Experimental Results (2022), 3, e14, 1–15
doi:10.1017/exp.2022.12

LIFE SCIENCE AND BIOMEDICINE
NOVEL-RESULT

Growth and yield performance of sorghum (*Sorghum bicolor* L.) crop under anthracnose stress in dryland crop-livestock farming system

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(Received 13 June 2022; Revised 15 August 2022; Accepted 15 August 2022)

Abstract

Dual-purpose sorghum response to anthracnose disease, growth, and yield was undertaken in Derashe and Arba Minch trial sites during March–June 2018 and 2019. Five sorghum varieties and Rara (local check) were arranged in a randomized complete block design with four replications. Variety Chelenko exhibited the tallest main crop plant height (430 cm) while Dishkara was the tallest (196.65 cm) at ratoon crop harvesting. Rara had a higher tiller number (main = 6.73, ratoon = 9.73) among the varieties. Dishkara and Chelenko varieties produced 50 and 10% more dry biomass yield (DBY) than the overall mean DBY, while Konoda produced 40% less. Although the anthracnose infestation was highest on the varieties Konoda (percentage severity index [PSI] = 20.37%) and NTJ_2 (PSI = 32.19%), they produced significantly ($p < .001$) higher grain yield (3.89 t/ha) than others. Under anthracnose pressure, Chelenko and Dishkara varieties are suggested for dry matter yield while NTJ_2 for grain yield production in the study area and similar agroecology.

Key words: correlation; disease incidence; dry matter yield; grain yield; sorghum; variety

Introduction

Sorghum is the third, next to teff and maize, most important crop in Ethiopia which covers 14.13% (1,829,662.39 ha) from total area of grains 81.31% (10,358,890.13 ha) and total production 15.7% (50,243,680.72 kg) (CSA, 2019). It is nutritionally staple grain crop for more than 500 million people, mostly in poor nations, providing carbohydrates, vitamins, protein, and minerals (Mayer et al., 2008). It is also a source of fodder for mostly smallholder farming community (Hariprasanna & Rakshit, 2016).

The productivity of the crop (1.54 t/ha) in the study area is below the national (2.53 t/ha) (CSA, 2019), regional (2.23 t/ha), and global (5.88 t/ha) reports. Anthracnose is among the most important sorghum (Tesema et al., 2022) diseases in the experimental area contributing to the low productivity of the crop (Lemu et al., 2021). Evaluation of 146 sorghum genotypes resulted in significant variation of plant height, 100-grain weight, and grain yield among genotypes (Reddy et al., 2007). Due to disease, anthracnose, and other related factors, there has been reported growth and yield variation among 225 sorghum genotypes in Ethiopia (Lemu et al., 2021). It has been trying to develop adapted sorghum variety to the dry land farming system, and this experiment was designed to extract data on agro-morphological traits of main and ratoon sorghum crops under the anthracnose pressure.

Materials and method

Description of study locations

Arba Minch site is located at 06°06′ N latitude and 37°35′ E longitude, while the Derashe site is located at 05°30′ N latitude and 37°12′ E longitude. Arba Minch and Derashe sites are laid at an altitude of 1,206 and 1,260 m above sea levels, respectively. The two experimental sites have a bimodal rainfall pattern. Monthly distributions of total rainfall and average maximum and minimum temperatures of Arba Minch and Derashe during 2018 and 2019 are presented in Figures 1a, b and 2a, b, respectively (NMA, 2021). A composite soil (0–30 cm) sample collected from Chanomile was characterized as sandy loam with pH 6.2, available phosphorus 14.47, total nitrogen 0.29, organic carbon 1.19, and organic matter 1.63, while the soil of Derashe is characterized as a sandy loam with pH 6.15, available phosphorus 14.5, total nitrogen 0.31, organic carbon 1.22, and organic matter 1.72 (Laboratory report).

Experimental planting materials

Six dual-purpose sorghum varieties: Chelenko, A-2267_2, and NTJ_2, Dishkara, Konoda, and Rara (local check) were collected from Melkasa Agricultural Research Center (MARC) and farmers of Derashe special district. Chelenko was released in 2005 from MARC A-2267_2 and NTJ_2 also collected from MARC and all three materials adapted to <1,600 m above sea level (Ministry of Agriculture (MOA), 2016). Dishkara and Konoda are the varieties of farmer and adapted to the altitude of 1,200–1,700 m above sea level. Rara (local check) was collected from the farmer store and adapted to the altitude of 1,200–1,700 m above sea level.

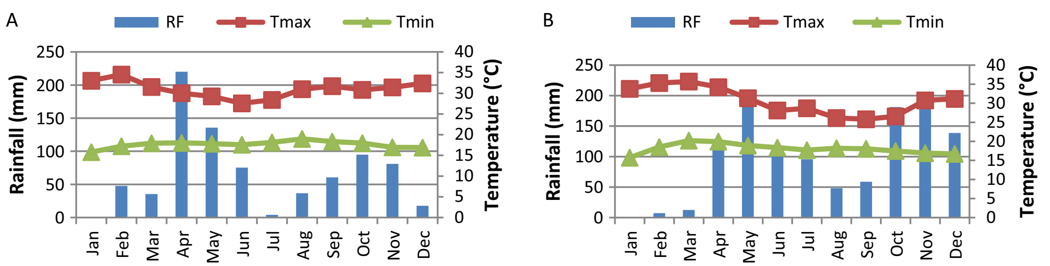

Figure 1. Total monthly rainfall and average minimum and maximum temperature during 2018 (a) and 2019 (b) in Arba Minch.

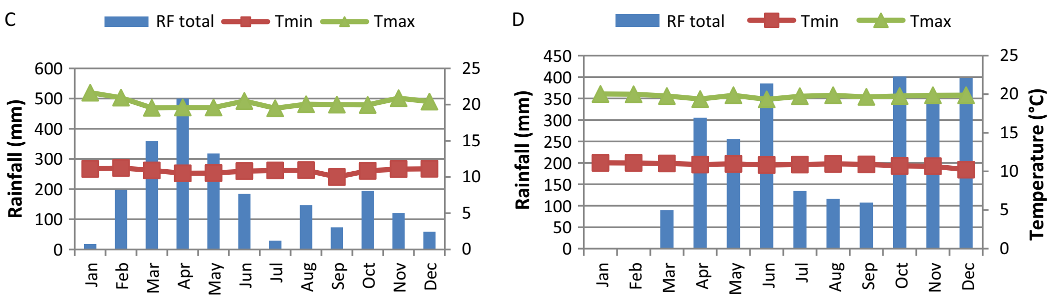

Figure 2. Total monthly rainfall and average minimum and maximum temperature during 2018 (a) and 2019 (b) in Derashe.

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Experimental design and procedures

The experiment was laid out in a randomized complete block design with four replications. The gross and net sizes of experimental plots were 2.4 m × 3 m (7.2 m^2) and 1.2 m × 3 m (3.6 m^2), respectively. Spacing between experimental plots and replications was 1 and 1.5 m, respectively. After plowing the selected experimental plots with oxen, the plots were prepared and leveled manually with the help of necessary farm tools. The six sorghum varieties were allocated to the experimental plots randomly using a randomized complete block design method. Seed sowing was carried out from late March to early April 2018 and 2019. Seeds were sown in a row at inter- and intra-spacing of 60 by 25 cm, respectively. To avoid the risk of failing seedling emergence, two seeds were planted per hill and the weak seedlings were thinned out after 40 days of planting to maintain only a single plant per hill. Experimental plots were fertilized with NPS (19% N, 37% P_2O_5, 7% S) at the rate of 100 kg/ha during planting time, and with urea (46% N) at the rate of 100 kg/ha in two splits as the first half top-dressed on the 45th days of planting and the remaining half applied after initial harvest for ratoon initiation. Experimental plots were kept weed-free until harvesting with frequent hand weeding. No irrigation was supplemented for this trial. No any chemical was applied throughout the experimental period. Harvesting was made by hand cutting the head to easy collection of the grain.

Data collection

Growth and yield parameters

Data collection for forage and grain yields from the main crop was performed by cutting plants at ground level in the net plot area after physiological maturity. The second harvesting from the ratoon crop was done after 105 days of the first harvest of the main crop. Both fresh and dry biomass yields (DBYs), as well as grain yield obtained from the net plot area (3.6 m^2), were converted into a hectare basis. Apart from the collection of forage and grain yields, data on vegetative grow parameters were collected timely. Plant height (PH cm) was measured at a date of 50% flowering from ground level to the tip of the plant with the linear meter. The number of leaves per plant was counted, as well as length and width of leaves in the middle of the plants were measured with linear meters at the forage harvesting time of both ratoon and main crops. The number of tillers per plant was counted also from both main and ratoon crops just before harvesting. To compute leaf to stem ratio, the cut pieces were collected from 12 plants to make a composite sample of 500 g for leaf and stem independently. Green forage yield per net plot area was measured using a spring balance and expressed as fresh biomass yield per hectare (FBY t/ha). The sample was taken to the laboratory and subjected to oven drying at 65°C for 24 hr to get constant dry weight. After cooling, the samples were weighed with sensitive balance and expressed as DBY (t/ha). DBYs were estimated by multiplying FBYs with the dry matter percentage of respective samples. Dry matter of the samples of both main crop and ratoon crops harvests was determined using the following formula:

$DM\% = \frac{ODW\,(gm)}{FW\,(gm)} * 100$, where DM% is the dry matter percent, ODW is the oven-dry weight, and FW is the fresh weight of a sample (500 g).

$DBY\,t/ha = FBY\,t/ha * DM\%$, where DBY is the dry biomass yield, FBY is the fresh biomass yield, and DM% is the dry matter content in percent.

Disease monitoring

Anthracnose incidence and severity assessment were started on 40 and 45 days after planting at Derashe and Arba Minch sites in 2018 and 2019 cropping seasons, respectively, when the first symptom of anthracnose appeared on plant leaves within the plot. Twelve randomly selected and tagged sorghum plants from the central rows of each plot were used for disease assessment, and a total of six assessments were made per location per season. Incidence (%) was determined by the rating of diseased plants per total number of plants assessed within the plot. Anthracnose severity was visually assessed from 15 pre-tagged plants per plot following the scale devised by Thakur et al. (2007), where 1 = no visible symptoms

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or presence of chlorotic flecks, 2 = 1–10% leaf area covered with hypersensitive lesions without acervuli, 3 = 11–25% leaf area covered with hypersensitive and restricted lesions with acervuli in the center, 4 = 26–50% leaf area covered with coalescing necrotic lesions with acervuli, and 5 = ≥50% leaf area covered with coalescing necrotic lesions with acervuli. Severity scores were transformed into percentage severity index (PSI) for analysis using the formula stated below (Wheeler, 1969).

$$\mathrm{PSI} = \frac{\text{Sum of numerical ratings}}{\text{No. of plants scored} \times \text{maximum score on scale}} \times 100.$$

Area under disease progress curve (AUDPC) (the development of disease on a whole plant or part of the plant during the epidemic periods) was estimated from PSI (anthracnose) and mean (turcicum leaf blight) values assessed at different days after planting for each sorghum varieties within the plot using the formula mentioned by Campbell and Madden (1990) as below.

$$\mathrm{AUDPC} = \sum_{\mathrm{i}=1}^{\mathrm{n}-1} 0.5\,(X_{\mathrm{i}} + X_{\mathrm{i}+1})\,(t_{\mathrm{i}-1} - t_{\mathrm{i}}),$$

where n is the total number of disease assessments, t_{i} is the time of the ith assessment in days from the first assessment date, and x_{i} is the PSI of disease at the ith assessment. AUDPC was articulated in %-days since severity (X) is expressed in percent and time (t) in days.

Data analysis

Genstat software 18th edition (Payne et al., 2015) package was used to compute analysis of variance (ANOVA) of all parameters considered in the study. Whenever the ANOVA results were significant, means of the parameters were separated using least significance difference at 5% level of probability.

Results and discussion

Growth performance

Plant height

Plant height of sorghum varieties for main plant was significantly ($p < .001$) varied for the interaction of variety × location × year (Table 1). The tallest plant height of 430 cm followed by 410.8 cm was recorded at Chano Mille subresearch substation during 2018 and 2019 planting season for the variety Chelenko while the lowest plant height of 174.3 cm was at Derashe in 2019 for the variety NTJ_2. Ratoon crops plant height was also significantly ($p < .001$) varied among sorghum varieties. Dishkara (227.7 cm) recorded the highest plant height at Arba Minch followed by A-2267_2 (203.9 cm) among other varieties while the lowest plant height was at Derashe for Rara (68.0 cm).

The plant height of the ratoon crops is presented in Table 2. Dishkara variety recorded significantly ($p < .05$) the tallest ratoon crop (196.65 cm) among the sorghum varieties while the variety Rara recorded the shortest (110.45 cm). Moreover, the average plant height of main crops (264.3 cm) was greater than the ratoon crops (159.61 cm).

The plant height recorded in the present study is generally greater than the plant heights of sorghum varieties reported by other researchers where the plant heights of the main and ratoon crops were 147 and 129 cm, respectively (Hassan et al., 2015). Plant height contributes and plays a great role in aboveground biomass accumulation (Halim & Idris, 2013). This may be due to the taller a plant, the higher the amount of light energy absorbed and the higher the rate of photosynthesis and consequently the amount of assimilate produced by the leaves (Ngo, 2017). Vinutha et al (2017) reported the higher average plant height of ratoon crops (259 cm) than main crops (228 cm) for 36 sorghum lines, which may be due to the variation among genotypes and other management options.

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Table 1. Growth performance of main crop as influenced by sorghum varieties, experimental years, and locations

Year	Location	Variety	PH_cm	LNPP	LW_cm	LL_cm	TNPP
2018	Chano	A_2267_2	335.3^{bcd}	12.87^{b-e}	8.68^{b-f}	89.1^{abc}	1.93^{cde}
		Chelenko	430.0^{a}	14.8^{ab}	9.66^{abc}	86.1^{a-d}	1.87^{cde}
		Dishkara	335.7^{bcd}	11.47^{d-h}	9.93^{abc}	98.2^{a}	2.2^{cde}
		Konada	398.6^{gh}	14.6^{abc}	9.95^{abc}	86.3^{a-d}	1.73^{de}
		NTJ_2	254.7^{ef}	10^{f-j}	11.03^{a}	93.0^{ab}	1.53^{e}
		Rara	255.4^{ef}	11.8^{c-g}	9.78^{abc}	85.47^{a-d}	2.47^{cde}
	Derashe	A_2267_2	259.3^{ef}	7.53^{jkl}	6.70^{fg}	62.93^{fgh}	2.33^{cde}
		Chelenko	386.1^{ab}	12.6^{b-f}	8.60^{b-f}	86.93^{a-d}	2.00^{cde}
		Dishkara	307.9^{cde}	9.27^{g-k}	8.02^{b-g}	88.47^{abc}	2.87^{cde}
		Konada	369.0^{abc}	10.27^{e-j}	9.13^{a-e}	87.67^{a-d}	2.27^{cde}
		NTJ_2	177.3^{gh}	5.73^{l}	6.20^{g}	63.2^{fgh}	2.33^{cde}
		Rara	227.9^{fgh}	8.53^{i-l}	8.45^{b-g}	84.13^{a-e}	2.6^{cde}
2019	Chano	A_2267_2	304.7^{de}	12.13^{b-f}	6.90^{efg}	71.53^{d-g}	2.47^{cde}
		Chelenko	410.8^{a}	17.13^{a}	9.40^{a-d}	84.47^{a-e}	2.80^{cde}
		NTJ_2	265.7^{ef}	10.13^{e-j}	9.13^{a-e}	79.4^{b-f}	1.53^{e}
		Rara	259.7^{ef}	13.47^{bcd}	10.07^{ab}	92.67^{ab}	2.67^{cde}
	Derashe	A_2267_2	239.2^{fg}	8.87^{h-k}	7.30^{d-g}	68.93^{efg}	2.47^{cde}
		Chelenko	306.2^{cde}	13.13^{bcd}	8.39^{b-g}	83.13^{a-e}	2.93^{cd}
		Dishkara	283^{def}	11.27^{d-i}	7.88^{b-g}	74.27^{c-g}	4.87^{b}
		Konada	182.6^{gh}	8.37^{jkl}	6.43^{fg}	50.87^{h}	2.08^{cde}
		NTJ_2	174.3^{h}	6.47^{kl}	6.93^{efg}	62.8^{gh}	3.20^{c}
		Rara	180^{gh}	8.07^{jkl}	7.71^{c-g}	74.13^{c-g}	6.73^{a}
Mean			264.3	9.94	7.76	73.1	2.79
p-value			<0.001	<0.001	<0.001	<0.001	0.019
$LSD_{0.05}$			62.84	2.84	2.27	16.5	1.36
CV%			14.5	17.4	17.8	13.7	30.1

Abbreviations: CV%, coefficient of variation; LL, leaf length; LNPP, leaf number per plant; $LSD_{0.05}$, least significant difference at $p < .05$; LW, leaf width; PH, plant height; TNPP, tiller number per plant.
The superscript footnote descriptions indicate mean values sharing common letters in the column are not significantly different.

Table 2. Dry biomass yield and growth performance of ratoon crop as influenced by sorghum varieties and experimental locations

Location	Variety	DMY t/ha	PH cm	TNPP	LL cm	LW cm	LNPP
Chano	A-2267_2	25.77^{b}	203.9^{ab}	2.8^{cd}	69.60	6.78^{bc}	9.8^{b}
	Chelenko	4.44^{de}	186.8^{bc}	2.27^{d}	71.70	7.35^{b}	9.93^{b}
	Dishkara	41.67^{a}	227.7^{a}	3.53^{cd}	80.70	7.52^{ab}	9.2^{b}
	Konada	3.56^{de}	156.1^{cd}	2.07^{d}	72.20	7.52^{ab}	9.0^{b}
	NTJ_2	15.06^{c}	155.5^{cd}	3.2^{cd}	61.90	6.97^{bc}	6.73^{c}
	Rara	16.47^{c}	152.9^{cd}	3.27^{cd}	69.30	8.19^{a}	9.13^{b}
Derashe	A-2267_2	3.53^{de}	145.5^{de}	5.2^{bc}	63.00	6.0^{d}	9.33^{b}
	Chelenko	5.39^{d}	186.6^{bc}	3.2^{cd}	61.50	6.3^{cd}	11.53^{a}
	Dishkara	5.7^{d}	165.6^{cd}	6.53^{b}	65.10	7.33^{b}	9.73^{b}
	Konada	3.56^{de}	156.1^{cd}	2.07^{d}	72.20	7.52^{ab}	9.00^{b}
	NTJ_2	2.34^{e}	110.6^{e}	11.33^{a}	45.10	4.95^{e}	6.27^{c}
	Rara	2.5^{e}	68.0^{f}	9.73^{a}	58.90	5.97^{d}	6.60^{c}
LSD0.05		2.42	37.82	2.596	NS	0.76	1.54
Mean	A-2267_2	14.65^{b}	174.7^{ab}	4.00^{cd}	66.3^{ab}	6.39^{cd}	9.57^{b}
	Chelenko	4.92^{d}	186.7^{a}	2.74^{de}	66.6^{ab}	6.83^{bc}	10.73^{a}
	Dishkara	23.68^{a}	196.65^{a}	5.03^{bc}	72.9^{a}	7.43^{a}	9.47^{b}
	Konada	3.56^{d}	156.1^{bc}	2.07^{e}	72.2^{a}	7.52^{a}	9.0^{b}
	NTJ_2	8.7^{c}	133.05^{cd}	7.27^{a}	53.5^{c}	5.96^{d}	6.5^{d}
	Rara	9.48^{c}	110.45^{d}	6.5^{ab}	64.1^{b}	7.08^{ab}	7.87^{c}
LSD0.05		1.17	26.74	1.84	7.61	0.54	1.09
CV%		13.2	14	31.3	9.6	6.5	10.3

Abbreviations: CV%, coefficient of variation; DMY, dry biomass yield; LL, leaf length; LNPP, leaf number per plant; $LSD_{0.05}$, least significant difference at $p < .05$; LW, leaf width; PH, plant height; TNPP, tiller number per plant.
The superscript footnote descriptions indicate mean values sharing common letters in the column are not significantly different.

Leaf number

Chelenko variety at Chano site produced significantly ($p < .001$) higher (17.13) main crop leaf number than others during 2019 followed by 14.8 leaves during 2018 (Table 1). NTJ_2 produced the lowest number (5.73) of main crop leaves at Derashe in 2018. The variety Chelenko at Derashe site produced higher ($p < .001$) ratoon leaf number (10.73) compared to other varieties at both locations while variety NTJ_2 recorded the lowest ratoon leaf number (6.5) (Table 2). NTJ_2 produced the lower leaf number in both main and ratoon crops in the present study. Generally, main crop produced higher average leaf number than ratoon crop. In agreement with our findings, significant variation on leaf number per plant of 8.4–10.3 was reported by Afzal et al. (2013). The increment of leaf number after two consecutive cuttings reported by Afzal et al. (2013) disagrees with the findings of the present study. Environmental conditions determine the number of leaves that ranges from 8 to 22 per plant (DuPlessis, 2008) where the results of our findings are included in this range.

Length and width of leaf

The results of leaf length and width of sorghum varieties at the main and ratoon cropping system are presented in Tables 1 and 2, respectively. Variety NTJ_2 produced significantly ($p < .001$) wider (11.03 cm) main crop leaves at Arba Minch site in 2018 while the similar variety gave narrower plant

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leaves of 6.2 cm at Derashe site in 2018. Dishkara variety demonstrated the longest (98.2 cm) leaves at Arba Minch in 2018 among other experimental units. Lower leaf length of 50.87 cm was observed for variety Konada at Derashe site in 2019. Rara variety demonstrated wider ratoon crop leaf followed by Dishkara variety at Arba Minch and Konoda variety at Arba Minch and Derashe sites. The width of leaves has received little attention in literature, and it is unknown how the width is related to other plant parameters (Bos et al., 2000). Leaf length and width are the superior estimators of the leaf area of a specific crop (Schrader et al., 2021). The leaf area of sorghum could be obtained by multiplying the leaf length, leaf width, and correction factor (0.75) (Krishnamurthy et al., 1974). Leaf area growth is an important parameter in which it determines the plant productivity (Koester et al., 2014). Some varieties like NTJ_2 in the present study demonstrate lower biomass with wider leaf concurs with the other result stating crops having higher leaf area demonstrate higher quality while the biomass content depends on the other factors (Weraduwage et al., 2015).

Number of tiller per plant

The results of tiller number are presented in Table 1 for main crops and in Table 2 for ratoon crops. The main crop tiller number per plant was significantly ($p < .001$) higher (6.73) for variety Rara at Derashe site during the 2019 cropping season while the lower tiller number (1.53) recorded from variety NTJ_2 at Arba Minch site during the 2018 and 2019 production seasons. Higher ratoon tiller number was recorded from variety NTJ_2 (11.33) followed by Rara variety (9.73) at Derashe site while the lowest tiller number was recorded from Konoda variety (2.07) at Arba Minch site. In the present study, tiller number was much higher in the ratoon crop (4.6) compared to main crop (2.79), which is in line with the previous findings of Vinutha et al. (2017) in which the tiller number of the ratoon crop was about five while the main crop recorded tiller number of three.

Internode length

The result of internodes presented for sorghum varieties is presented in Figure 3. There was significant ($p < .01$) variation of internode length among sorghum varieties in the main crop. Chelenko had wider internodes (16.73 cm) while Dishkara (8.4 cm), Konoda (8.4 cm), and NTJ_2 (9.53 cm) had the shortest internodes. Internode length contributes to the DBY where varieties with the longer internodes gave higher DBY. The varieties with taller juicy stems with longer internodes are characterized as forage sorghum (Havilah, 2017). Stem internodes of sorghum genotypes with 5 cm fully grown stem reported previously (Kebrom et al., 2017) while the current varieties have longer internodes of 16.73 cm.

Dry biomass yield

The results of DBY of ratoon and main crops of sorghum varieties are presented in Tables 2 and 3, respectively. DBY of the main crop was significantly ($p < .001$) different among sorghum varieties, location, and years. The highest main crop DBYs were recorded by Chelenko variety at Derashe site

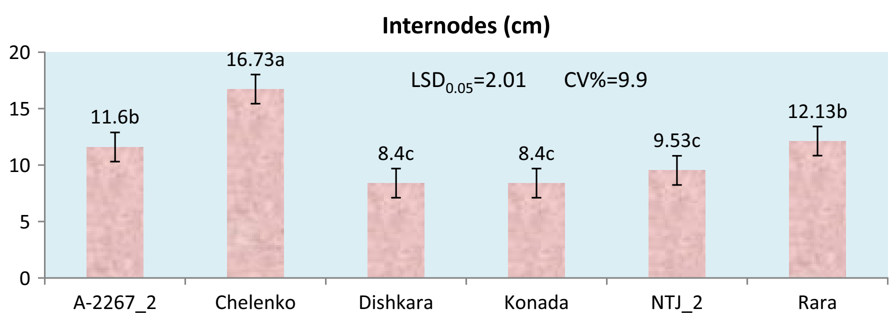

Figure 3. Length of internodes of main crop as influenced by sorghum varieties.

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Table 3. Dry biomass yield of main crop as influenced by sorghum varieties, experimental years, locations, and their interaction

	DMY t/ha			
	Arba Minch		Derashe	
Sorghum varieties	2018	2019	2018	2019
A-2267_2	12.42^{g}	24.51^{cd}	24.00^{cde}	7.59^{ghi}
Chelenko	22.55$^{c–f}$	38.41^{ab}	42.20^{a}	10.29^{gh}
Dishkara	18.87^{f}	—	35.94^{b}	10.04^{ghi}
Konada	19.12^{ef}	—	20.57^{def}	5.08^{i}
NTJ_2	9.13^{ghi}	26.00^{c}	10.37^{gh}	6.57^{hi}
Rara	12.03^{g}	37.33^{ab}	24.12^{cde}	7.66^{ghi}
Mean	15.69	21.04	26.2	8.26
$LSD_{0.05}$	5.04			
CV%	17.30			

Note. Means with common letter (s) are not statistically different (*p*.05).
Abbreviations: CV%, coefficient of variation; DMY, dry biomass yield; $LSD_{0.05}$, least significant difference at $p < .05$.

during the 2018 growing season (42.2 t/ha) and at Arba Minch site during the 2019 (38.41 t/ha) and Rara variety at Arba Minch site during the 2019 (37.33 t/ha), which were statistically similar. The lowest DBY was recorded by variety Konoda grown at Derashe site during the 2019 growing season (Table 3).

DBYs of ratoon crop harvested at 105 days after main crop were significantly ($p < .001$) varied among varieties and locations. Variety Dishkara demonstrated the highest total (DBY of main crop + ratoon crop) DBY (41.67 t/ha) at Arba Minch site while Rara (2.5 t/ha)) and NTJ_2 (2.34 t/ha) varieties recorded the lowest DBYs at Derashe site (Table 2).

As indicated in Figure 5, Dishkara variety produced significantly ($p < .05$) higher total (yield of main crop + ratoon crop) DBY (45.3 t/ha) followed by Chelenko variety (33.3 t/ha) while the lowest DBY was obtained from Konada variety (18.5 t/ha).

Ratoon crops are very important for contribution of dry lowland forage production system where dual-purpose sorghum varieties could generate both grain and forage production. Forage DBY parameter is an important agronomic trait in forage crops production (Lauer, 2006), especially for the production of dual-purpose sorghum varieties (Chen et al., 2020). The higher DBYs in the main crop than in the ratoon could be associated with the change in seasonal conditions for growth of the crops and probably depletion of nutrient levels in the soil (Vinutha et al., 2017). To boost the production, it needs the amendment of the nutrient depletion during the harvesting of main crops and ratoon crops (Afzal et al., 2013).

Grain yields

The mean values of grain yields for sorghum varieties are presented in Figure 4. Grain yield was significantly ($p < .01$) varied among sorghum varieties. Variety NTJ_2 (3.89 t/ha) followed by Konada (3.77 t/ha) demonstrated the highest grain yield than other varieties while variety Chelenko (1.74 t/ha) gave the lowest yield. Grain yields of A-2267_2, Chelenko, Dishkara, and Rara were not varied significantly. Varieties in the present study producing higher DBY gave lower grain yield and vice versa. For example, Konoda and NTJ_2 demonstrated higher grain yield with lower DBY than other varieties in the test. This result is in agreement with the findings of Borghi et al. (2013) where sorghum DBY was reduced by increased grain yield. The extent of grain yields of dual-purpose sorghum varieties recorded in the present study was in line with findings of other researchers (Mahfouz et al., 2015). Sorghum varieties

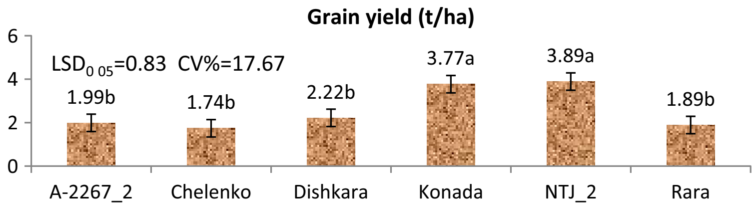

Figure 4. Standard mean value of main crop grain yield as influenced by sorghum varieties.

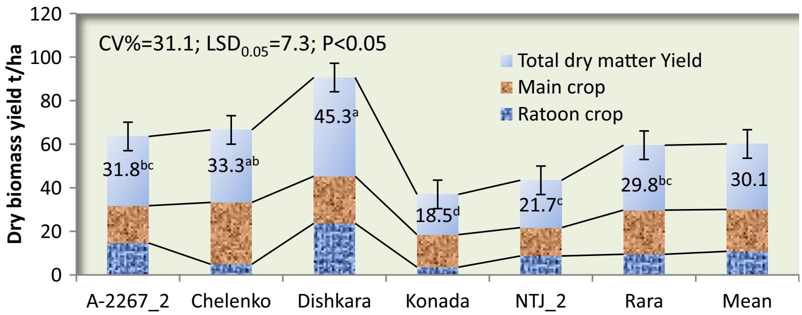

Figure 5. Total dry biomass yields of sorghum varieties used in the present study.

used in the present study generally gave relatively higher mean grain yield (2.58 t/ha) compared to reports for dual-purpose sorghum genotypes, which recorded grain yield of 0.62 t/ha in winter and 0.55 t/ha in summer production (Hassan et al., 2015).

Anthracnose incidence, severity, and AUDPC

The incidence, severity, and AUDPC were significantly ($p < .05$) varied among the tested sorghum varieties at Arba Minch and Derashe districts in the 2018 and 2019 cropping season (Table 4). The highest mean anthracnose incidences of 98.90 and 100% were recorded from A-2267_2 variety grown at Arba Minch site during the 2018 and 2019 cropping seasons, respectively. Similarly, highest anthracnose severity of 43.67 and 40.36% and AUDPC of 860 and 1,085.27%-days were recorded from the same variety grown at Arba Minch site during the 2018 and 2019 cropping seasons, respectively. The lowest mean anthracnose incidence, severity, and AUDPC were recorded from Konada variety during the 2018 growing season. Similarly, the lowest incidence (on in 2019), severity (in 2019), and AUDPC (in 2019) were recorded from varieties Rara, Konada, and Konada grown at Arba Minch site. The highest mean (100%) anthracnose incidence was noticed from genotype A-2267_2 in 2018, while in 2019 the highest mean anthracnose incidence (100%) was recorded from A-2267_2 and NTJ_2 varieties at Derashe with the lowest mean anthracnose incidence was noted from Rara (61.15%). The highest mean anthracnose severity was recorded from the varieties A-2267_2 (32.02%), NTJ_2 (31.98%), and Dishkara (26.81%) in 2018, while in 2019 the highest mean anthracnose severity was noted from all varieties except for Konada and Rara varieties at Derashe. AUDPC values were recorded higher from A-2267_2 (829.92%-days) in 2018, while the highest mean AUDPC values were noticed from A-2267_2 (829.92%-days), Dishkara (696.22%-days), and NTJ_2 (741.55%-days) in 2019 at Derashe. Anthracnose is the most severe and distressing sorghum disease in terms of dry biomass and grain yields in the study areas (Getachew et al., 2021). The plant disease epidemic development is highly affected by availability of optimum temperature, relative humidity, host tissue, levels of host resistance, and other factors during the growing periods of the crop (Campbell & Madden, 1990).

https://doi.org/10.1017/exp.2022.12 Published online by Cambridge University Press

Table 4. Incidence, severity, and AUDPC of sorghum varieties to Anthracnose at different sites during the 2018 and 2019 main cropping seasons

	Arba Minch						Derashe					
	2018 cropping season			2019 cropping season			2018 cropping season			2019 cropping season		
Sorghum varieties	PDI_f (%)	PSI_f (%)	AUDPC (%-days)	PDI_f (%)	PSI_f (%)	AUDPC (%-days)	PDI_f (%)	PSI_f (%)	AUDPC (%-days)	PDI_f (%)	PSI_f (%)	AUDPC (%-days)
A-2267_2	98.90^{a}	43.67^{a}	840.00^{a}	100^{a}	40.36^{a}	1085.27^{a}	100^{a}	32.02^{a}	829.92^{a}	100^{a}	31.22^{a}	734.23^{a}
Chelenko	83.08^{b}	26.67^{bc}	583.33^{b}c	91.88^{ab}	$31.33^{a\text{-}c}$	671.49^{bc}	67.28^{bc}	24.60^{b}	576.33^{d}	90.78^{a}	25.29^{ab}	537.44^{b}
Dishkara	83.08^{b}	27.22^{bc}	$711.67^{a–c}$	$88.55^{a–c}$	$31.96^{a\text{-}c}$	819.08^{bc}	76.28^{bc}	26.81^{ab}	703.13^{bc}	95.18^{ab}	28.84^{a}	696.22^{a}
Konada	77.14^{b}	20.00^{c}	560.00^{c}	82.29^{bc}	22.58^{c}	577.99^{c}	75.05^{bc}	19.70^{b}	553.28^{d}	78.85^{c}	19.20^{b}	507.77^{b}
NTJ_2	82.67^{b}	31.11^{b}	750.56^{ab}	93.50^{ab}	34.77^{ab}	863.80^{b}	81.13^{ab}	31.98^{a}	741.55^{ab}	100^{a}	30.88^{a}	724.15^{a}
Rara	79.78^{b}	30.56^{b}	617.83^{bc}	75.34^{c}	29.13^{bc}	592.87^{c}	61.15^{c}	23.43^{b}	599.86^{d}	86.64^{bc}	26.43^{b}	575.60^{b}
p-value	<0.05	<0.001	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.001	<0.05	<0.05	<0.001
Grand mean	84.11	29.87	703.56	88.60	31.69	768.42	76.81	26.42	667.34	91.91	26.98	629.23
LSD (0.05)	13.09	10.35	172.42	13.87	10.01	208.48	19.48	7.23	115.58	11.41	7.00	117.69
CV (%)	8.75	19.49	13.78	8.80	17.76	15.25	14.26	15.40	9.73	6.98	14.59	10.51

Note. Means within each column for each parameter that are not followed by the same letter(s) are significantly different ($p \leq .05$), while those followed by the same letter(s) are not significantly different ($p > .05$). Abbreviations: AUDPC, area under disease progress curve; CV, coefficient of variation; LSD, least significant difference at a 5% probability level; PDI_f, percent disease incidence at final date; PSI_f, percent severity index at final date.

Correlation analysis of growth and yield parameters as influenced by sorghum variety, location, and years

The correlation of yields (dry biomass and grain) with growth and disease assessment parameters for main and ratoon crops are presented in Tables 5 and 6, respectively. DBY of main crops was positively correlated with plant height, tiller number leaf length, leaf number, and internodes. The correlation of DBY was significantly ($p < .001$) strong with internodes (0.946) of main crops. Tiller number and leaf length of the main crop had weak relationship with DBY of sorghum varieties. Day biomass yield of the main cropping season was negatively correlated (−0.785) with grain yield. DBY of main crop was the function of internodes of the stem in the present study. DBY of ratoon crops was positively correlated with plant height, tiller number, leaf length, leaf width, and leaf number. The positive correlation of biomass yield of ratoon crop with AUDPC showed anthracnose disease not affected the growth and development of ratoon crops in this study. Positive correlation of parameters either for main or ratoon crops of sorghum varieties indicates that selection on any one of the traits will increase in the other traits, thereby improving biomass yield in sorghum. The phenotypic correlation of plant height of sorghum varieties with biomass yield was reported as 0.349 (Narkhede and Seeds, 2020) while the correlation of plant height for the present study was as higher as 0.804 for main crop and 0.426 for ratoon crop (Tables 5 and 6).

Table 5. Correlation of dry biomass and grain yield with growth and disease assessment parameters for main cropped sorghum varieties

	DMY	PH	TNPP	LL	LNPP	Internodes	GY	AUDPC
DMY	1							
PH	0.804	1						
TNPP	0.019	−0.419	1					
LL	0.387	0.175	−0.394	1				
LNPP	0.67	0.839*	−0.695	0.591	1			
Internodes	0.946**	0.851*	0.077	0.128	0.616	1		
GY	−0.785	−0.491	−0.069	−0.332	−0.426	−0.648	1	
AUDPC	−0.223	−0.141	0.3	−0.733	−0.542	−0.156	−0.093	1

Abbreviations: AUDPC, area under disease progress curve; DMY, dry biomass yield; GY, grain yield; LL, leaf length; LNPP, leaf number per plant; PH, plant height; TNPP, tiller number per plant.
*$p < 0.05$; **$p < 0.01$.

Table 6. Correlation of dry biomass yield with growth and disease assessment parameters for ratoon cropped sorghum varieties

	DMY	PH	TNPP	LL	LW	LNPP	AUDPC
DMY	1						
PH	0.426	1					
TNPP	0.32	−0.585	1				
LL	0.271	0.586	−0.707	1			
LW	0.113	0.239	−0.492	0.878*	1		
LNPP	0.088	0.796	−0.801	0.728	0.436	1	
AUDPC	0.562	0.269	0.287	−0.28	−0.633	−0.078	1

Abbreviations: AUDPC, area under disease progress curve; DMY, dry biomass yield; LL, leaf length; LNPP, leaf number per plant; LW, leaf width; PH, plant height; TNPP, tiller number per plant.
*$p < 0.05$; **$p < 0.01$.

Conclusion

Plant height, leaf number, tiller number, and dry biomass and grain yield variation observed for main and ratoon crop sorghum varieties under anthracnose stress at Derashe and Arba Minch during 2018 and 2019 cropping season. Based on the current finding, Dishkara and Chelenko could be recommended for dry matter production while NTJ_2 for grain production in the Arba Minch, Dhirashe, and similar agroecologies under anthracnose stress in smallholder dryland farming system.

Acknowledgments. The authors highly acknowledge Southern Agricultural Research Institute (SARI) and Arba Minch Agricultural Research Center for technical and financial support. Getinet Kebede is duly thanked for data collection and field management.

Authorship contributions. Conceptualization, T.T.A.; Curation and analysis, T.T.A., G.G.M.; Data collection, T.T.A., G.G.M.; Draft paper writing, T.T.A.; Methodology, T.T.A.; Reviewing and editing, T.T.A., G.G.M.

Conflict of interest. The authors have no conflicts of interest to declare.

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Cite this article: Atumo TT, Mengesha GG (2022). Growth and yield performance of sorghum (*Sorghum bicolor* L.) crop under anthracnose stress in dryland crop-livestock farming system. *Experimental Results,* 3, e14, 1–15. https://doi.org/10.1017/exp.2022.12

Peer Reviews

Reviewing editor: Dr. Michael Nevels
University of St Andrews, Biomolecular Sciences Building, Fife, United Kingdom of Great Britain and Northern Ireland, KY16 9ST

Minor revisions requested.

doi:10.1017/exp.2022.12.pr1

Review 1: Growth and yield performance of sorghum (Sorghum bicolor L.) crop under anthracnose stress in dryland crop-livestock farming system

Reviewer: Dr. Jiban Shrestha

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Date of review: 28 June 2022

Conflict of interest statement. Reviewer delcares none.

Comment

Comments to the Author: Authors need to see each comments made within the attached manuscript file (see comments on yellow highlighted tex comment boxes). The writing english sentences needs to be improved.

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