Response of dual-purpose sorghum (*Sorghum bicolour* L.) varieties to anthracnose disease, growth and yield performances under dry land crop-livestock farming systems of southern Ethiopia

***Tessema Tesfaye Atumo*[1*], *Getachew Gudero Mengesha*[2]**

[1]Agronomy, Southern Agricultural Research Institute (SARI), Arba Minch Research Center, P.O. Box 2228, Arba Minch, Ethiopia

[2]Crop protection, Southern Agricultural Research Institute (SARI), Arba Minch Research Center, P.O. Box 2228, Arba Minch, Ethiopia

***Corresponding author:** tessema4@gmail.com

Received: March 8, 2022 **Accepted:** May 21, 2022

Abstract: *Integration of food crop production with feed supply in quantity and quality by considering some important foliar diseases could be an ideal approach in the crop-livestock farming system of tropical agriculture. Evaluating the responses of dual-purpose sorghum varieties to anthracnose diseases, growth and yield performances under the dry land farming system was undertaken in Arguba and Chamomile research substation during the 2018 and 2019 major production seasons. Five sorghum varieties (Chelenko, A-2267_2 and NTJ_2, Dishkara, Konoda) and one local check (Rara) were arranged factorial in a randomized complete block design with four replications. The assessment was done on plant height, leaf number, leaf width, leaf length, tiller number, dry biomass and grain yields, as well as on anthracnose disease infection. Variety Chelenko exhibited the tallest main crop plant height while Dishkara was the tallest at ratoon crop harvesting. Rara had a higher tiller number among the varieties. Chelenko had a higher dry biomass yield at the main crop while Dishkara at ratoon harvesting. The total dry biomass yield recorded by Dishkara, Chelenko A-2267_2, Rara, NTJ_2 and Konoda varieties was 45.3, 33.3, 31.8, 29.8 21.7 and 18.5 t/ha, respectively. Dry biomass yield was strongly and positively correlated with plant height. The varieties A-2267_2 and NTJ_2 recorded Anthracnose incidence of 98.90 and 100%, respectively while the severity was about 43.67 and 40.36% in the same order. Similarly, the area under disease progress curves for A-2267_2 and NTJ_2 varieties were 860 and 1085.27%-days, respectively. Dishkara and Chelenko varieties produced 45.3 t/ha and 33.3 t/ha dry biomass yields, which were 33.6% and 9.6%, respectively, higher ($P<0.05$) compared to the overall mean dry biomass yield (30.1 t/ha). On the other hand, the Konoda variety produced about 62.7% (18.5 t/ha) less dry biomass yield than the overall mean dry biomass yield. Although the anthracnose infection was highest in the varieties Konoda and NTJ_2, they produced significantly ($P<0.001$) higher grain yield (3.89 t/ha) than others. Under anthracnose pressure, Chelenko and Dishkara varieties are suggested for dry biomass yield while NTJ_2 for grain yield production in the study area and areas with similar agro-ecologies. Further research on the performance of the varieties under irrigation conditions and the inclusion of their feed quality is also recommended.*

Keywords: Animal feed, AUDPC, biomass yield, disease incidence, disease severity

1. Introduction

Regenerating perennial pastures which could survive for years are a major element in successful livestock enterprises (Collet, 2004). Sorghum (*Sorghum bicolour*) is inherently producing high biomass accumulation, high productivity per unit of water utilized and ratoon crop after harvesting of the plant (Vinutha *et al*., 2017). The crop is truly grown for dual purposes for both feed Stover and grain that are highly valued infrequent drought areas (Balmuri *et al*., 2018). Sorghum is the third most important crop in the study area next to tef and maize and is the fourth important crop in terms of area coverage and volume of production in Ethiopia (MOA, 2016) which has been produced by 5 million smallholder farmers in 2 million hectares with a production of 4.3 million tons and grain productivity of 2 t/ha (CSA, 2018).

The importance of sorghum as a feed crop in the semi-arid tropics and drier parts of the world has been proven where livestock rearing takes a part in the agricultural production system (Mohammed, 2010). Forage sorghum has been characterized as a sweet tall plant from 1.9 to 2.7 meters (Vinutha *et al*., 2017) and adapted to a ratoon production system. It is best utilized as a silage crop, although it can be grazed or cut for hay if managed appropriately and improve fiber supplement for digestion in milking cows (Hassan *et al*., 2015). According to Vinutha *et al*. (2017), the quality of forage sorghum in terms of nitrogen content for 36 lines was ranging from 2.06% to 2.89% with the production of above-ground dry biomass up to 33.8 t/ha. Structural carbohydrates and starch are the main energy resources that are accumulated in the grain and dry biomass of cereal crops, and they are important for dairy cows (Mohammed, 2010). However, anthracnose (*Colletotrichum graminicola*) (Madhusudhana, 2019) and turcicum (*Exserohilum turcicum*) leaf blight (TLB) (Kiran and Patil, 2019) diseases are the most destructive and affect all aerial tissues of the plant and can cause dry matter and seed yield losses of up to 50% in severely affected fields of sorghum.

In Ethiopia, the feed balance has been reported negative in terms of dry matter at 21.2%, feed metabolizable energy at 51.7% and crude protein at 9.5% whereas in southern Ethiopia including the experimental locations dry matter is 40.3%, metabolizable energy at 62.6% and crude protein 57.9% (Shapiro *et al*., 2015). Negative feed balance in terms of dry matter and forage quality has been affecting animal production in the Ethiopian livestock system (Atumo *et al*., 2022).

Therefore, the objectives of the present study were to assess forage dry biomass yield, grain yield, agro-morphological traits, and leaf to stem ratio of main and ratoon sorghum varieties under the pressure of anthracnose disease, as well as to determine the intensity of anthracnose on the tested six sorghum varieties associated with their growth and yield performances under field conditions in Chamomile and Arguba trial locations, southern Ethiopia. This is particularly to help smallholder farmers in using the most productive dual-purpose sorghum varieties in terms of forage and grain yield under the pressure of major foliar diseases to be resistant to alternative varieties for food production and supplying feed to their livestock in particular circumstances and to provide background data for planning future breeding programs.

2. Materials and Methods

2.1. Description of study areas

Evaluation of sorghum varieties for dry biomass yield under the pressure of anthracnose disease was conducted at Chamomile and Arguba in Arba Minch Zuriya and Derashe special districts, respectively, of southern Ethiopia during the 2018 and 2019 main cropping seasons. The two study sites are situated in the semi-arid tropical belt of southern Ethiopia. Geographically, the Chamomile site is located at 06°06´ N latitude and 37°35´ E longitude, while the Arguba site is located at 05°30´ N latitude and 37°12´ E longitude. Chamomile and Arguba sites are laid at an altitude of 1206 and 1260 meters above sea levels, respectively.

The two experimental sites have a bimodal rainfall pattern. The short rainy season falls from March to May and the long rainy season extends from June to November. Chamomile and Arguba receive mean annual precipitation of 937.9 and 1009.2 mm with average maximum and minimum temperatures of 30.3 and 17.3 ^{0}C, and 27.31 and 18.93 ^{0}C, respectively (NMA, 2021). Monthly distributions of mean rainfall and average maximum and minimum temperatures of Arguba and Chamomile experimental sites for 30 years (1989 to 2019) are presented in Figures 1 and 2, respectively.

According to the analysis results of the collected composite (0–30 cm) sample, soil of Chanomile site was categorized as sandy loam and had 14.47 mg/kg, 0.29%, 1.19% and 1.63% available phosphorus, total nitrogen organic carbon and organic matter, respectively, with the pH of 6.2 (Atumo *et al*., 2021). Similarly the soil of Arguba site was categorized to textural classification of sandy loam and had available phosphorus, total nitrogen, organic carbon and organic matter of 14.5 mg/kg, 0.31%, 1.22% and 1.72%, respectively, with the pH of 6.15.

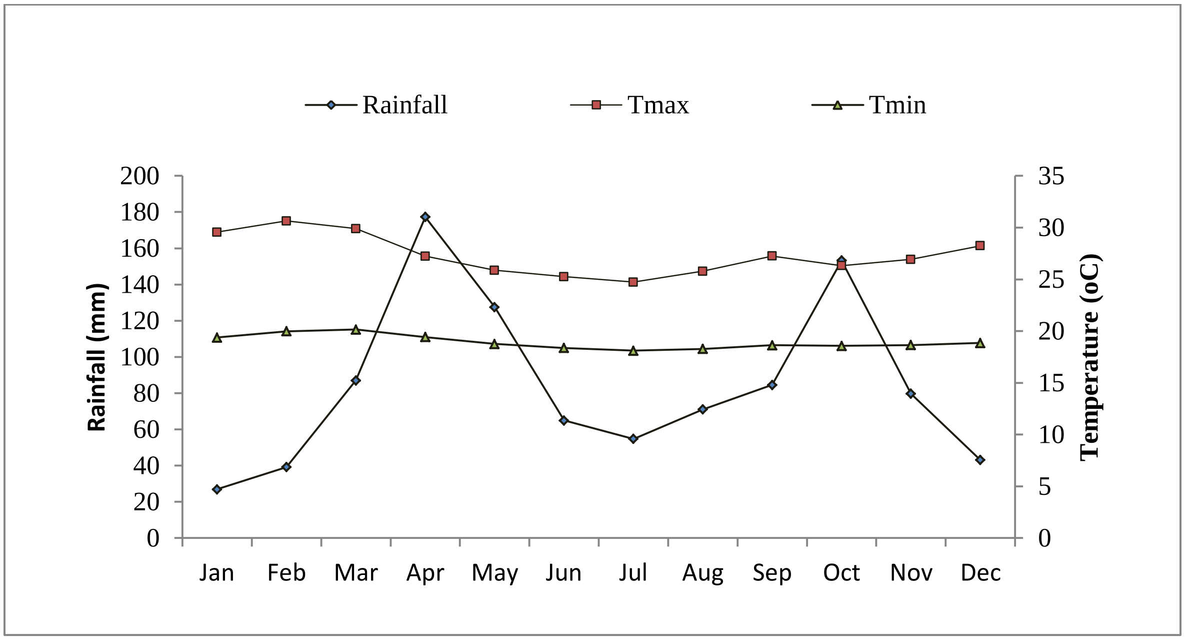

Figure 1: Rainfall, minimum and maximum temperatures of Arguba site during the last 30 years (1989-2019)

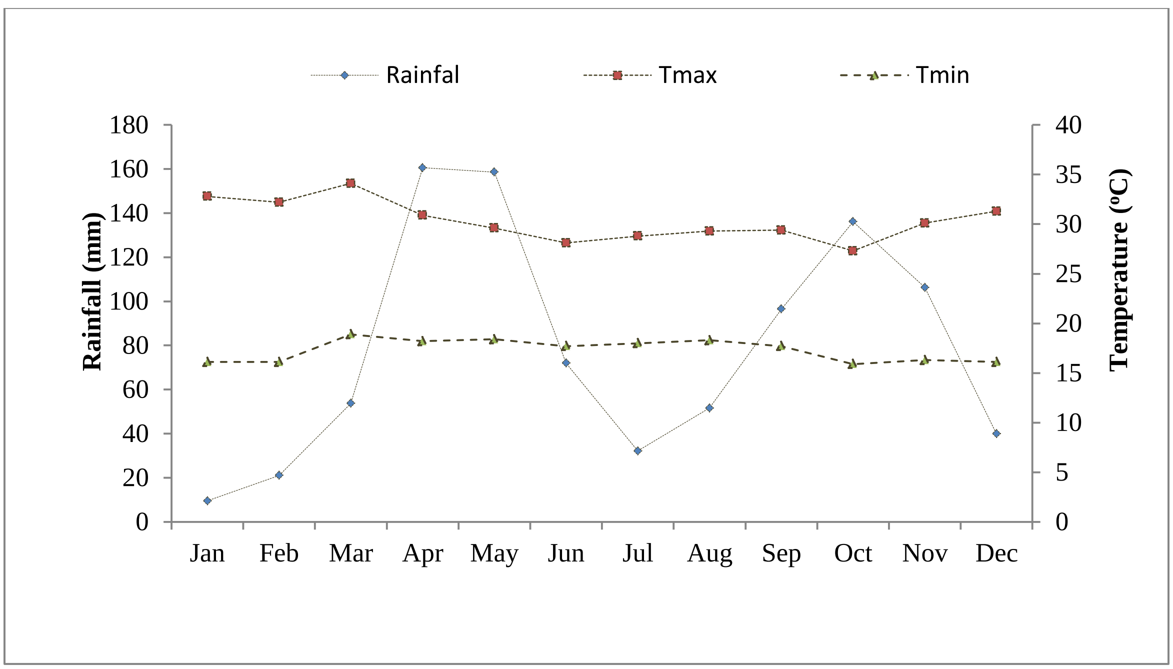

Figure 2: Rainfall, minimum and maximum temperatures of Chamomile site during the last 30 years (1989-2019)

2.2. Description of experimental materials

A total of six dual-purpose sorghum genotypes were used for the study. While the seeds of Chelenko, A-2267_2 and NTJ_2 varieties were collected from Melkasa Agricultural Research Center (MARC), seeds of the remaining Dishkara and Konoda varieties and one local check (Rara) were collected from farmers in Derashe special district (Table 1).

Table 1: Sorghum varieties used in the study

Variety	Adaptation area	Release year	Remark
A_2276_2	<1600	-	
Chelenko	<1600	2005	(MOA, 2016)
Dishkara	1200-1700	-	Farmer cultivar
Konoda	1200-1700	-	Farmer cultivar
NTJ_2	<1600	-	
Rara	1200-1700	-	Farmer cultivar

2.3. Experimental design and procedures

At both experimental sites, the six varieties were 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* 3m (3.6 m^2), respectively. Spacing between experimental plots and replications were 1m and 1.5m, respectively.

After ploughing 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 cm 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 (MOA, 2016). Experimental plots were kept weed-free with frequent hand weeding.

2.4. Data collection

2.4.1. *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, as well as grain yield obtained from the net plot area, were converted into a hectare basis. Apart from the collection of forage and grain yields, data on vegetative growth parameters were collected timely. Plant height 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. Tillers per plant were also counted from both main and ratoon crops just before harvesting. However, growth performance parameters of Dishakara and Konoda varieties at Chanomile site during the 2019 growing season couldn't be collected due seed emergence problems.

Green forage yield per net plot area was measured using a spring balance and expressed as fresh biomass yield per hectare. The sample was taken to the laboratory and subjected to oven drying at 65°C for 24 hours to get constant dry weight. After cooling, the samples were weighed with sensitive balance and expressed as dry biomass yield. Dry biomass yields were estimated by multiplying fresh biomass yields with the dry matter percentage of respective samples. Dry matter of the samples and dry biomass yield of both main crop and ratoon crops were determined using the formulas below as indicated by Tarawali *et al.* (1995):

$$DM\ (\%) = \left(\frac{ODW\ (g)}{FW(g)}\right) * 100 \qquad [1]$$

Where
DM = dry matter percent, ODW = oven dry weight, FW = fresh weight of a sample (500 g)

$$DBY\ (t/ha)\ = FBY\ (t/ha) * DM(\%) \qquad [2]$$

Where
DBY = dry biomass yield, FBY = fresh biomass yield, DM% = dry matter content in percent

2.4.2. *Disease monitoring*

Anthracnose incidence and severity assessments were started 40 and 45 days after planting at Arguba and Chamomile sites in the 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.

Disease 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 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 = $\geq$ 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).

$$\text{PSI} = \left(\frac{\text{Sum of numerical ratings}}{\text{No. of plants scored x maximum score on scale}}\right) * 100$$

The area under the 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 on different days after planting for each sorghum varieties within the plot using the formula mentioned by Campbell and Madden (1990) and indicated as below.

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5\ (X_i + X_{i+1})\ (t_{i-1} - t_i) \qquad [4]$$

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 PSI of disease at the i^{th} assessment.

AUDPC was articulated in %-days since severity (X) is expressed in percent and time (t) in days.

2.5. Data analysis

Genstat software (Payne *et al*., 2015) package was used to compute the analysis of variance (ANOVA) of all parameters considered in the study. Whenever the ANOVA results were significant, the means of the parameters were separated using Least Significance Difference (LSD) at a 5% level of error. The two seasons and locations were recorded as distinct environments due to heterogeneity of error variances in Bartlett's test as indicated by Gomez and Gomez (1984). Due to this, data were separately analyzed as location and season effects. Associations of anthracnose incidence, severity and AUDPC with growth and yield-related traits of sorghum varieties were examined using simple correlation analysis. Spearman correlation coefficients (r) were used to indicate the strength of the relationships among the parameters.

3. Results and Discussion

3.1. Growth performance

3.1.1. *Plant height*

The plant height of sorghum varieties for the main plant was significantly (P<0.001) varied for the interaction of variety*location*year (Table 2). The tallest plant height of 430 cm followed by 410.8 cm was recorded at the Chanomile sub research substation during the 2018 and 2019 planting season for the variety Chelenko while the lowest plant height of 174.3 cm was at Aruba in 2019 for the variety NTJ_2. Ratoon crops' plant height was also significantly (P<0.001) varied among sorghum varieties. Dishkara (227.7 cm) recorded the highest plant height at Chanomile followed by A-2267_2 (203.9 cm) among other varieties while the lowest plant height was at Arguba for Rara (68.0 cm).

The plant height of the ratoon crops is presented in Table 3. Dhishakara variety recorded significantly (P<0.05) as 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 to and plays a great role in aboveground biomass accumulation (Halim *et al*., 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 assimilation produced by the leaves (Ngo, 2017). Some scholars reported a higher average plant height of ratoon crops (259 cm) than main crops (228 cm) (Vinutha *et al*., 2017) for 36 sorghum lines. That may be due to the variation among genotypes and other management options.

3.1.2. *Leaf number*

Chelenko variety at Chanomile site produced significantly (P<0.001) higher (17.13) main crop leaf number than others during 2019 followed by 14.8 leaves during 2018 (Table 2). NTJ_2 produced the lowest number (5.73) of main crop leaves at Arguba in 2018. The variety Chelenko at the Aruba site produced a higher (P<0.001) 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 3). NTJ_2 produced the lower leaf number in both main and ratoon crops in the present study. Generally, the main crop produced a higher average leaf number than the ratoon crop. In agreement with our findings, a significant variation in leaf number per plant of 8.4 to 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 ranging from 8 to 22 per plant (Plessis, 2008) and the results of our findings is included in this range.

3.1.3. *Length* and *width of a leaf*

The results of leaf length and width of sorghum varieties at the main and ratoon cropping system are presented in Tables 2 and 3, respectively. Variety NTJ_2 produced significantly (P<0.001) wider (11.03 cm) the main crop leaves at Chanomile site in 2018 while the similar variety gave narrower plant leaves of 6.2 cm at Arguba site in 2018. Dishkara variety demonstrated the longest (98.2 cm) leaves at Chamomile in 2018 among other experimental units. A lower leaf length of 50.87 cm was observed for the variety Konada at the Arguba site in 2019. Rara variety demonstrated wider ratoon crop leaf followed by Dishkara variety at Chamomile and Konoda variety at Chamomile and Arguba sites.

The leaf length and width of a given plant are important parameters that influence leaf area index and thus the productivity of the given plant (Krishnamurthy *et al*., 1974, Koester *et al*., 2014, Schrader *et al*., 2021). Some varieties like NTJ_2 in the present study demonstrating lower biomass yield with wider leaf concurs with the results of other researchers who stated crops having higher leaf area demonstrate higher quality while the biomass yield depends on the other factors (Weraduwage *et al*., 2015).

3.1.4. *Number of tillers per plant*

The results of tiller number are presented in Table 2 for main crops and in Table 3 for ratoon crops. The main crop tiller number per plant was significantly (P<0.001) higher (6.73) for variety Rara at Arguba site during the 2019 cropping season while the lower tiller number (1.53) was recorded from variety NTJ_2 at Chanomile site during the 2018 and 2019 production seasons. A higher ratoon tiller number was recorded from variety NTJ_2 (11.33) followed by the Rara variety (9.73) at the Aruba site while the lowest tiller number was recorded from the Konoda variety (2.07) at the Chamomile site.

In the present study, the tiller number was much higher in the ratoon crop (4.6) compared to the main crop (2.79), which is in line with the previous findings of (Vinutha *et al*., 2017) which the tiller number of the ratoon crop was about 5 while the main crop recorded tiller number of 3.

3.1.5. *Internode length*

The results of internodes of sorghum varieties are presented in Figure 3. There was a significant (P<0.01) 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 dry biomass yield whereas varieties with the longer internodes gave higher dry biomass yield. The varieties with taller juicy stems with longer internodes are characterized as forage sorghum (Havilah, 2017). Generally, the internode lengths observed in the present study were relatively high compared to the previous reports where an internode length of 5 cm was reported (Kebrom *et al*., 2017).

Table 2: Growth performance of the main crop sorghum as influenced by variety, experimental years and locations

Year	Location	Variety	PH (cm)	LNPP	LW (cm)	LL (cm)	TNPP
2018	Chanomile	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}
	Arguba	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	Chanomile	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}
	Arguba	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

PH = plant height, LNPP = leaf number per plant, LW = leaf width, LL = leaf length, TNPP = tiller number per plant, $LSD_{0.05:}$= least significant difference at $P < 0.05$, CV% = coefficient of variation

Table 3: Dry biomass yield and growth performance of ratoon crop as influenced by sorghum variety and location

Location	Variety	DMY t/ha	PH cm	TNPP	LL cm	LW cm	LNPP
Chanomile	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}
Arguba	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
Main effect variety	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

DMY= dry biomass yield, PH = plant height, TNPP = tiller number per plant, LL = leaf length, LW = leaf width, LNPP = leaf number per plant, $LSD_{0.05}$ =: least significant difference at P<0.05, CV% = coefficient of variation

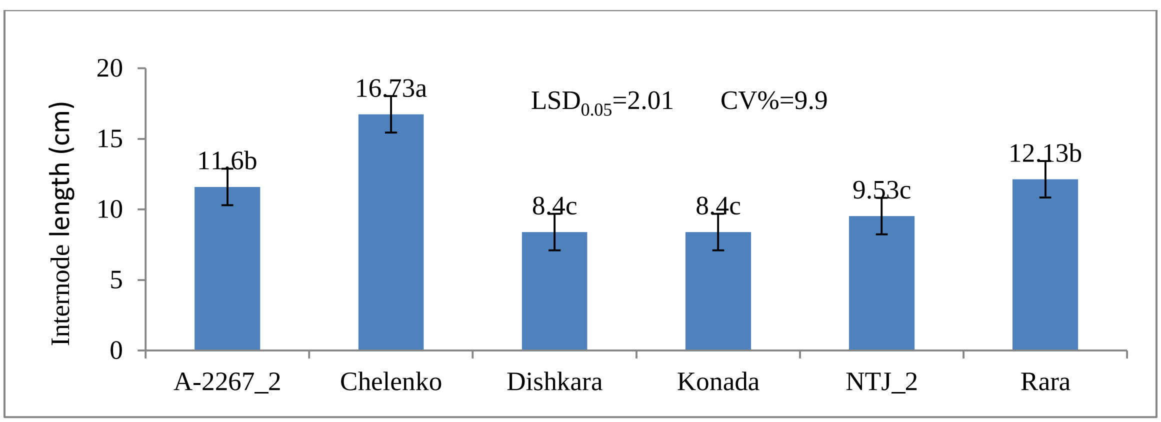

Figure 3: Internode length of the main crop as influenced by sorghum varieties

3.2. Grain yields

The mean values of grain yields for sorghum varieties are presented in Figure 4. Grain yield was significantly (P<0.01) 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 dry biomass yield gave lower grain yield and vice versa. For example Konoda and NTJ_2 demonstrated higher grain yield with lower dry biomass yield than other varieties in the test. This result is in agreement with the findings of Borghi *et al*. (2013) where sorghum dry biomass yield 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 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).

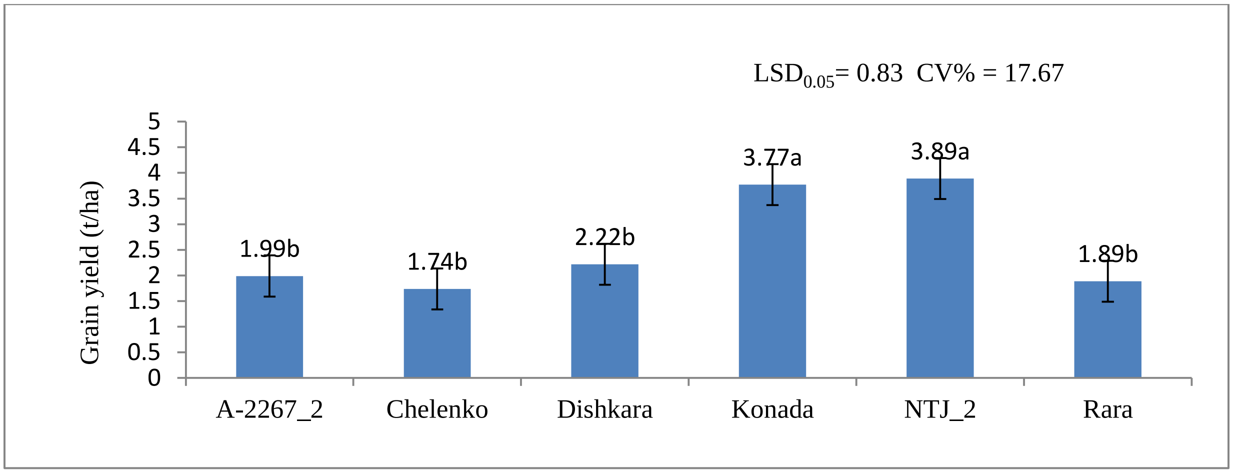

Figure 4: Grain yield of sorghum main crop as influenced by different varieties

3.3. Dry biomass yield

The results of dry biomass yield of ratoon and main crops of sorghum varieties are presented in Table 3 and 4, respectively. Dry biomass yield of the main crop was significantly ($P<0.001$) different among sorghum varieties, location and years. The highest main crop dry biomass yields were recorded by Chelenko variety at Arguba site during the 2018 growing season (42.2 t/ha) and at Chanomile site during the 2019 (38.41 t/ha) and Rara variety at Chanomile site during the 2019 (37.33 t/ha), which were statistically similar. The lowest dry biomass yield the main crop was recorded by variety Konoda grown at Arguba site during the 2019 growing season (Table 4).

Dry biomass yields of ratoon crop harvested at 105 days after main crop were significantly ($P<0.001$) varied among varieties and locations. Variety Dishkara demonstrated the highest total (dry biomass yield of main crop + ratoon crop) dry biomass yield (41.67 t/ha) at Chanomile site while Rara (2.5 t/ha) and NTJ_2 (2.34 t/ha) varieties recorded the lowest dry biomass yields at Arguba site (Table 3).

As indicated in Figure 5, Dishkara variety produced significantly ($P<0.05$) higher total (yield of main crop + ratoon crop) dry biomass yield (45.3 t/ha) followed by Chelenko variety (33.3 t/ha) while the lowest dry biomass yield 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 dry biomass yield parameter is important agronomic trait in forage crops production (Lauer, 2006), especially for the production of dual purpose sorghum varieties (Chen *et al*., 2020). The higher dry biomass yields in the main crop than in the ratoon could be associated to 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).

Table 4: Dry biomass yield of sorghum main crop as influenced by variety, experimental year and location

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

Means with common letter (s) are not statistically different (P.0.05), $LSD_{0.05}$ = Least Significant Difference at P < 0.05, CV% = coefficient of variation

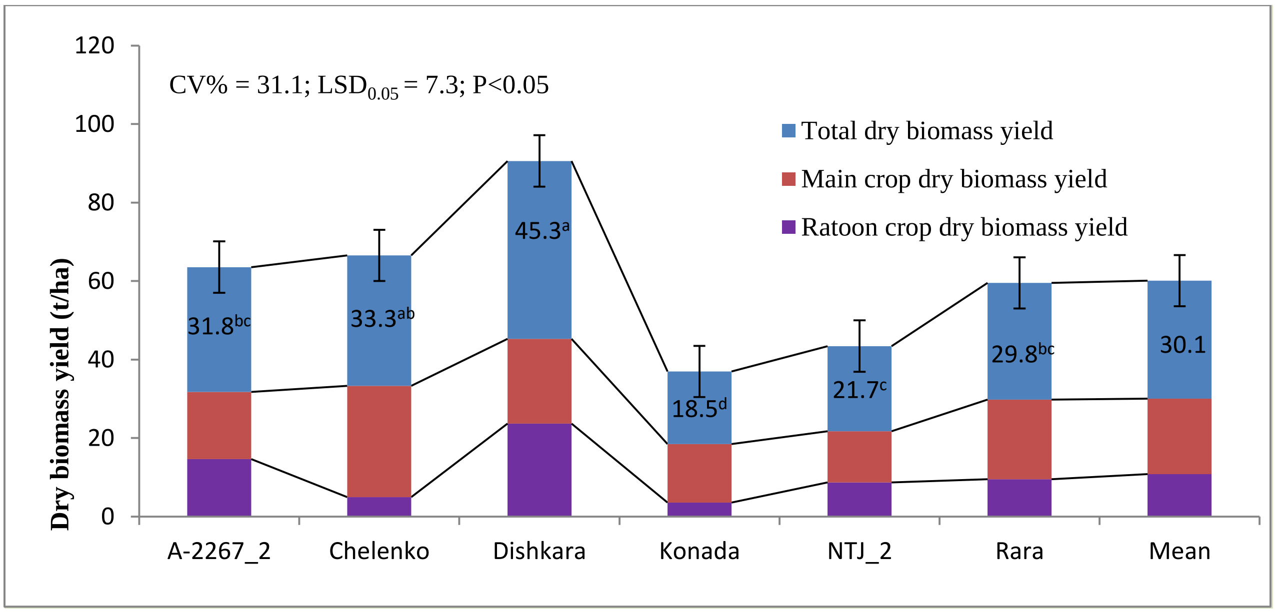

Figure 5: Dry biomass yields of sorghum varieties used in the present study

3.4. Incidence, severity and AUDPC of Anthracnose

The incidence, severity and AUDPC were significantly (P < 0.05) varied among the tested sorghum varieties at Chanomile and Arguba districts in the 2018 and 2019 cropping season (Table 5). In Chanomile site, the highest mean anthracnose incidences of 98.90 and 100% were recorded from A-2267_2 variety grown during the 2018 and 2019 cropping seasons, respectively. Similarly, highest anthracnose severity of 43.67 and 40.36% and AUDPC of 860 and 1085.27%-days) were recorded from the same variety grown at Chanomile 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, severity and AUDPC were recorded from variety Rara grown at Chanomile site in 2019.

At Arguba site, the highest mean anthracnose incidence (100%) 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. 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. The highest value of AUDPC at Arguba site was recorded from the variety A-2267_2 (829.92%-days) followed by NTJ_2 (741.55%-days) and (Dishkara 703.13%-days) during the 2018 growing season, while the highest mean AUDPC values were observed from the varieties A-2267_2 (734.23%-days), Dishkara (696.22%-days) and NTJ_2 (724.15%-days) during the 2019 growing season.

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 and Madden, 1990).

Table 5: Incidence, severity and AUDPC of sorghum varieties to Anthracnose at different sites during the 2018 and 2019 main cropping seasons

Sorghum varieties	Chanomile						Arguba					
	2018 cropping season			2019 cropping season			2018 cropping season			2019 cropping season		
	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	98.90a	43.67a	840.00a	100a	40.36a	1085.27a	100a	32.02a	829.92a	100a	31.22a	734.23a
Chelenko	83.08b	26.67bc	583.33bc	91.88ab	31.33a-c	671.49bc	67.28bc	24.60b	576.33d	90.78a	25.29ab	537.44b
Dishkara	83.08b	27.22bc	711.67a-c	-	-	-	76.28bc	26.81ab	703.13bc	95.18ab	28.84a	696.22a
Konada	77.14b	20.00c	560.00c	-	-	-	75.05bc	19.70b	553.28d	78.85c	19.20b	507.77b
NTJ_2	82.67b	31.11b	750.56ab	93.50ab	34.77ab	863.80b	81.13ab	31.98a	741.55ab	100a	30.88a	724.15a
Rara	79.78b	30.56b	617.83bc	75.34c	29.13bc	592.87c	61.15c	23.43b	599.86d	86.64bc	26.43b	575.60b
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	90.18	33.89	803.36	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

Means following with the same letter(s) in a column are not significantly different ($P \leq 0.05$) PDI_f = Percent disease incidence at final date; PSI_f = Percent severity index at final date; AUDPC = area under disease progress curve; LSD = least significant difference at a 5% probability level; and CV = coefficient of variation

3.5. 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 6 and 7, respectively. Dry biomass yield of main crops was positively correlated with plant height, tiller number leaf length, leaf number, and internodes. The correlation of dry biomass yield was significantly (P<0.001) strong with internodes (0.946) of main crops. Tiller number and leaf length of the main crop had weak relationship with dry biomass yield of sorghum varieties. Day biomass yield of the main cropping season was negatively correlated (-0.785) with grain yield. Dry biomass yield of main crop was the function of internodes of the stem in the present study.

Dry biomass yield of ratoon crops was positively correlated with plant height (0.426), tiller number (0.32), leaf length (0.271), leaf width (0.113), and leaf number (0.088). The positive correlation of biomass yield of ratoon crop with area under disease progress curve 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. Similar finding with the present result was reported by other scholar for fifteen genotypes of sorghum (Naharudin *et al*., 2021). 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.

Positive association of dry biomass yield with plant height and tiller number for main and ratoon crops was reported previously as plant height and tillering were contributing to forage yield (Bhat, 2019). The association of dry biomass and grain yields with growth parameters was also supported by another findings on sorghum production (Madhusudhana, 2019).

Table 6: Relationships of growth, yield and disease parameters of main crop of sorghum as influenced by variety, location and year

	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

Table 7: Relationships of growth, yield and disease parameters of ratoon crop of sorghum as influenced by variety, location and year

	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

PH = plant height, TNPP = tiller number per plant, LL= leaf length, LNPP = leaf number per plant, GY = grain yield, AUDPC = area under disease progress curve, DMY = dry biomass yield

4. Conclusion and Recommendations

Plant height, leaf number, tiller number, and dry biomass and grain yield variations for main and ratoon crop sorghum varieties under anthracnose stress at Arguba and Chanomile sites were observed during the 2018 and 2019 cropping season. Chelenko variety exhibited higher plant height for main crops while Dishkara for ratoon crops. Anthracnose disease affected more the grain yield than dry biomass yield. Dishkara variety recorded 45.3 t/ha total biomass yield, which is about 33.6% more yield compared to the overall mean value (30.1 t/ha) followed by Chelenko variety which gave about 9.6% more total biomass yield. The variety Konoda recorded the lowest total dry biomass yield (18.5 t/ha), which was reduced by 40% compared to the mean value. Dry biomass yield of main crop had positive association with plant height, leaf number per plant, leaf length and tiller number per plant and negative association with grain yield. While the dry biomass yield of ratoon crop had positive association with all parameters. The correlation analysis result indicated that anthracnose disease didn't affect the ratoon yield. Under anthracnose stressed areas of Arba Minch, Dhirashe and areas with similar agro-ecologies, the varieties Dishkara and Chelenko for dry biomass yield production and variety NTJ_2 for grain production could be recommended.

Acknowledgement

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.

Conflict of interest

Authors declare no conflict of interest.

References

Afzal, M., Ahmad, A. and Ahmad, A.H. (2013). Effect of Nitrogen on Growth and Yield of Sorghum Forage (Sorghum Bicolor (L.) Moench Cv.) under Three Cuttings System. *Cercetari Agronomice in Moldova*, *45*(4): 57–64. https://doi.org/10.2478/v10298-012-0065-y

Afzal, M., Ahmad, A.U.H., Zamir, S.I., Khalid, F., Mohsin, A.U. and Gillani, S.M.W. (2013). Performance of multicut forage sorghum under various sowing methods and nitrogen application rates. *Journal of Animal* and *Plant Sciences*, *23*(1): 232–239.

Atumo, T.T., Mengesha, G.G., Heliso, M.F., and Kalsa, G.K. (2022). Yield Dynamics and Nutrient Quality of Napier Grass (*Pennisetum purpureum*) Varieties under Consecutive Harvests. *Ethiopian Journal of Science* and *Sustainable Development*, *9*(1): 1–19.

Atumo, T.T., Kauffman, D., Talore, D.G., Abera, M., Tesfaye, T., Tunkala, B.Z., Zeleke, M. and Kalsa, G.K. (2021). Adaptability, forage yield and nutritional quality of alfalfa (*Medicago sativa*) genotypes. *Sustainable Environment*, *7*(1):1895475.

Balmuri, S.S. and Sajjan, A.S.B. (2018). Grouping of Landraces Based on Seed, Seedling and Plant Morphological Traits in rabi Sorghum [Sorghum bicolor (L.) Moench]. *International Journal of Current Microbiology* and *Applied Sciences*, *7*(09): 1583–1592.

Bhat, B.V. (2019). Breeding forage sorghum. In C. Aruna, K.B.R.S. Visarada, B.V. Bhat, and V.A. Tonapi (Eds.), *Breeding Sorghum for Diverse End Uses* (pp. 175–191). Woodhead Publishing.

Bos, H.J., Tijani-Eniola, H., and Struik, P.C. (2000). Morphological analysis of leaf growth of maize: Responses to temperature and light intensity. *Netherlands Journal of Agricultural Science*, *48*(2): 181–198.

Campbell, C., and Madden, L. (1990). *Introduction to Plant Disease Epidemiology* (1st ed.). Wiley-Interscience, USA

Chen, J., Zhu, M., Liu, R., Zhang, M., Lv, Y., Liu, Y., Xiao, X., Yuan, J. and Cai, H. (2020). BIOMASS YIELD 1 regulates sorghum biomass and grain yield via the shikimate pathway. *Journal of Experimental Botany*, *71*(18): 5506–5520.

Collet, I.J. (2004). Forage Sorghum and Millet. *Agfact (NSW) P2.5.41* (3rd ed. Available at: http://betuco.be/coverfodder/Fodder%20sorghum-millet.pdf

CSA. (2018). Report on Crop and Livestock Product Utilization (Private Peasant Holdings, Meher Season). The Federal Democratic Republic of Ethiopia Central Statistical Agency, Addis Ababa, Ethiopia.

Getachew, G., Tariku, S., Melese, L., Selamawit, M., and Dizgo, C. (2021). Genetic variability in sorghum (*Sorghum bicolor* (L.) Moench) genotypes for anthracnose (*Colletotrichum sublineolum*) resistance, growth and yield related traits at Arba Minch and Derashe districts in southern Ethiopia. *Journal of Agricultural Science* and *Practice*, *6*(2): 41–59.

Gomez, K.A., and Gomez, A.A. (1984). *Statistical Procedures for Agricultural Research*. *2nd ed*. John Wiley and Sons, Inc. New York, Chichester, Brisbane, Toronto and Singapore. 680 pp.

Halim, R.A., Shampazuraini, and Idris, A.B. (2013). Yield and nutritive quality of nine Napier grass varieties in Malaysia. *Malaysian Society Animal Production*, *16*(2): 37–44.

Hassan, S.A., Mohammed, M.I., and Yagoub, S.O. (2015). Breeding for dual purpose attributes in sorghum: Effect of harvest option and genotype on fodder and grain yields. *Journal of Plant Breeding* and *Crop Science*, *7*(4): 101–106.

Havilah, E.J. (2017). Forages and Pastures: Annual Forage and Pasture Crops—Species and Varieties. *Reference Module in Food Science*. Available at: https://doi.org/10.1016/B978-0-08-100596-5.21855-6

Kebrom, T.H., McKinley, B., and Mullet, J.E. (2017). Dynamics of gene expression during development and expansion of vegetative stem internodes of bioenergy sorghum. *Biotechnology for Biofuels*, *10*(1): 1–16.

Kiran, B.M., and Patil, P.V. (2019). Integrated management of leaf blight of sweet sorghum caused by *Exserohilum turcicum* (Pass.) Leonard and Suggs. *Indian Phytopathology*, *72*: 63–69.

Koester, R.P., Skoneczka, J.A., Cary, T.R., Diers, B.W. and Ainsworth, E.A. (2014). Historical gains in soybean (*Glycine max* Merr.) seed yield are driven by linear increases in light interception, energy conversion, and partitioning efficiencies. *Journal of Experimental Botany*, *65*(12):3311–3321.

Krishnamurthy, K., Jagannath, M.K., Rajashekara, B. G., and Raghunatha, G. (1974). Estimation of Leaf Area in Grain Sorghum from Single Leaf Measurements. *Agronomy Journal*, *66:* (4544–545).

Lauer, J. (2006). *The Relationship between Corn Grain Yield* and *Forage Yield : Effect of Moisture, Hybrid* and *Environment*. University of Wisconsin, Available at: http://128.104.50.45/AA/pdfs/A041.pdf

Madhusudhana, R. (2019). Genetics of important economic traits in sorghum. In C. Aruna, K. B. R.S. Visarada, B. V. Bhat, & V.A. Tonapi (Eds.), *Breeding Sorghum for Diverse End Uses* (pp. 141–156). Woodhead publishing.

Mahfouz, H., Mohamed Ali, A.M., Megawer, E.A. and Mahmoud, A.S. (2015). Response of Growth Parameters, Forage Quality and Yield of Dual-Purpose Sorghum to Re-Growth and Different Levels of FYM and N Fertilizers in New Reclaimed Soil. *International Journal of Current Microbiology* and *Applied Sciences*, *4*(11): 762–782.

MOA (Ministry of Agriculture). (2016). *Crop Variety Register Issue No. 18*. Plant variety release, protection and seed quality control directorate, Addis Ababa, Ethiopia.

Mohammed, M.I. (2010). Sorghum for feed and fodder production. *Regional Workshop on Optimum Industrial utilization of Sorghum in Sudan*, 1–10 April, Khartoum North. Sudan

Naharudin, N.S., Muhmmad, A.H., and Zaini, A.H. (2021). Relationship among yield and quality traits in Sorghum bicolor L. Moench. for biomass and food utilization. IOP *Conference Series Earth* and *Environmental Science, 756*. https://doi.org/10.1088/1755-1315/756/1/012067

Narkhede, G.W., Mehtre, S.P., Jadhav, R.R., and Ghuge, V.R. (2017). Correlation and Path Analysis for Grain Yield , its Components and Drought Tolerance in Sorghum [*Sorghum bicolor* (L.) Moench]. *Journal of Agriculture Research* and *Technology*, *42*(3): 173–178.

Ngo, L.T. (2017). Effect of Blue-Violet Light on Antioxidants in Sorrento Broccoli. Available at: https://www.researchgate.net/publication/314948003

NMA. (2021). *Rainfall, minimum* and *maximum temperatures National Meteorology Agency:* Daily Weather. www.https//ethiomet.gov.et

Payne, R., Murray, D., Harding, S., Baird, D., and Soutar, D. (2015). *Introduction to Genstat® for Windows* (18th Ed.). VSN International, 2 Amberside, Wood Lane, Hemel Hempstead, Hertfordshire HP2 4TP, UK.

Plessis, J. (2008) Sorghum Production. ARC-Grain Crops. Available at: http://www.nda.agric.za/docs/Infopaks/FieldCrops_Sorghum.pdf

Schrader, J., Shi, P., Royer, D.L., Peppe, D.J., Gallagher, R.V., Li, Y., Wang, R., and Wright, I. J. (2021). Leaf size estimation based on leaf length, width and shape. *Annals of Botany*, *128*(4):395–406.

Shapiro, B.I., Gebru, G., Desta, S., Negassa, A., Negussie, K., Aboset, G., and Mechal, H. (2015). Ethiopia livestock master plan: Roadmaps for growth and transformation, Addis Ababa, Ethiopia. Available at: https://doi.org/10.11648/j.aff.20140303.11

Tarawali, S.A., Tarawali, G.A., Larbi, A., and Hanson, J. (1995). *Methods for the Evaluation of Legumes, Grasses* and *Fodder Trees for Use as Livestock Feed.* (ILRI Manual; No. 1). *ILRI (International Livestock Research Institute),* Nirobi, Kenya. Available at: https://research.wur.nl/en/publications

Thakur, R., Reddy, B.V., and Mathur, K. (2007) *Screening Techniques for Sorghum Diseases. Information: Bulletin No. 76*, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India. Available at: http://oar.icrisat.org/id/eprint/4062

Vinutha, K.S., Kumar, G.S.A., Blümmel, M. and Rao, P.S. (2017). Evaluation of yield and forage quality in main and ratoon crops of different sorghum lines. *Tropical Grass*lands-*Forrajes Tropicales*, *5*(1): 40–49.

Weraduwage, S.M., Chen, J., Anozie, F.C., Morales, A., Weise, S.E., and Sharkey, T.D. (2015). The relationship between leaf area growth and biomass accumulation in *Arabidopsis thaliana*. *Frontiers in Plant Science*, *6*: 1–21.

Wheeler, B.J. (1969). An Introduction to Plant Diseases. John Wiley and Sons, Inc. Mitton, 374 pp.