129	0.0358	91.50	0.0452	0.0072	0.1106	92.40
Seredo	0.0138	0.0005	0.0221	91.80	0.0205	0.0067	0.1887	86.80
Gambella-1107	0.0172	0.0024	0.0252	90.60	0.0207	0.0047	0.0304	90.90
Rara	0.0392	0.0072	0.0565	91.60	0.0489	0.0050	0.1888	84.20
Kentera	0.0207	0.0033	0.0181	92.20	0.0187	0.0015	0.1086	86.70
Shulayita	0.0263	0.0107	0.0261	91.10	0.0317	0.0049	0.3856	85.10
Harbora	0.0255	0.0033	0.0170	93.40	0.0361	0.0130	0.2215	86.00
Gechante	0.0227	0.0067	0.0025	91.30	0.0229	0.0029	0.2658	88.70

[a] Results of rates of disease progress obtained from regression line of disease severity against the time of disease assessment; SE = Standard error of rate and parameter estimates (intercept); and R^2 = Coefficient of determination for the Logistic epidemiological model.

Overall, significant variations between and among the evaluated sorghum genotypes across the locations. This variability among the evaluated sorghum genotypes might be elucidated by the genetic inheritance and response of the genotypes and other factors like adaptability and conduciveness of the surrounding environments, favorable weather conditions (Figure 1). Previous researchers suggested that the highest TLB development resulted from the genetic status of the host, aggressiveness of TLB, favorable environmental conditions, and combinations of these components in the pathosystems [17, 18, 46 and 47]. Comparatively, the mean DPR was higher at Derashe than Arba Minch. In this regard, the weather conditions during the epidemic period (Figure 1) along with other factors like environmental adaptability played significant roles in the epidemic development of TLB of sorghum. Ngugi et al. [23], Campbell and

Madden [40], Ngugi et al. [46], and Madden et al. [47] amount of precipitation, relative humidity, temperatures, inocula load, and other factors favor infection and rapid epidemic development of diseases in a given environment.

3.2.2. Incidence, severity, and area under disease progress curve (AUDPC)

Turcicum leaf blight typical symptom was first observed on the same genotypes such as Arghiti and Dekeba and Rara (check) at 54 and 60-days after sowing at Arba Minch and Derashe, respectively. The symptoms look-alike large and elongated lesions, spindle-shaped spots, and grey to tan lesions (Figure 2). Characteristic TLB symptoms observed on the genotypes were similar to the reports of [37, 38 and 48]. Highly significant ($P < 0.001$) variation was detected in the magnitude TLB incidence, severity, and AUDPC type between and among the tested sorghum genotypes as well as the two locations in 2018 (Table 2 and 4).

Figure 2 Characteristic symptoms of sorghum turcicum leaf blight (*Exserohilum turcicum*) were observed at experimental sites Arba Minch zuriya and Derashe special districts, southern Ethiopia, during the 2018 cropping year

The highest mean (100%) TLB incidence was noticed from Dekeba, Kentera, and Rara genotypes, which was statistically similar with Arghiti (83.58%), Gechante (89.94%), and Harbora (96.13%) at Arba Minch. Conversely, the lowest mean TLB incidence was noted from Seredo (24.31%) and Gambella-1107 (30.84%) at Arba Minch (Table 4). Whereas, at Derashe, the highest mean (100%) TLB incidence was recorded from Dekeba, Gobye, and Arghiti. However, these genotypes were statistically on a party with the rest of the tested genotypes, except Seredo, Gambella-1107, and Shulayita, at Derashe. The lowest mean TLB incidence was perceived from Seredo (42.11%), Gambella-1107 (36.74%), and Shulayita (36.48%) at Derashe (Table 4). Consistently, the lowest mean TLB incidence was recorded from the genotype Seredo and Gambella-1107, while the highest mean TLB incidence was observed on Dekeba, Rara, and Kentera in the two locations. In this regard, Seredo and Gambella-1107 genotypes minimized TLB incidence by 75.69 and 69.16% and 57.89 and 63.26% as compared to Rara (check) genotype at Arba Minch zuriya and Derashe, respectively. The overall TLB incidence was comparatively higher at Arba Minch zuriya than Derashe in 2018.

Based on ANOVA results, the highest mean TLB severity (59.80 and 83.60%) and AUDPC (988.65 and 1261.38%-days) were noted from Rara at Arba Minch and Derashe, respectively. The lowest mean TLB severity (7.97 and 13.64%) was recorded from the genotype Gambella-1107 at Arba Minch and Derashe, respectively (Table 3). However, the lowest mean severity values were statistically similar with Seredo (9.22 and 15.22%), 76TI#23 (11.73 and 18.72%), Meko-1 (13.26 and 20.78%), and Gobiye (14.08 and 22.90%) in the two locations in that order during the growing period. Similarly, the lowest mean AUDPC of TLB (132.66 and 214.84%-days) was recorded from the genotype Gambella-1107 at Arba Minch and Derashe, respectively (Table 3). Nevertheless, the lowest mean AUDPC of TLB values were not statistically different from Seredo (132.66 and 214.84%-days), Meko-1 (109.71 and 189.14%-days), and 76TI#23 (140.63 and 230.38%-days) in that sequence during the epidemic periods (Table 4). Gambella-1107, Seredo, 76TI#23, and Gobiye reduced mean TLB severity by 86.67 and 83.68%, 84.58 and 81.67%, 80.38 and 77.61% and 77.83 and

75.14% compared with Rara at Arba Minch and Derashe, respectively. Likewise, at Arba Minch and Derashe, the mean AUDPC value was minimized by 88.90 and 85.01% (Meko-1), 86.58 and 80.42% (Gambella-1107), 85.78 and 81.74% (76TI#23), and 84.20 and 82.97% (Seredo) as compared to Rara, respectively.

Consistent results for a number of genotypes were observed for TLB severity and AUDPC in the two locations. Overall differences between and among the evaluated sorghum genotypes might be due to the genetic makeup of the host, environmental adaptability, and other factors. Several research reports indicated that sorghum genotypes exhibited varying responses to various diseases. Mayada [18], Ramathani et al. [38], Durga [49], and Beshir et al. [50] reported that evaluation of sorghum genotypes to TLB exhibited significantly various responses concerning incidence, severity, and AUDPC. Sorghum genotypes with different backgrounds were tested for TLB at different areas of India (1999) and Uganda (in 2010 and 2015), and entries (accessions/lines) showed significant variability regarding TLB, incidence, severity, and AUDPC across the locations [17, 18, 50 and 51].

In this study, relatively higher TLB pressure was observed at Darashe than at Arba Minch in the growing period (Figure 2; Table 4). In this regard, sorghum sowing at Arba Minch decreased TLB incidence, severity, and AUDPC by 14.80, 29.35, and 25.07% compared with at Derashe, respectively. Weather variables, genetic response, and other factors might be played significant roles in the epidemic development of TLB during the growing period. Thus, the highest TLB pressure could be due to the prevailing relatively mild temperature, relative humidity, and precipitation or sub-optimal condition of these factors, which might help to cool of microclimate and lead to infection of *E. turcicum* (Figure 1; Table 4). Other studies suggested that frequent precipitation along with high relative humidity and mild temperature, even in sub-optimal conditions, favor infection and rapid development of TLB in the field [23, 27, 46 and 47]. In addition, Campbell and Madden [40] and van der Plank [44] also suggested that the degree of disease pressure is affected by environment, susceptibility availability of host tissue, pathogen aggressiveness, temperature, moisture, plant resistance levels, and other factors.

3.2.3. Reaction of sorghum genotypes turcicum leaf blight

Highly significant ($P < 0.0001$) variation for mean TLB severity (for the epidemic period, not for the last assessment dates) in levels of resistance determination was observed among the tested sorghum genotypes at both locations (Table 2 and 4). According to ANOVA, the tested sorghum genotypes exhibited a variable response to TLB in the two locations. Genotypes such as Gambella-1107, Seredo, 76TI#23, Meko-1, Gobiye, and Shulayita were showed resistance reaction for TLB at Arba Minch. At Derashe, the former four genotypes exhibited resistance reaction against TLB. Arghiti, Dekeba, and Rara were categorized under susceptible at Arba Minch. Arghiti, Dekeba, Harabora and Gechante, and Rara were susceptible and highly susceptible at Derashe, respectively. The remaining sorghum genotypes such as Melkam, Teshale, Kentera, Harbora, and Gechante, and Melkam, Teshale, Gobiye, Shulayita, and Harbora were grouped under moderately resistant at Arba Minch and Derashe, respectively. Based on TLB mean severity score, sorghum genotypes were categorized as 42 and 29% resistant, 35 and 35% moderately resistant, 23 and 28% susceptible, and 0 and 8% highly susceptible at Arba Minch and Derashe, respectively.

Variation in reaction to TLB observed among genotypes might inform the presence of variability in genetic makeup between and among the tested sorghum genotypes. This infers that sorghum genotypes might be utilized in the breeding program for genetic improvement regarding resistance sorghum genotype development against TLB. In the current study, Gambella-1107, Seredo, 76TI#23, and Meko-1 genotypes showed consistent results for TLB reaction in the two locations. These could be utilized to develop resistance genotypes against TLB in the study areas and elsewhere having similar agro-ecologies. The present findings were in correspondence with the work of [17, 18, 49 and 51], who confirmed the existence of variability in levels of resistance (resistance, moderately resistance, susceptibility, or highly susceptible) regarding sorghum genotypes against TLB both under greenhouse and field conditions.

Table 4 Sorghum genotypes responded for turcicum leaf blight incidence, severity, area under disease progress curve, and reaction category in Arba Minch and Derashe, Southern Ethiopia, during the 2018 *Belg* rainy season

Sorghum genotypes	Arba Minch					Derashe				
	DF	DI$_f$ (%)	AUDPC (%-days)	Reaction to TLB		DF	DI$_f$ (%)	AUDPC (%-days)	Reaction to TLB	
				MTLB severity (%)	Reaction type				MTLB severity (%)	Reaction type
76TI#23	53.10^{b-e}	11.73g	140.63g	6.12f	R	95.07a	18.72fg	230.38f	9.83f	R
Melkam	70.55^{a-d}	21.24e-f	352.92d-g	14.07d-f	MR	96.74a	24.88e-g	421.04d-f	16.50d-f	MR
Teshale	76.81^{a-c}	17.23e-f	315.04d-g	12.18d-f	MR	86.81a	26.14e-g	437.39d-f	17.20d-f	MR
Meko-1	57.59^{a-e}	13.26fg	109.71g	5.71f	R	95.58a	20.78fg	189.14f	9.26f	R
Arghiti	83.58^{ab}	38.94bc	683.94a-c	26.66bc	S	100.0a	47.46b-d	834.32bc	32.10bc	S
Gobiye	76.46^{a-c}	14.08fg	246.20d-g	9.61ef	R	100.0a	21.90fg	354.56ef	14.61ef	MR
Dekeba	100.0^{a}	44.38b	778.74ab	30.67ab	S	100.0a	61.13b	974.16ab	39.20b	S
Seredo	24.31^{e}	9.22fg	156.24fg	6.17f	R	42.11b	15.32g	247.03f	9.80f	R
Gambella-1107	30.84de	7.97g	132.66g	5.32f	R	36.74b	13.64g	214.84f	8.58f	R
Rara	100.0a	59.80a	988.65a	39.98a	S	100.0a	83.60a	1261.38a	52.27a	HS
Kentera	100.0a	23.64d-f	463.99c-f	17.59c-e	MR	100.0a	34.78d-f	613.38c-d	23.87c-e	MR
Shulayita	36.79c-e	17.91e-f	216.59e-g	9.76ef	R	36.48b	27.05e-g	329.13ef	14.61ef	MR
Harbora	96.13ab	36.95b-d	477.68b-e	21.04b-d	MR	93.52a	52.77bc	650.61c-e	28.87b-d	S
Gechante	89.94ab	29.28c-e	540.84b-d	20.99b-d	MR	86.15a	41.06c-e	721.22b-d	28.30b-d	S
P-value	< 0.0049	< 0.0001	< 0.0001	< 0.0001		< 0.0001	< 0.0001	< 0.0001	< 0.0001	
Grand mean	71.15	24.69	400.28	16.13		83.51	34.95	534.18	21.74	
Standard error	5.1819	2.5678	47.1070	1.8113		4.0081	3.2901	55.8090	2.1915	
LSD (0.05)	43.15	14.94	311.65	11.14		18.77	16.73	358.25	12.74	
CV (%)	36.26	26.19	32.55	21.33		13.44	28.64	33.09	35.05	

Means within each column for each parameter that are not followed by the same letter(s) are significantly different ($P \leq 0.05$), while those followed by the same letter(s) are not significantly different ($P > 0.05$). Reaction type of genotypes were grouped by standard severity scale [0- 10% (R = Resistant), 10.1-25% (MR = Moderately resistant), 25.1-50% (S = Susceptible) and > 50.1% (HS = Highly susceptible)] following Adipala et al. [37] and Ramathani [38]. DIi = Disease incidence at final assessment date; DSf = Disease severity at final assessment date; AUDPC = Area under disease progress curve assessed in %-days; MTLB = Mean turcicum leaf blight severity for reaction type determinations (%); LSD = Least significant difference at a 5% probability level; and CV = Coefficient of variation.

3.3. Phenology, growth, and yield parameters assessment

3.3.1. Phenology parameters

Phenological parameters such as 50% DoE, 50% DoH and 90% DoPM were significantly ($P < 0.0001$) varied at both locations in 2018 (Table 2 and 5). At Arba Minch, the genotype Harbora (8.66) showed the shortest mean 50% DoE, followed by 76TI#23, Dekeba and Kentera with the same (9.33) for mean 50% DoE. Gambella-1107 (14.33) and Gobiye (14.33) took the longest mean 50% DoE, which was statistically on a party with genotype Arghiti (13.33) at Arba Minch (Table 5). At Derashe, Harbora (10.67) took the shortest mean 50% DoE, which was statistically similar with 76TI#23 (11.33), Dekeba (11.33), Kentera (11.33), and Seredo (12.37). The longest mean 50% DoE was recorded from genotype Gambella-1107 (16.33) and Gobiye (16.67) at Derashe. However, it was statistically similar with Arghiti and Gechante genotypes with the same (15.33) mean 50% DoE at Derashe. Harbora (56.66 and 67.00) and 76TI#23 (58.00 and 68.67) genotypes took the shortest mean 50% DoH at Arba Minch and Derashe, respectively. Conversely, Shulayita (100.33) and Gambella-1107 (99.67) took the longest mean 50% DoH at Arba Minch and Derashe, respectively. Mean duration for 90% DoPM was highest on Shulayita (141.66) and Gambella-1107 (141.00), whereas the lowest mean 90% DoPM was recorded on the genotype Seredo (89.33 and 98.33) at Arba Minch and Derashe, respectively. In the present study, significant variability was observed between and among the tested sorghum genotypes for 50% DoE, 50% DoH, and 90% DoPM across the locations. These variability among the genotypes might be due to genetic inheritance, environmental adaptability, and other factors. A number of previous studies also confirmed that sorghum genotypes exhibited significant variability associated with phenology parameters under different environmental conditions [8, 52, 53, 54, 55 and 56].

Table 5 Mean phenology results of sorghum genotypes for their response against turcicum leaf blight under field conditions in Arba Minch and Derashe districts, southern Ethiopia, during the 2018 *Belg* rainy season

Sorghum genotypes	**Arba Minch**			**Derashe**		
	50% DoE	50% DoH	90% DoPM	50% DoE	50% DoH	90% DoPM
76TI#23	9.33de	58.00gh	105.66e	11.33de	68.67fg	116.00d
Melkam	11.33b-d	65.33de	109.66e	13.67bc	77.00d	120.33d
Teshale	12.66a-c	60.33f-h	124.33c	14.67a-c	71.33e-g	136.33ab
Meko-1	10.66c-e	61.33e-g	117.66d	12.67c-e	72.33ef	129.00c
Arghiti	13.33ab	80.33c	121.66cd	15.33ab	94.67b	133.33bc
Gobiye	14.66a	62.66ef	99.00f	16.67a	73.67de	108.67e
Dekeba	9.33de	61.00fg	117.66d	11.33de	72.00ef	129.00c
Seredo	10.66c-d	69.33d	89.33h	12.67de	81.67c	98.33g
Gambella-1107	14.33a	84.66b	130.00b	16.33a	99.67a	141.00a
Rara	11.33b-d	61.33e-g	97.33fg	13.33b-d	72.33ef	107.00ef
Kentera	9.33de	61.66e-g	98.66fg	11.33de	73.00d-f	108.00ef
Shulayita	12.00bc	100.33a	141.66a	14.67bc	93.33b	133.33bc
Harbora	8.66e	56.66h	97.00fg	10.67e	67.00g	106.33ef
Gechante	13.33ab	69.33d	130.00b	15.33ab	81.67c	102.33fg
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Grand mean	11.50	68.02	110.21	13.52	78.45	119.21
Standard error	0.3323	1.8841	2.3828	0.3343	1.6036	2.1988
LSD (0.05)	2.01	4.16	5.33	2.06	4.65	6.30
CV (%)	10.48	3.66	2.90	9.13	3.55	3.16

Mean values in the same column with various letters represent significant variation at 5% probability level. 50% DoE = Days to 50% emergence; 50% DoH = Days to 50% heading; 90% DoPM = Days to 90% physiologically matured; LSD = Least significant difference at a 5% probability level; and CV = Coefficient of variation.

3.3.2. Growth, yield, and yield-related parameters

Analysis of variance revealed significant ($P < 0.0001$) variations for SC, NPP, PH, PL, TSW, and GY at both locations (Table 2, 6, and 7). Of the tested sorghum genotypes, the highest mean SC (141.33 and 109) and NPP (107.66 and 84) were recorded from the genotype Seredo and Rara at Arba Minch and Derashe, respectively. However, there were statistically equal to mean SC (129 and 108) and NPP (98.18 and 83) recorded from Seredo and Rara genotypes at Arba Minch and Derashe, respectively. Comparatively, the genotype Kentera exhibited the lowest mean SC (63.33 and 49) and NPP (37.33 and 22.33) at Arba Minch and Derashe, respectively (Table 6 and 7). At Arba Minch and Derashe, the tallest (200.38 and 215.61 cm) and lowest (118.01 and 126.98 cm) mean PH were detected from Arghiti and Gobiye genotypes, respectively. The shortest PH values recorded from genotype Gobiye were not statistically varied from 76TI#23 genotype at both locations. Among the evaluated genotypes, Arghiti (24.25 and 22.50 cm) and Melkam (23.30 and 21.53 cm) exhibited maximum average PL, while the minimum average PL was noticed from Rara (15.62 and 14.43 cm) and Kentera (16.64 and 15.37 cm) genotypes at Arba Minch and Derashe, respectively (Table 6 and 7). These results indicated that the tested genotypes were not similar in their performance for growth traits, and this might be due to environmental or genetic variation.

Table 6 Mean results of growth, and yield-related traits of sorghum genotypes tested under the pressure of turcicum leaf blight an open environments in Arba Minch, Southern Ethiopia, during the 2018 *Belg* rainy season

Sorghum genotypes	**SC**	**NPT**	**PH (cm)**	**PL (cm)**	**TSW (g)**	**GY (kg ha^{-1})**
76TI#23	115.b-d	83.66bc	127.44fg	19.35b-d	33.33a	4444.44a
Melkam	120.a-c	91.00bc	140.78de	23.30a	35.56a	4444.44a
Teshale	90.00ef	60.00ef	183.37b	20.71b	32.23a	4296.30a
Meko-1	113.33b-d	78.66cd	148.99d	20.25bc	31.10a	4222.22a
Arghiti	118.67bc	89.66bc	200.38a	24.25a	33.30a	4000.00ab
Gobiye	106.c-e	82.33cd	118.01g	20.71b	31.86a	4000.00ab
Dekeba	112.33b-d	82.00cd	135.61ef	19.22b-d	29.53a	2370.37bc
Seredo	141.33a	107.66a	165.97c	18.02c-e	27.20ab	2000.00cd
Gambella 1107	96.33de	68.00de	165.97c	20.71b	16.16c	280.00e
Rara	129.00ab	98.18ab	135.46ef	15.62f	16.20c	272.22e
Kentera	63.33g	37.33g	129.92e-g	16.64ef	19.36bc	530.00de
Shulayita	65.67g	47.33fg	211.24a	19.34b-d	16.06c	280.00e
Harbora	71.00fg	48.00f	163.27c	17.30d-f	16.10c	280.00e
Gechante	73.67fg	56.00ef	138.08d-f	19.18b-d	19.60bc	540.00de
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Grand mean	101.24	73.56	154.60	19.60	25.56	2282.86
Standard error	4.0917	3.3788	4.3614	0.3984	1.3433	308.8100
LSD (0.05)	21.40	15.24	12.82	2.35	8.69	1679.00
CV (%)	12.64	12.39	4.96	7.19	20.36	23.97

Mean values under same column with various letters represent significant variation at 5% probability level. SC = Stand count assessed in counting of all stand plants within the central rows; NPP = Number of productive plants per plot; PH (cm) = Plant height measured in cm; PL (cm) = Panicle length measured in cm; TSW (g) = Thousand seed weight measured in gram; GY (kg ha-1) = Grain yield in kg ha-1; LSD = least significant difference at a 5% probability level; and CV = coefficient of variation.

Heavier TSW was determined from released varieties (except Seredo at Derashe and Gambella-1107), while the lighter TSW was obtained from all landraces at both locations (Table 6 and 7). The variance of the analysis revealed that 76TI#23 (4444.44 kg ha^{-1}) and Melkam (4444.44 kg ha^{-1}) best-performed genotypes for GY, followed by Teshale (4296.30 kg ha^{-1}), Meko-1 (4222.22 kg ha^{-1}), Argiti (4000 kg ha^{-1}), and Gobiye (4000 kg ha^{-1}) at Arba Minch location. In contrast, the highest mean GY penalty was observed on Rara (272.22 kg ha^{-1}), followed by Gambella-1107 and all remaining landraces at Arba Minch (Table 6). At Derashe, the heaviest (1333.33 kg ha^{-1}) mean GY was gathered from the Dekeba genotype; however, it was not statistically different from the mean GY recorded on 76TI#23 (1111.11 kg ha^{-1}) and Seredo (1111.11 kg ha^{-1}) genotypes. Contrariwise, the lightest mean (212.22 kg ha^{-1}) GY was registered from genotype Rara, which was not significantly different from mean GY recorded on Gambella-1107 and the rest of landraces, except Kentera and Gechante, at Derashe (Table 7). Genotype Rara showed significant GY reduction among the evaluated genotypes (Table 6 and 7) and was severely infected by TLB during the growing period (Tables 4). The sorghum genotype 76TI#23 sustained consistent GY potential (Tables 6 and 7) and TLB severity, AUDPC, and resistant reaction (Tables 4) at both locations. In this regard, about 93.88 and 80.90% GY advantage was noticed from 76TI#23 in comparison with the genotype Rara at Arba Minch zuriya and Derashe, respectively. This suggested that the use of improved sorghum genotypes had brought a considerable yield advantage over local cultivars (landraces).

In the current study, significant variability with best and worst-performing genotypes for growth parameters was observed at both locations. Seyoum et al. [8], Getachew et al. [12], and Lema [54] suggested that growth parameters can contribute comparative yield boost in sorghum genotypes. From the given results, most of the traits showed a wide range of variability at Direshe (Table 7). Overall, ANOVA pointed out a significant genotypic disparity for SC, NPP, PH, PL, TSW, and GY at both experimental locations. Therefore, the presence of such a range of variations of the traits indicated the presence of a large amount of genetic variation among the genotypes, which is the source of variable in genetic material. Several earlier research reports affirmed the existence of significant genotypic differences among sorghum genotypes for growth, yield, and yield-related traits at various environmental conditions, greenhouse, and different agro-ecologies, for whys and wherefores in Ethiopia [8, 12, 54, 55, 56 and 57].

Table 7 Mean results of growth, and yield-related traits of sorghum genotypes tested under the pressure of turcicum leaf blight an open environments in Derashe, Southern Ethiopia, during the 2018 *Belg* rainy season

Sorghum genotypes	**SC**	**NPT**	**PH (cm)**	**PL (cm)**	**TSW (g)**	**GY (kg ha^{-1})**
76TI#23	69.00b-d	44.33bc	137.13fg	17.88b-d	25.89ab	1111.11ab
Melkam	68.00b-d	48.00b	151.48de	21.53a	28.13a	814.81a-d
Teshale	82.67b	53.33b	197.31a	19.06b	24.79ab	784.84a-d
Meko 1	72.00b-d	43.66bc	160.32d	18.71bc	23.66ab	888.89a-d
Arghiti	66.00b-e	46.00bc	215.61a	22.50a	25.86ab	962.96a-c
Gobiye	64.33c-f	44.33bc	126.98g	18.91b	24.43ab	942.96a-c
Dekeba	68.67b-d	45.33bc	145.92ef	17.77b-d	21.46ab	1333.33a
Seredo	109.00a	84.00a	178.59c	16.65c-e	19.99b	1111.11ab
Gambella 1107	78.33bc	53.33b	184.43c	19.14b	8.73c	220.33cd
Rara	108.00a	83.00a	145.75ef	14.43f	9.43c	212.22d
Kentera	49.00f	22.33d	139.79e-g	15.37ef	11.93c	470.00b-d
Shulayita	50.67ef	32.33cd	227.30a	17.88b-d	8.63c	220.00cd
Harbora	56.33d-f	33.00cd	175.68c	15.98d-f	8.66c	220.22cd
Gechante	60.33d-f	41.00bc	148.58d-f	17.72b-d	12.16c	480.00b-d
P-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.05
Grand mean	71.60	48.12	116.35	18.11	18.12	701.58
Standard error	3.0316	2.8143	4.6930	0.3682	1.2813	81.639
LSD (0.05)	16.98	14.86	13.79	2.17	7.24	745.80
CV (%)	14.18	18.46	4.96	7.18	23.88	13.56

Mean values under same column with various letters represent significant variation at 5% probability level. SC = Stand count assessed in counting of all stand plants within the central rows; NPP = Number of productive plants per plot; PH (cm) = Plant height measured in cm; PL (cm) = Panicle length measured in cm; TSW (g) = Thousand seed weight measured in gram; GY (kg ha^{-1}) = Grain yield in kg ha^{-1}; LSD = least significant difference at a 5% probability level; and CV = coefficient of variation.

Comparatively, growth, yield, and yield-related parameters were lower at Derashe than Arba Minch in 2018. This might be the adaptability of the genotypes in that environment (including weather conditions), the host susceptible to TLB, and other factors. At Arba Minch, the higher growth, yield, and yield-related performance could be elucidated by its lower TSP pressure (Table 4) and conducive weather condition (Figure 1) for the growth and development of the crop. Also, lower GY found from Derashe might not be linked only to TLB epidemic development but also adaptability of the evaluated sorghum genotypes to the arena might be other factors that could lead to trimmed GY of the evaluated genotypes. Research work has been done by Getachew et al. [12], Blum et al. [52], Teressa et al. [56], Can and Yoshida [58], Kassahun et al. [59], and Markos et al. [60] showed that growth, yield, and yield-related characters performance found significant variations between and among the evaluated sorghum genotypes for the studied parameters. As suggested by the authors, a significant difference is ascribed to the presence of variability among genetic makeup genotypes, environmental adaptability of genotypes, weather conditions, biotic constraints, and other factors. Yield reductions found in the present study could not be solely indorsed to TLB pressure among biotic constraints as some impairments were noted due to anthracnose, bird attacks and other pests. The consequences of the listed factors have not been fully discussed by the present study; however, their associated effect cannot be undervalued in the GY reductions.

3.4. Association of disease epidemics and grain yield attributes

Variable levels of significant ($P > 0.05$ to < 0.0001) associations were examined between TLB incidence, severity, AUDPC, DPR, 50% DoE, 50% DoH and 90% DoPM, SC, NPP, PH, PL, TSW and GY at both locations (Table 8). At both locations, significant positive correlations were observed between TLB incidences, severity, AUDPC, and DPR although non-significant results were observed between incidences, severity, AUDPC with DPR at both locations (Table 8). The positive correlation result between these parameters indicated that epidemiological factors were found interconnected to each other during the epidemics periods. Mayada [18] and Campbell and Madden [40] reported that epidemiological parameters had interrelated to one another during the epidemic periods. The association analysis also showed that positive correlations were perceived between crop phenology, growth, yield, and yield-related parameters even if non-significant outcomes were observed between some parameters in the two locations. In this regard, non-significant was observed between PH and 50% DoE, SC and 90% DoPM, NPP with PH and PL, and TSW with 50% DoE and 50% DoH at Arba Minch, while 50% DoH and TSW, and PH with NPP, TSW, and GY at Derashe (Table 8). The correlation study revealed that crop phenology, growth, yield, and yield-related parameters had a positive association among and between themselves. Seyoum et al. (2019), Getachew et al. (2021), Kassahun et al. (2015), and Teressa et al. (2021) reported the existence of significant and positive relationships between and among crop parameters in their studies.

On the other hand, a significant and negative association was detected between epidemiological, crop phenology, growth, yield, and yield-related parameters (Table 8). Disease incidence had significant ($P < 0.01$) and negative associations with 90% DoPM and GY at Arba Minch, and 50% DoH, 90% DoPM, PH, and GY at Derashe. Days to 50% physiological maturity (at Arba Minch), PH, PL (at Arba Minch), NPP (at Derashe), TSW, and GY were significantly ($P < 0.05$ to 0.0001) and negatively associated with TLB severity at the final date of assessment at both locations. Epidemiological parameters such as AUDPC exhibited significantly ($P < 0.05$ to 0.0001) and negatively correlated with DoPM, PH, PL, SC, and NPP (except at Arba Minch), TSW, and GY at both locations. Stand count and NPP had a significant and positive association with AUDPC at Arba Minch. This might be associated with the high plant population within the plot, which makes cooling the microclimate around the plant and led to high infection due to cool environs for the disease. Even though negative associations between DPR and all crop parameters were observed, most of these parameters exhibited a non-significant relationship with DPR (except SC and GY at Arba Minch) at both locations (Table 8). Negative relationships between epidemiological and crop parameters would signpost the magnitude to which TLB might be upset associated GY of sorghum genotypes. Furthermore, the association analysis exhibited epidemiological parameters had a significant adverse consequence on crop parameters during the growing period. Overall, the association study revealed a positive and significant relationship between epidemiological parameters and a negative and significant correlation between crop characters. The results obtained in this study are in correspondence with the report of Casela and Frederiksen [21], Agrios [24], Campbell and Madden [40], and Guant [61] that disease and crop parameters have negative associations and are responsible for various reasons and could result in recognizable yield reductions.

Table 8 Spearman correlation coefficients values between and among turcium leaf blight intensity, phenology, growth, and yield-related parameters of sorghum genotypes in Arba Minch (upper diagonal) and Derashe (lower diagonal), southern Ethiopia, during the 2018 *Belg* cropping season

Parameters	**DS_f**	**DI_f**	**AUDPC**	**DPR**	**50% DoE**	**50% DoH**	**90% DoPM**	**PH**	**PL**	**SC**	**NPP**	**TSW**	**GY**
DS_f	1	0.72****	0.96****	0.36ns	-0.01ns	-0.16ns	-0.85***	-0.61**	-0.73***	0.08ns	0.98***	-0.58*	-0.87****
DI_f	0.36*	1	0.74****	0.43ns	-0.09ns	-0.30ns	-0.55**	-0.29ns	-0.05ns	0.12ns	0.44ns	-0.38ns	-0.57*
AUDPC	0.95****	0.38*	1	0.61**	-0..07ns	-0.16ns	-0.91****	-0.57*	-0.59**	0.43*	0.88***	-0.50*	-0.86***
DPR	0.56ns	0.28ns	0.77**	1	-0.09ns	-0.06ns	-0.67*	-0.32ns	-0.11ns	0.36*	0.31ns	-0.49ns	-0.60*
50% DoE	-0.21ns	-0.14ns	-0.13ns	-0.07ns	1	0.57****	0.66**	0.19ns	0.49***	0.90**	0.75**	0.06ns	0.68*
50% DoH	-0.18ns	-0.47***	-0.08ns	-0.23ns	0.60****	1	0.48*	0.46**	0.34*	0.42*	0.41*	0.14ns	0.98****
90% DoPM	-0.19ns	-0.46*	-0.78**	-0.55**	0.59*	0.37*	1	0.49***	0.50***	0.11ns	0.36*	0.42*	0.51*
PH	-0.59***	-0.47***	-0.55**	-0.11ns	0.29ns	0.45***	0.45***	1	0.34*	0.52*	0.42ns	0.34ns	0.35*
PL	-0.35*	-0.12ns	-0.42*	-0.10ns	0.51***	0.38*	0.54****	0.26*	1	0.15ns	0.23ns	0.45**	0.49***
SC	-0.16ns	-0.12ns	-0.36*	-0.21ns	0.58*	0.68*	0.78**	0.44*	0.09ns	1	0.97****	0.48**	0.41**
NPP	-0.82**	-0.41*	-0.62**	-0.25ns	0.62**	0.38*	0.53*	0.18ns	0.04ns	0.91****	1	0.46***	0.41***
TSW	-0.43*	-0.42ns	-0.44*	-0.27ns	0.08ns	0.12ns	0.46*	0.35ns	0.43***	0.64***	0.37*	1	0.78****
GY	-0.81**	-0.38*	-0.79*	-0.44ns	0.88***	0.76**	0.79**	0.29ns	0.42**	0.49*	0.34*	0.57***	1

DI_f = Disease incidence at final assessment date; DS_f = Disease severity at final assessment date; AUDPC = Area under disease progress curve assessed in %-day; DPR = Disease progress rate in unit day^{-1}; 50% DoE = Days to 50% emergence; 50% DoH = Days to 50% heading; 90% DoE = Days to 90% maturity; PH = Plant height measured in cm; PL = Panicle length measured in cm; SC = Stand count assessed in counting of all stand plants within the central rows; NPP = Number of productive plants per plot; TSW = Thousand seed weight measured in gram; GY = Grain yield in kg ha^{-1}; * = Significance difference at $P < 0.05$; ** = Significance difference at $P < 0.01$; *** = Significance difference at $P < 0.001$; **** = Significance difference at $P < 0.0001$; and ns = Not significant ($P > 0.05$).

4. Conclusion

In the present study, considerable differences were observed for TLB incidence, severity, AUDPC, DPR, crop phenology, growth, yield, and yield-related parameters among the tested sorghum genotypes at Arba Minch and Derashe. This could indicate the presence of resistance genes may use as a source of material against TLB and agronomic characters. In this regard, the evaluated sorghum genotypes were categorized as 42 and 29% resistant, 35 and 35% moderately resistant, 23 and 28% susceptible, and 0 and 8% highly susceptible at Arba Minch and Derashe, respectively. Among tested sorghum genotypes, Gambella-1107, Seredo, 76TI#23, and Meko-1 were showed resistance reaction for TLB at both Arba Minch and Derashe. Genotype 76TI#23 exhibited the highest yield potential and TLB resistance and provide 4444.44 kg ha^{-1} at Arba Minch and 1111.11 kg ha^{-1} at Derashe, at this Dekeba showed the highest yield potential even if it was susceptible to TLB. Association between epidemiological parameters and agronomic traits point out an inverse association between them and a positive correlation between each of which is under consideration. The results obtained from this study displayed the presence of potential for TLB resistance together with essential agronomic characters to develop promising sorghum genotypes through genetic improvement. Based on pooled results, 76TI#23 genotype with appropriate agronomic practices is suggested for minimizing TLB pressure and yield losses in the study areas as well as elsewhere having similar agro-ecological conditions. Moreover, Gambella-1107, Seredo, 76TI#23, and Meko-1 genotype utilize as a source of parental materials for resistance against TLB. However, further study should be considered to assess sorghum genotypes for more locations and seasons to substantiate their consistency against TLB resistance reaction and agronomic parameters.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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