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ARTICLE

Evaluation of Sorghum (*Sorghum bicolor*) Landraces for Drought Tolerance Using Morphological and Yield Characters under Rainfed Conditions of Sub Region Hagaz, Eritrea

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ABSTRACT

Sorghum is an important food crop in Eritrea where it is widely grown in the mid and low lands, of semi-arid regions. Eritrea being the center of origin of sorghum, a large variability exist in its landraces being grown by the farmers since generations. In order to improve the productivity of sorghum under moisture stress conditions, it is imperative to evaluate these landraces for drought tolerant characteristics and their use for further crop improvement programmes. Therefore, a field study was conducted in a randomized complete block design with three replications to estimate the extent of genetic variability of 20 sorghum genotypes for moisture stress tolerance using various morphological, phenological, yield and yield related parameters under rainfed conditions at Hagaz Research Station. Significant difference was observed for almost all the characters in the individual analysis of variance suggesting that these sorghum accessions were highly variable. Accessions EG 537, EG 1257, EG 849, EG 791, EG 783 and EG 813 showed promising results for post flowering drought tolerance, grain yield and stay green traits. Higher PCV and GCV were also obtained in parameters like plant height, leaf area, biomass, peduncle exertion, panicle length, and grain yield and panicle weight. The genotypes also exhibited varying degrees of heritability estimates. Characters such as plant height, panicle length, days to flowering and maturity showed higher heritability. Cluster analysis revealed that sorghum landraces were grouped on the basis of their morphological traits and geographical sites. 77.3% of the total variation of sorghum landraces was contributed by the first four principal components analysis having Eigen value > 1. Overall, the current study confirmed that EG 537, EG 849, EG 1257, EG 791, and EG 813 are drought tolerant sorghum landraces during post flowering stage.

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1. Introduction

Sorghum [*Sorghum bicolor (L.)* Moench] ranks fifth worldwide after wheat, rice, maize, and barley [1]. The crop is produced for grain which is used for food, and stalks used for fodder and building materials in developing countries. In developed countries, grain or sweet stem of sorghum is used primarily as animal feed, making sugar, syrup, and molasses [2]. This crop is widely adaptable to several types of stresses, though its production has been limited to water- and heat-stresses within subtropics and tropical regions of the world [3,4].

Sorghum is an important food crop in Eritrea where it is widely grown in the mid lands, low lands and semi-arid regions of Eritrea [5]. Eritrea is a center of origin and diversity for sorghum which exists a large number of variability. As a result, a large number of sorghum germplasm accessions have been collected by the Eritrean Genetic Resource Center, in the National Agricultural Research Institute (NARI) since 1993. Even though most of the sorghum accessions collected, they have not been characterized and evaluated using morphological, biochemical and DNA molecular markers [5].

The local landraces have been grown for generations in Eritrea and have exhibited useful characters to adapt under drought conditions. Farmers prefer these landraces due to their ability to produce some yield under low rain fall conditions in a situation when modern cultivars fail.

In addition sorghum productivity in Eritrea is less than 1 t/ha^{-1} which is below the average global production [6]. This low productivity of sorghum is due to moisture stress, *Striga* weed and poor understanding and exploitation on the potentials of the genetic diversity in the country. Post-flowering drought stress is the most important factor that severely reduces the yield. Therefore, the present investigation was carried out to evaluate the sorghum land races for drought tolerance using morphological and yield characters.

2. Materials and Methods

The experiment was conducted under rainfed condition at Hagaz Research Station which is located in Anseba region, about 25 kilometers South West of Keren town, at an altitude of 860 meters means above sea level. The area receives a mean annual rainfall ranging from 300 mm to 400 mm. It is characterized by hot and dry climate where minimum and maximum temperature ranges from 24 °C and 42 °C, respectively. It has a sandy soil with fair amount of clay and silt [7].

The germplasm used in this field study comprised of 20 sorghum genotypes including 11 accessions selected from Zoba Gash Barka, 5 from Zoba Anseba and 3 from Zoba Debub. Among the 20 genotypes, 19 are landraces and one genotype B-35 was an improved cultivar obtained from International Crop Research Institute for Arid and Semi-Arid Tropics (ICRISAT) (Table 1). These genotypes were tested in randomised complete block design with three replications during summer, 2017. All the genotypes were sown on 7th July at a plant to plant and row to row spacing of 20 cm and 75 cm, respectively with uniform fertilizer and agronomic practices.

Table 1. Sorghum genotypes used in this study along with their local names and area of origin

No	Accession Number	Local name	Area of collection
1	EG 849	Hugurtay	Gash Barka
2	EG 786	Embulbul	Gash Barka
3	EG 526	Wedi-Aker	Gash Barka
4	EG 469	TsedaBazenay	Gash Barka
5	EG 537	Anseba	Debub
6	EG1224	Muhagen	Gash Barka
7	H-35-1	TsedaMeshala	Debub
8	EG 836	Hugurtay	Anseba
9	EG 711	Embulbul	Anseba
10	EG 1257	Gedem hamam	Gash Barka
11	B-35	B-35	ICRISAT
12	EG 783	Aklomay	Gash Barka
13	EG 791	Koro-Kora	Gash Barka
14	EG 787	Duruta	Gash Barka
15	EG 782	Tseda Hele	Debub
16	EG 789	Ajebsidu	Gash Barka
17	EG 806	Hariray	Gash Barka
18	EG 481	Wedi Susa	Anseba
19	EG 813	Wedi-Ferej	Anseba
20	EG 797	Wedi Aker Short	Anseba

Note: Except B-35 which is an improved type from ICRISAT others are Land races and H-35-1 failed.

In this study various morphological, phenolgical, yield and yield related traits that contribute for drought tolerance assessment were included. The data recorded included plant height, leaf area, panicle orientation, time to 50% flowering, days to maturity, root length, flag leaf area, peduncle exertion, panicle length and width. After harvesting each of the land races depending upon their time of maturity (70-90 days), the root zone of randomly selected plants was given sufficient water to soften the soil. Thereafter, roots were manually pulled and the length of primary roots was measured with the help of measuring scale. Over all agronomic scores were taken based on a scale of 1 to 5 where 5 = most desirable and 1 = least desirable.

Other characters such as grain yield, 1000 grain weight, harvest Index and stay-green scores at maturity based on visual ratings [8] were assessed. Stay green was evaluated on 1 to 5 scale basis where 1 = < 10% leaves stay green and 5 = > 75% leaves stay green which are most desirable based on the proportion of leaf area of normal sized leaves that had greenness and dried leaves. The rate of stay green determines the maintenance of quality flowers and seed set [9].

Data collected on the various morphological traits were analysed using the GENSTAT 14 Statistical software, Carl Pearson correlation matrix, Principal component analysis (PCA), Cluster analysis was also done using the UPGMA system. Dendrograms were constructed using the SAHN Soft Ware Program.

Analysis of Genetic, and Genotypic Variability, Genotypic and phenotypic coefficient of variation and broad sense heritability were estimated using the formulas illustrated below.

i. Genotypic variance, GV= MSg-MSe/r where MSg = mean square of genotypes, M Se = mean square of error, and r = number of replications.

ii. Phenotypic variance, PV= GV+ MSe where GV = genotypic variance and MSe = mean square of error.

iii. Phenotypic coefficient of variation, PCV = $\sqrt{(PV)}/\bar{x}$ * 100 where PV = phenotypic variance and x^{-} = mean of the character.

iv. Genotypic coefficient of variation, GCV =$\sqrt{\bar{x}}$ *100 where GV = genotypic variance and $\bar{x}$ = mean of the character.

v. Heritability (broad sense heritability), H= $\sqrt{GV}/PV$ = where GV and PV are genotypic and phenotypic variances respectively.

3. Results and Discussion

3.1 Morphological and Phenological Parameters

The data on various morphological parameters like plant height, leaf area, agronomic score, root length, stay green, flag leaf area and phenological parameters like days to flowering and days to maturity evaluated in the study have been presented in Table 2 and discussed here below.

Plant height*:* A critical perusal of the data in Table 2 reveal that the plant height of different sorghum landraces ranged from 107.4 cm to 277.3 cm. While landraces EG 836 and EG 813 produced significantly taller plants of height 277.3 cm and 258.4 cm, respectively, the improved variety B-35 and landrace EG 797 produced significantly dwarfed plants of 107.4 cm and 128.9 cm height, respectively. The remaining land races produced plants of medium height ranging from 207.4 cm to 246.5 cm. This is in conformity with Nouri, R. A. H. [10], who reported that there was significant variation among the sorghum landraces in plant height.

Leaf area: The leaf area of different landraces ranged from 259.9 cm^2 to 433.1 cm^2 (Table 2). Among the tested landraces EG 791, EG 836, EG 782, EG 537, EG 849 and improved variety B-35 produced significantly higher leaf area resulting in higher transpiring and photosynthetic surface area than remaining landraces. This is in agreement with Khaliq, I., et al. [11], who reported that although, leaf area has positive correlation with grain yield in many cereal crops but larger leaf area might cause more water losses due to more evapo-transpiration from the surface. Mortlock, M.Y. and Hammer, G.L. [12] reported that plants having larger leaf area transpire more water than plants with smaller leaf area.

Agronomic score: There were statistically significant differences in overall agronomic scoring among the sorghum landraces (Table 2). Significantly higher (4.3-5.0) agronomic score was recorded by accessions EG 526, EG 469, EG 1224, EG 791, EG 849, EG 789, EG 806, EG 813, EG 797 and EG 787. Whereas lower score (3-3.7) was recorded by accessions EG 836, B35, EG-782 and EG 786 (Table 2). This was in disagreement with Tesfamichael, A., et al. [13], who reported that EG 791, EG 711, EG 783, EG 836, EG 782 were among the varieties scored higher agronomic score because of comparatively favourable gene environment interaction obtained under mid hill conditions of Hamelmalo experiencing comparatively less drought stress in off season.

Root length: There was significant difference among the sorghum landraces in root length which ranged from 38.0 cm to 47.23 cm (Table 2.). Among the land races, EG 789 (47.23 cm), EG 1257 (43.7 cm) and EG 469 (40.1 cm) being statistically at par produced significantly longer roots to extract water from deeper layers for drought tolerance. On the other hand land races EG 786, EG 723 and EG 711 produced significantly shorter roots (24.9 cm ~ 27.8 cm.) making the plants susceptible to moisture stress. This study showed that roots are the first plant parts that are affected by moisture stress and express their response in the leaf surface. This is in agreement with Xiong L., et al. [14] and Khodarahmpour, Z. [15], who reported that roots are the place where plants first encounter water stress which senses and responds to the stress condition. According to the researchers [16,17], root length is an important trait for drought tolerance response in crop varieties especially if the variety/landraces has a longer root growth it has the ability for resistance to drought and produce higher yield.

Stay green: There was statistically significant difference among the sorghum landraces for stay green with the values ranging from 2.67-5.0 (Table 2). Except landraces EG 786, EG 711, EG 782 and EG 481 all other land races under study were superior in stay green character. This study confirmed that a variety/landrace with better stay green behavior plays a significant role in post flowering drought stress by avoiding leaf senescence during grain filling stage. This is in agreement with the report of Kouressy, M. [18], who confirmed that further increase in yield can be achieved through increasing the sink capacity by improving the assimilate availability through early expression of stay-green traits and delaying leaf senescence.

Flag leaf area: There was statistically significant difference among the sorghum landraces in flag leaf area (Table 2). Landraces that scored higher flag leaf area were EG 789, B-35, EG 1224, EG 836, EG 537, EG 782 with the value of 216.0 cm^2, 193.7 cm^2, 176.7 cm^2, 164.1 cm^2, 159.8 cm^2, and 156.6 cm^2, respectively. Whereas landraces EG 786, EG 787, EG 813, EG 783 and EG 711 produced lower (73.0 cm^2 ~ 110.5 cm^2) flag leaf area helping them to transpire less water for better drought tolerance. The current study confirmed that crops with optimum flag leaf area have less transpiring surface than crops with wider flag leaf area. This is in agreement with Tsuji, W., et al. [19], who reported that although, flag leaf area has positive correlation with grain yield in many cereal crops but more flag leaf area might cause more water losses due to more evapotranspiration from the surface and that drought tolerance in sorghum is associated with its smaller flag leaf area. Khaliq, I., et al. [11] also reported optimum leaf area is required for carrying out adequate amount of photosynthesis to run the essential processes of plant growth. Furthermore' Karamanos, A. J. and Papatheohari, A. Y. [20] reported that, traits like reduced leaf area and prolonged stomata closure, decrease water loss, which results in reduced dry matter production and reduced final yield.

Reported [21] that in flag leaf photosynthetic activity had important role in rice grain yield. It is also reported [22] that the top three leaves especially flag leaf contributes most to grain yield and greater carbohydrate translocation from vegetative plant parts to the spikelets. So flag leaf has an important role in rice yield by increasing grain weight by 41 to 43 percent.

Days to flowering: There was significant difference among the sorghum landraces for days to 50% flowering. The current experiment confirmed that sorghum landraces took less number of days (< 63 days in average) to flowering due to stress condition (Table 2). However, B-35, EG 836, EG 782, EG 813 being at par took significantly more (67-70) number of days to 50 percent flowering over remaining land races. This is in agreement with Nouri, R. A. H. [10], who reported that stressed plants significantly took fewer days to reach 50% flowering compared to plants grown at normal condition.

Days to maturity: There was statistically significant difference among the sorghum landraces for days to maturity. The current study confirmed that early and medium maturing varieties gave better grain yield in comparison with late maturing ones. This is in agreement with Nouri, R. A. H. [10], who reported that stressed plants took significantly less days to reach milking and maturity stages compared to late matured plants. It was observed that early maturity had an obvious advantage in grain yield and harvest index under drought conditions because late flowered plants deplete more moisture before the critical periods. Therefore they are not suitable to be cultivated in low rain fall areas.

3.2 Yield and Yield Related Parameters

The data on grain yield, biomass yield, harvest index and yield related parameters like panicle length, panicle width, panicle weight and thousand grain weight have been presented in Table 3 and discussed here below.

Panicle length: There was a significant difference among the sorghum landraces in panicle length. Landraces with significantly higher panicle length (22.2 cm ~ 23.7 cm) were EG 789, EG 791 and B-35. Whereas, the landraces with lower panicle length (8.4 cm ~ 10.2 cm) were EG 786, EG 836, EG 782 and EG 783 and EG 481 (Table 3). The period of stress might have stimulated stressed plants to hasten the development of their root system and consequently accelerates head development. These results were in agreement with the findings of Younesi, O and Moradi, A. [23] but in contradiction to the finding of Tesfamichael, A., et al. [13], who reported that EG 469 (28 cm) scored highest and EG 836 (9 cm) scored the lowest panicle length due to gene environment interaction. The present study was conducted at a location having comparatively more drought stress with higher maximum and minimum temperature and lower rainfall than the location of Hamelmalo where Tesfamichael, A., et al. [13] conducted his study in off season.

Panicle width: There was significant difference among the sorghum landraces for panicle width. Sorghum landraces with higher panicle width were, EG 836, EG 782, EG 849, EG 813, EG 537, and EG 789, values ranging from 14.10 cm to 22.7 cm. This result is in disagreement with Tesfamichael, A., Githiri, S.M., Kasili, R., Woldeamlak, A. and Nyende, A.B., who reported that EG 889, EG 797, and EG 469 were among the landraces that scored higher panicle width when grown under comparatively less drought prone environment of Hamelmalo having comparatively lower temperatures and higher rainfall.

Table 2. Mean performance of sorghum landraces for morphological and phenological parameters.

S.N.	LR	PH	LA	FLA	RL	STG	AS	DF	DM
1	EG 849	207.6	373.3	149.0	35.6	4.67	4.7	61	89
2	EG 786	219.8	259.9	73.0	24.9	2.67	3.7	65	87
3	EG526	176.8	313.9	125.8	33.4	4.67	5.0	62	90
4	EG 469	237.7	339.5	142.4	40.1	5.00	5.0	64	91
5	EG 537	246.5	381.2	159.8	38.3	4.33	4.0	63	89
6	EG1224	229.9	348.9	176.7	31.1	5.00	5.0	63	90
7	EG 836	277.3	431.9	164.1	37.6	5.00	3.0	69	93
8	EG 711	232.0	313.1	100.2	27.8	3.00	4.0	60	87
9	EG 1257	234.2	350.2	141.4	43.7	4.33	4.7	65	90
10	B-35	107.4	420.0	193.7	38.4	4.33	3.3	70	98
11	EG783	242.0	349.5	109.8	26.7	4.00	4.3	49	70
12	EG 791	239.3	433.1	142.1	37.2	5.00	5.0	65	89
13	EG 787	239.9	335.3	106.5	29.9	4.33	5.0	63	96
14	EG 782	226.1	386.0	156.6	34.1	3.33	3.7	68	91
15	EG 789	227.1	403.2	216.0	47.2	5.00	4.3	64	93
16	EG 806	207.4	308.4	115.2	28.8	4.33	4.7	59	86
17	EG 481	229.3	307.7	123.5	26.9	3.00	4.0	54	76
18	EG 813	258.4	379.3	110.5	38.0	4.00	4.3	67	90
19	EG 797	128.9	378.9	148.9	31.9	4.33	4.7	63	87
	Mean	219.	336.1	139.7	34.3	4.23	4.3	62.9	86.6
	LSD (5%)	30.2	80.1	59.4	12.2	1.52	0.9	4.00	21.8
	CV (%)	6.3	10.3	21.9	17.7	16.2	8.0	2.4	10
	P.value	<0.001	0.013	0.04	0.03	0.04	<0.001	<0.001	0.04

Note: LR= Landraces PH=Plant height (cm); LA=Leaf area (cm^2); FLA= Flag leaf area (cm^2) RL= Root length (cm); STG= Stay green (1-5 scale); AS= agronomic score, (1-5 score); DF: Days to flowering, DM: Days to Maturity, LSD = Least significant difference; CV (%) = Coefficient of Variation.

Panicle weight: There was no significant difference among the sorghum landraces for panicle weight but numerically EG 1257 with minimum and EG 526 showed maximum value in panicle weight with 30.0 grams ~ 52.8 grams, respectively. The decreased panicle weight was due to reduced grain size and potential grain number under water stress. These results are in agreement with Bakheit, B. R. [24] and Ahmed, S. H. [25] and who found that moisture stress reduced the mean grain yield per plant and panicle weight per plant during flowering and grain filling period. Furthermore Balko, L. G. [26] reported that water stress during growth stage three usually reduces the seed weight and becomes smaller in size.

Thousand grain weight: Thousand grain weight showed statistically significant difference among the sorghum landraces. Landraces with higher thousand grain weight were, EG 791, EG 789, EG 806, EG 849, EG 836 and EG 787 with values ranging from 15 grams to 28.33 grams per 1000 seed weight (Table 3). This might be due to better capability of these genotypes to tolerate drought stress by maintaining higher water content, which helped in prolonging their grain filling period by translocation of photosynthates from the source (foliage) to the sink (grains) for longer period.

Grain yield: Grain yield showed a significant difference among the sorghum landraces (Table 3). Land races EG 1257, EG 537, EG 849, EG 791, EG 813 and EG 789 being statistically at par resulted in significantly higher grain yield. The study confirmed that moisture stress during post flowering stage affected the yield potential of the sorghum landraces evaluated in the study area. This was in agreement with Sheoran, I.S. et al. [27], who reported such yield reduction due to drought stress in wheat and rice. Blum, A. [28] also reported drought escape by shortening the life cycle of the crops at the expense of the yield potential of the crop in drought prone areas. Yield potential obtained under stress serves as important criteria in the selection for drought tolerance in varieties or landraces. Rehman, S., et al. [29] reported that yield potential of the landrace is the principal selection index used commonly under drought stress conditions.

Biomass yield: There was significant difference among the sorghum landraces in biomass yield which ranged from 5670 kg/ha to 7530 kg/ha. The current experiment showed that landraces having longer duration recorded higher biomass than early maturing ones. This is in agreement with Blum, A. [30], who reported that the genotypes with longer growth duration produced more stover and total biomass with a lesser amount of grains per panicle and per unit area, as compared with genotypes of shorter growth duration.

Harvest index: There was no significant difference among the sorghum landraces for harvest index but numerically EG 783 recorded higher harvest index and EG 469 with minimum harvest index values ranging from 13.6% to 32.83% respectively. This non-significance is due to the reduced yield and increased biomass that leads to lower harvest index. This is in contradiction with results of Blum, A. [30] ,who reported that harvest index varied extensively among the genotypes due to moisture stress.

Overall the results related to superior landraces could be discussed using the major yield contributing parameters.

The superior landrace EG 537 was characterized by early maturity, stay green, higher panicle width and higher grain yield, EG 849 characterized by early flowering and maturity, stay green, higher panicle width and grain yield, EG 1257 by longer root length and higher grain yield, EG 791 was characterized by higher leaf area, stay green, higher thousand seed weight and grain yield, EG 783 was characterized by early flowering and maturity, higher harvest index and grain yield, EG 813 was characterized by higher root length, panicle weight, panicle width and higher grain weight as compared to the rest of the landraces. In general their superiority is based on grain yield obtained at harvest and are listed in the conclusion part for further breeding and research.

Table 3. Mean performance of sorghum landraces for yield and yield related parameters .

S.No.	LR	PL (cm)	PWTH (cm)	PWT (g)	THGWT (g)	GY (t/ha)	BM (t/ha))	HI (%)
1	EG849 849	9.9	21.8	37.7	25.7	17.0	65.0	25.8
2	EG786 cm^2 786	8.4	14.1	34.7	20.7	9.4	43.0	22.3
3	EG526	16.8	15.5	52.8	21.0	8.9	38.3	23.3
4	EG469	20.6	15.4	36.1	18.7	10.1	73.4	13.6
5	EG537 537	14.2	20.9	40.2	21.3	18.3	75.3	24.6
6	EG12244	20.5	16.3	44.4	24.7	11.3	40.9	27.9
7	EG836 836	9.8	22.3	38.6	25.0	6.8	44.7	14.9
8	EG711 711	14.0	16.2	35.8	23.3	11.0	49.5	23.2
9	EG1257 1257	19.1	19.0	30.0	21.7	18.2	69.3	26.4
10	B-35	22.2	14.2	41.1	18.5	6.4	32.1	20.2
11	EG783	10.2	16.3	45.0	20.7	14.3	50.9	32.8
12	EG791 791	22.6	18.1	40.8	28.3	16.0	64.3	25.1
13	EG787 787	9.8	19.5	40.8	25.0	12.4	56.7	21.9
14	EG782 782	12.1	22.2	45.6	22.3	11.0	43.1	24.3
15	EG789 789	23.7	19.9	50.4	26.0	12.8	52.9	24.9
16	EG806 806	10.9	17.8	46.4	26.0	10.7	39.3	27.1
17	EG481 481	9.9	14.3	42.1	19.7	9.3	45.3	20.5
18	EG813 813	15.4	21.2	50.2	16.7	12.9	47.0	27.3
19	EG797 797	17.4	14.1	42.8	15.0	7.2	29.3	23.5
	Mean	15.1	17.87	42.3	22.11	11.80	50.5	23.62
	LSD (5%)	2.7	5.12	NS	5.12	5.63	25.6	NS
	CV (%)	6.8	2.6	22.9	7.0	14.0	17.2	21.5
	P.value	<0.001	0.006	0.06	<0.001	<0.001	0.002	0.26

Note: LR= Landraces; GY=Grain yield (Q/ha); BM=Biomass (Q/ha); PL=Panicle length (cm); PWTH=Panicle width (cm); PS=Panicle size (cm^2); PWT=Panicle weight (g); HI=Harvest Index (%); THSWT=Thousand grain weight (g); LSD=Least significant difference; CV (%) =Coefficient of Variation.

3.4 Correlation Analysis of Selected Morphological Traits

Plant height had significant and positive correlation with grain yield, biomass and non-significant positive correlation with harvest index. This means that landraces having tall and medium plant height had both higher grain yield and biomass. This is in agreement with Mohammadi, M., et al. [31], who reported that a positive correlation between plant height and grain yield normally exist due to increased translocation of the stored dry matter from the stem reserves.

Stay green also showed a positive correlation with grain yield, biomass and agronomic score but it was negatively correlated with harvest index which implies that landraces with better agronomic and stay green trait produced significantly more yield as compared with those landraces with poor agronomic performance and senescence leaves. This is in agreement with Tesfamichael, A., et al. [13], who reported that stay-green had a positive association with grain yield and with overall agronomic score implying that genotypes with high stay green and good agronomic performance gave high grain yield.

3.5 Assessment of Heritability, Phenotypic and Genotypic Coefficients of Variations

Studying phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) is useful for comparing the relative variability of the landraces taking into account different traits.

Generally, the GCV were lower in magnitude than the PCV (Table 5). High GCV and PCV were also observed for some characters. This reveals that the genotypes have a broad genetic base as well as good potential in responding positively to selection. High heritability estimates were observed in some characters such as plant height, panicle length, days to flowering and maturity and these characters are expected to respond positively to selection. This result is in conformity with Tesfamichael, A., et al. [13], who reported that highest heritability was recorded in days to flowering, days to maturity, panicle length and overall agronomic score. Eckebil, J.P., [32] also confirmed that characters like number of nodes per plant, panicle length, and early number of leaves per plant, plant height, days flowering and days to maturity would respond positively to selection due to higher values related to broad sense heritability.

3.6 Principal Component Analysis of Various Morphological Traits

Principal component (PC) analysis showed that the first four, out of the 7 PCs explained majority of the total variation. Eigen value is mathematical value of a parameter with non-zero value under a given condition. These four PCs with Eigen value ≥1 (Table 5.) contributed 77.3% of the total variability amongst the sorghum landraces assessed for various morphological traits (Table 5). The

Table 4. Simple correlation analysis among morphological traits recorded under drought stress condition

	PH	LA	AGS	STG	PEX	DFL	DM	GY	BM	HI	TSWT	PWT	RL	FLA
PH	1													
LA	–0.03	1												
AGS	–0.01	–0.23	1											
STG	0.01	0.57*	0.42	1										
PEX	–0.04	0.24	0.62**	0.65**	1									
DFL	–0.14	0.47*	–0.30	0.23	0.24	1								
DM	–0.24	0.43	–0.09	0.42	0.39	0.90**	1							
GY	0.45*	0.11	0.37	0.15	0.21	–0.22	–0.15	1						
BM	0.55*	0.10	0.30	0.26	0.34	–0.08	0.01	0.79**	1					
HI	0.03	–0.08	0.30	–0.09	–0.08	–0.45	–0.43	0.54*	0.05	1				
TSWT	0.41	0.16	0.16	0.33	0.09	–0.02	0.14	0.36	0.29	0.14	1			
PWT	–0.14	0.13	0.14	0.20	–0.02	–0.11	–0.05	–0.21	–0.46*	0.33	–0.04	1		
RL	0.05	0.66**	0.02	0.62**	0.61**	0.54*	0.61**	0.30	0.43*	–0.18	0.08	0.01	1	
FLA	–0.24	0.73**	–0.13	0.61**	0.39	0.39	0.51*	–0.02	0.01	–0.13	0.16	0.20	0.71**	1

Note:* Correlation is significant at the 0.05 level (2-tailed), **. Correlation is significant at the 0.01 level (2-tailed) PH= Plant height, LA= Leaf area AGS= Agronomic sore, STG= Stay green, PEX= Peduncle exsertion, DF= Days to flowering, DM= Days to maturity, GY= Grain yield, BM= Biomass, HI= Harvest index, TSWT= Thousand seed weight, PS= Panicle size, PWT= Panicle weight, RL= Root length, FLA= Flag leaf area remaining 3 components contributed only 15.8% towards the total morphological diversity for this set of sorghum landraces. The PC I contributed maximum towards the variability (34.3%) followed by PC II (20.7%), PC III (13%) and PC IV (9.3%). The most important characters in PC I was due to variations among the sorghum landraces mainly for days to maturity, flag leaf area, peduncle exertion, panicle length, root length and stay green. Similarly PC II was related to diversity among sorghum landraces due to specific biomass, grain yield, days to 50% flowering, and plant height. The PC III was explained mainly by variation among genotypes resulting from harvest index, panicle weight and biomass.

3.7 Cluster Analysis

The percentage similarity between accessions ranged from 0.7 to 0. 98 (Figure 1). The phenotypic dendrogram showed that the accessions could be grouped into three main clusters (I, II and III). The result of the component analysis obtained in this study was similar to those of studies [13,33,34] on various agro-morphological traits in sorghum. Moreover, the principal components analysis also showed that the variation in the germplasm materials cannot be explained on the basis of very few characters.

In order of diminishing importance, the explanation of greater proportion of the entire phenotypic diversity has involved major traits dealing with panicle width, panicle weight and peduncle exertion), as well as leaf traits like stay-green, flag leaf area and leaf area; yield related traits like grain weight and biomass and plant phenology traits plant height, days to flowering and maturity. This is in conformity with Ayana, A. and Bekele, E. [35], who described the importance of all these traits in contributing towards the overall diversity of the sorghum germplasm. These results on the effect of environment on yield components of sorghum are in conformity with those of William, W.T. et al. [36].

Morphological cluster analysis confirmed the presence of variation among genotypes. Besides, sorghum landraces indicated in cluster ‘I’ are also known for their drought tolerance and high yielding ability. These sorghum landraces were clustered together mainly based on the geographical sites (region), morphological and pedigree relationship. Likewise studies [37-39] detect clustering of sorghum accessions based on their collection site and pedigree relationship. Teshome, A., et al. [40] evaluated 117 sorghum accessions from North Shewa and South Welo regions of Ethiopia using 14 morphological traits and reported on the extensive variation of the accessions based on geographical locations.

Table 5. Estimates of means, genotypic and phenotypic variation, genotypic and phenotypic coefficients of variation and heritability for major morphological parameters.

Traits	Mean	δ^2p	δ^2g	PCV (%)	GCV (%)	h^2_{BS} (%)
Plant height	219.3	1921.0	1599.0	295.8	270.0	83.0
Leaf area	361.0	3431.0	1089.0	308.2	173.4	32.0
Number of leaves	12.2	2.4	0.8	44.4	25.6	33.0
Stay green	4.2	1.6	0.8	62.0	44.0	50.0
Agronomic score	4.3	0.5	0.3	34.1	26.4	60.0
Days to flowering	62.9	29.3	23.5	68.0	61.0	80.0
Days to maturity	88.3	45.3	33.1	71.4	61.0	73.0
Panicle width	17.8	14.9	5.3	91.0	54.0	35.0
Peduncle exertion	38.4	66.1	42.1	131.0	104.4	64.0
Panicle length	15.1	28.1	25.4	136.0	129.6	91.0
Panicle weight	919.0	101294.0	21880.0	1049.8	487.8	22.0
Grain yield	11.8	21.0	9.4	133.0	88.9	44.0
Biomass	50.5	296.9	125.1	242.2	157.2	42.0
Harvest index	24.7	58.2	4.8	153.0	44.0	8.2
Root length	34.3	73.6	18.9	146.3	74.2	26.0

Note: δ^2p = phenotypic variation, δ^2g = genotypic variation, GCV (%) = Genotypic coefficient variance, PCV (%) = Phenotypic coefficient variance and h^2_{BS} (%) = Heritability in broad-sense.

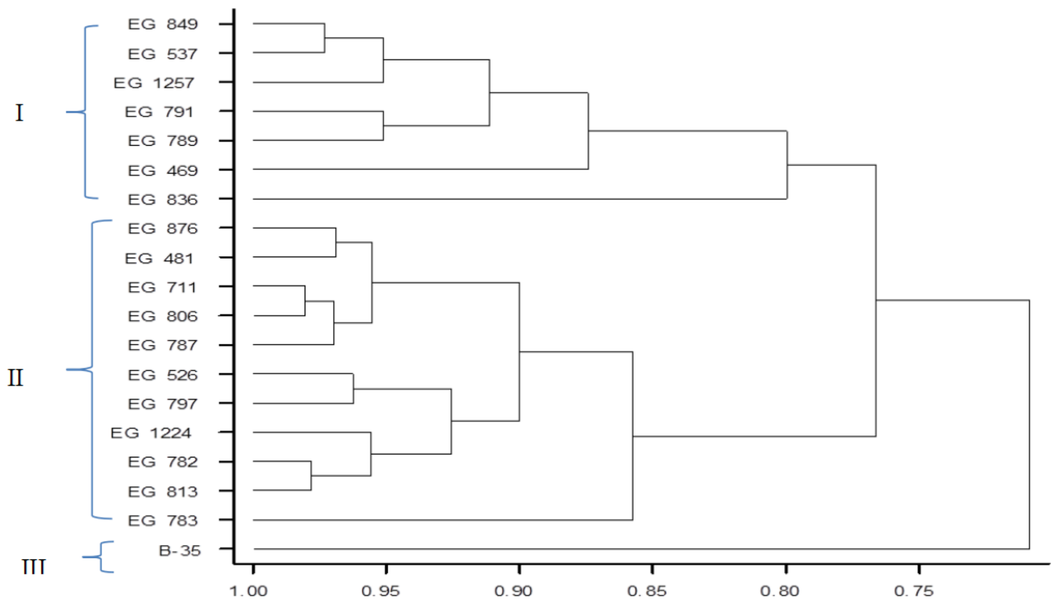

Figure 1. Genetic similarity among sorghum landraces

4. Conclusions

It can be concluded from the study that based upon grain yield and stay green characters, EG 537, EG 849, EG 1257, EG 791, EG 783 and EG 813 were the superior land races for cultivation under semi-arid conditions of Hagaz and its vicinity. The superior sorghum landraces with longer root length responding to post flowering drought tolerance were EG 789, EG 1257; EG 469, B-35, EG 537, and EG 813 with values ranging from 38 cm to 47.23 cm. High GCV and PCV observed for some characters revealed that the sorghum landraces had a broad genetic base as well as good potential responding positively to selection. High heritability estimates were observed in some characters such as plant height, panicle length, days to flowering and maturity. Having the minimum threshold Eigen of one, out of seven principal components (PCs), the first four principal components (PCs) accounted for a cumulative of about 77.3% of the whole phenotypic diversity observed among the sorghum landraces. The result of the dendogram demonstrated variation of landraces based on morphological traits and the region or place where the landraces have been collected are a valuable source for sorghum improvement programs particularly the three geographical regions mainly Gash Barka, Anseba and Debub and different parts of Eritrea as a whole.

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Conflict of Interest

There is no conflict of interest.

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ARTICLE

Management of *Fusarium anthophilum* (Pathogen of Cereals and White Yams) Using Different Measures

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ABSTRACT

Fusarium species (including *Fusarium anthophilum)* have many insidious effects on mankind, animals, and plants. Their attack may lead to diseases or spoilage, and the production of mycotoxins. This study was conducted to find solutions to the infections by *F. anthophilum*. Three sub-trials (botanical, chemical and biocontrol sub-trials) were set up using completely randomized design, and each treatment was replicated thrice. The percentage inhibition of *F. anthophilum* in the botanicals-alone subtrial (i.e., *Eucalyptus, Euphorbia, Andrographis,* and *Melaleuca* spp.) at 50% and 100% concentrations ranged from 20% to 100%. At 72, 120, and 168 HAI (hours after inoculation), Eucalyptus (all concentrations) controlled the pathogen significantly more, followed by Melaleuca (all concentrations). All the botanicals (at both concentrations) controlled *Fusarium* sp. significantly more compared to the control. Based on the second sub-trial: the best synthetic fungicide+*Trichoderma harzianum* treatment was Mancozeb100%, and the percentage inhibition by these combined chemical+biocontrol treatments ranged from 28% to 50%. Mancozeb100%, followed by Metalaxyl+Cu(I)O 100% produced the highest inhibition. All chemical treatments were significantly different compared to the control (120 hours after inoculation). Based on the third subtrial: the best Botanical+*T. harzianum* treatment was Alligator pepper100% followed by Tumeric100%. The percentage inhibition of *Fusarium* sp. by these treatments ranged from 28% to 70%. Alligator pepper100% followed by Tumeric100%, then Tumeric50%, and Eucalyptus100% … were significantly different compared to the control. Combining different agents was effective in controlling the pathogen. However, lower percentage inhibitions were obtained. More research on integrating the control agents is being admonished.

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1. Introduction

Globally, the highest quantity of yams (54 million metric tons of yams annually) comes from West Africa: Benin, Togo, Ghana, Côte d'Ivoire and notably Nigeria. Nigeria is the highest world producer of yams [1,2]. Yams serve various socio-economic roles; as a source of food, medicines, and industrial raw materials. Cereals (i.e., maize, millet, sorghum, barley, and rice) are major staple foodstuffs that sustain most of the world's population. These very important agricultural produce are susceptible to infection by *Fusarium* species, which cause wilting as the major symptom, and ultimately death of the plant.

However, these infections by *Fusarium* species have other insidious consequences. Nelson et al. [3] demonstrated that isolates of *F. anthophilum* (A.Braun) Wollenw and seven other *Fusarium* species produced the mycotoxin - fumonisin B1 in culture. These researchers scored *F. anthophilum* and *F. dlamini* as minor pathogens because they did not find these two species in association with corn or other major food grains. This was the first report of the production of fumonisins by *F. anthophilum, F. dlamini*, and *F. napiforme*. This scoring was based on their presence in cereal production systems only.

The production of mycotoxins was not considered by Nelson et al. [3] even though the health hazard may result in the rejection of the agricultural produce for export or consumption. Additionally, *Fusarium* species produce many mycotoxins (like zearalenone, zearalene, deoxynivalenol or nivalenol, T-2 toxin, diacetoxyscirpenol, etc.) which have economic importance due to their toxicity to animals, humans, and plants. These fungi are commonly associated with grains, and agricultural produce [4,5]. Thus many species of *Fusarium* need to be managed to mitigate their effects on agriculture and society. This is necessary considering the high yield losses (due to tuber rot, and grain contamination) as well as the excessive cost of treating cases of mycosis like fusariosis.

Nahar and Mushtaq [6] reported that *F. anthophilum* and five other *Fusarium* species infect sunflower (*Helianthus annuus*) and most of them are soil-borne plant pathogens. Ndifon and Lum [2] reported that *F. anthophilum* and seven other fungi species were isolated from rotted white yam (*Dioscorea rotundata* Poir) tubers. These tuber rot agents cause heavy yield loss of yam tubers in store annually.

Control of mycopathogens using synthetic pesticides is still very much in vogue based on their efficacy and timeliness. Abdullah et al. [7] stated that *Fusarium* species, in general, are resistant to the older azoles (e.g. itraconazole and fluconazole), and echinocandins. *Fusarium* species show variable resistance to triazoles. These researchers revealed that Amphotericin B is the most active drug, followed by voriconazole, posaconazole, isavuconazole, and natamycin. However, fluconazole, itraconazole, and micafungin have little effect on the treatment of fusariosis.

Isman [8] expressly pointed out that the impact of botanicals in agriculture is still highly limited (only pyrethrum and neem are well-established pesticides commercially). Nowadays some plant essential oil pesticides are available commercially although the use of rotenone seems to be declining. Regulatory barriers and the availability of competing products (newer synthetic pesticides, products from fermentation, and anti-microbials) that are cost-effective and relatively safe compared to their predecessors are factors militating against the use of botanicals. However, botanicals have a niche in integrated pest and disease management, organic farming, and post-harvest protection of food even in developing countries.

On another promising note, Verma et al. [9] reported that *Trichoderma* species control pathogens using mycoparasitism, competition (for space and nutrients), antibiosis (through secretion of enzymes and secondary metabolites), and induction of plant defence system. *Trichoderma* species produce a wide range of commercial enzymes (namely; cellulases, hemicellulases, proteases, and α-1, 3-glucanase), which are essential in the industry. *Trichoderma* species and other microbes may be rallied and set in battle array against pathogenic fungi like *F. anthophilum.* Based on the foregoing informative discourse, this study was carried out to assay the potential of utilizing botanical, bio-control, and chemical measures to manage *F. anthophilum* infections.

2. Materials and Methods

2.1 Site of the Study

This study was carried out at Alex Ekwueme Federal University Ndufu-Alike, Abakaliki (at 6.069°N by 8.199°E). Here the mean relative humidity is usually above 70% for 9 months per annum. Thus plant disease outbreaks are very common in the area. This university is located in the derived savannah ecological zone of Nigeria with well-drained iron-rich loamy soils which are excellent for yam and cereal cultivation.

Based on Figure 1, the patterns of the up/down bars show that the cross-over points are in August-September when the heavy rainfall coupled with low maximum temperatures result in damp weather. Moreover, the mean relative humidity is at its peak from July to September. These conditions may favour severe plant disease outbreaks.

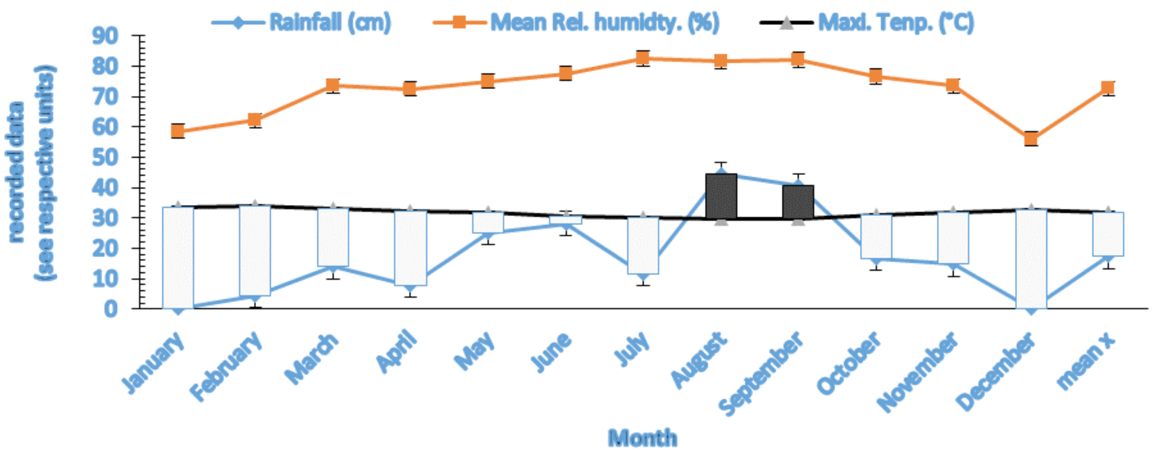

Figure 1. Climatic pattern for Abakaliki (Ebonyi State) showing the monthly rainfall, monthly mean relative humidity and maximum monthly temperatures for the area and its environs

* The error bars were calculated using standard error

Sources: 35-year climate trends. Meteoblue® Weather 2006-2020. Climate-data.org. Timeanddate.com 1999-2020 as compiled by Ndifon EM. 2020, FAG, AE-FUNAI, Nigeria.

2.2 Isolation and Identification of the Fungi Utilized in the Trials

The infected white yam tubers utilized for this research were obtained from south-eastern Nigeria. While the *Trichoderma species was* isolated from farm-land soils collected from yam farms in south-eastern Nigeria. The fungi (*Fusarium anthophilum* and *Trichoderma harzianum*) were isolated using potato dextrose agar (PDA) which was autoclaved at 120°C and 15 psi for 15 min according to the manufacturer's (LifeSave Biotech; USA) instructions. The isolated fungi were sub-cultured to obtain pure cultures, which were used to identify the fungi with the aid of literature on fungi morphology [10,11].

2.3 Trial 1: Antimycotic Effects of Botanical Extracts (Alone) on *Fusarium anthophilum*

The experiment was laid out in the Faculty of Agriculture laboratory using a completely randomized design (CRD) with 11 treatments, and each treatment was replicated thrice. The treatment set included control, Metalaxyl+Copper (I) oxide (MetCu(I)O) 50%, MetCu(I)O 100%, Melaleuca 100%, Melaleuca 50%, Euphorbia 100%, Euphorbia 50%, Eucalyptus 50%, Andrographis 50%, Andrographis 100%, and Eucalyptus 100%.

The plant extracts (i.e., Eucalyptus (*Eucalyptus globolus*), Cajeputi (*Melaleuca cajeputi*), Asthma plant (*Euphorbia hirta*), and Creat or green chiretta (*Andrographis paniculata))* were weighed at the rate of 333.3 g leaves per L of distilled water) to make 100% concentration. Metalaxyl (12%)+Copper (I) oxide (60%) is a synthetic commercial wettable powder fungicide. The plant extracts were obtained by blending the tissues, soaking them in sterile distilled water for seven hours, and then straining the suspension through double-layered Whatman No. 1 filter paper.

2.4 Trial 2: Management of *Fusarium anthophilum* Using Botanicals Concomitant with a Biocontrol Agent

The experiment was laid out in Petri dishes using completely randomized design and each treatment was replicated three times. The treatment set consisted of seven treatments (viz Tumeric 100%, Tumeric 50%, Alligator pepper 100%, Alligator pepper 50%, Eucalyptus 100%, Eucalyptus 50%, and a control (inoculated with *Trichoderma* sp. and the pathogen only)). Thus *Trichoderma harzianum* isolate AIBN was incorporated into all the Petri dishes. The control was inoculated with *F. anthophilum*. This trial was inoculated by placing the different cultures at the edge of the Petri dish. Alligator pepper is *Aframomum melegueta,* and tumeric is *Curcuma longa*. The plant extracts were prepared as discussed above.

2.5 Trial 3: Management of *T. anthophilum* Isolate Using Selected Synthetic Fungicides Concomitant with a Biocontrol Agent

The experiment was laid out in Petri dishes using completely randomized design and each treatment was replicated three times. The treatment set consisted of seven treatments (viz; MetCu(I)O) 50%, MetCu(I)O 100%, Mancozeb 100%, Mancozeb 50%, and a control). The control was inoculated with *Trichoderma* sp. and the pathogen only. Thus *Trichoderma harzianum* isolate AIBN was incorporated into all the Petri dishes. The control was inoculated with *F. anthophilum*. This trial was inoculated by placing the different cultures at the edge of the Petri dish. The commercial grades of Mancozeb 80% WP and Metalaxyl (12%)+Copper (I) oxide (60%) were utilized for this trial (utilized each at 5.0 g/L to give 100% concentration i.e. 100 µL/plate).

2.6 Data Collection (for All the Sub-trials)

The radius of each *F. anthophilum* colony was measured using a transparent ruler at 24-hour intervals starting from day 1 until each sub-trial was terminated. The percentage inhibition of the pathogen was calculated using the following equation.

$$PI = ((C - T)/C) \times 100\%$$

where,

PI = Percentage inhibition of the growth of the pathogen

C = Perpendicular* radius of the pathogen colony in the control plate

T = Perpendicular radius of the pathogen colony in the treated plate

NB: * perpendicular refers to 'right angle' in this context [12].

2.7 Data Analysis

The data were subjected to the analysis of variance (ANOVA) procedure, and the means were separated using Duncan's multiple range test (DMRT) (as obtainable with Genstat® Discovery 2nd Edition statistical package). Descriptive statistics were used to illustrate the trends in the growth of the pathogen and its management (as obtainable with IBM statistical package for social sciences (SPSS) version 25 and Microsoft Excel 365 procedure).

3. Results

3.1 The Trends of the Percentage Inhibition of the Pathogen

Percentage inhibition of the mycelial growth of *Fusarium anthophilum* due to application of low concentration of plant extracts *in vitro* is presented in Figure 1. It revealed that the best treatment was Andrographis 50% followed by Eucalyptus 50%. The percentage inhibition of *F. anthophilum* by plant extracts at 50% concentrations ranged from 22.5% to 100%.

The percentage inhibition of the mycelial growth of *F. anthophilum* due to the application of a high concentration of plant extracts *in vitro* is presented in Figure 2. The best treatment was Eucalyptus 100% followed by Melaleuca 100%. The percentage inhibition of *F. anthophilum* by plant extracts (alone) ranged from 20% to 100%.

Percentage inhibition of the mycelial growth of *F. anthophilum* due to application of *Trichoderma* species+chemical fungicides *in vitro* is presented in Figure 3. It shows that the best treatment was Mancozeb 100% followed by MetCu(I)O 100%, then Mancozeb 50%, and finally MetCu(I)O 50%. The percentage inhibition of the mycelial growth of *F. anthophilum* by synthetic fungicides+*Trichoderma* sp. ranged from 28% to 50%.

Percentage inhibition of mycelial growth of *F. anthophilum* due to application of Plant extracts+*Trichoderma* species is presented in Figure 4. It shows that the best treatment was Alligator pepper 100% followed by Tumeric 100%, then Tumeric 50%, Eucalyptus 100%, Alligator 50%, and Eucalyptus 50% in descending order of magnitude. The percentage inhibition of mycelial growth of *F. anthophilum* by plant extracts+*Trichoderma* sp. ranged from 28% to 70%.

3.2 Separation of the Treatment Means

The means were separated using the ANOVA procedure. The separation of the means of the radii of *F. anthophilum* due to the application of a low concentration of plant extracts *in vitro* is presented in Table 2. It shows that at 72 HAI, Eucalyptus 50% controlled the pathogen significantly more, followed by Melaleuca 50%, then Andrographis 50%, Euphorbia 50%, and MetCu(I)O 50%. At 120 HAI, Eucalyptus 50% controlled the pathogen significantly more, followed by Melaleuca 50%, then all the other treated plots compared to the control.

At 168 HAI, Eucalyptus 50% controlled the pathogen significantly more, followed by Melaleuca 50%, then the other treated plots compared to the control. All the treated plots controlled the pathogen significantly more compared to the control at 72, 120, and 168 HAI.

The separation of the means of the radii of mycelia of *Fusarium anthophilum* due to the application of a high concentration of plant extracts is presented in Table 3. It shows that at 72 HAI and 120 HAI, Eucalyptus 100% caused significantly more inhibition of the pathogen compared to the other treatments.

The ranking of the means of the treatments revealed that the performance of Eucalyptus 100% was followed by Melaleuca 100%, but all the other treatments (i.e. Euphorbia 100%, MetCu(I)O 100%, and Andrographis 100%) were at par.

At 168 HAI, the same trend of significant differences between the treatment means was observed, although Andrographis 100% controlled the pathogen significantly more than Euphorbia 100%, and MetCu(I)O 100%. All the treated plots controlled the pathogen significantly more compared to the control at 72, 120, and 168 HAI.

Separation of the means of the radii of mycelia of *Fusarium anthophilum* due to the application of high concentrations of chemical fungicides+ *Trichoderma* species are presented in Table 4. It shows that all the treatments were significantly different compared to the control at 120 HAI. The treatment with significantly highest inhibition rate was Mancozeb 100%, followed by MetCu(I)O 100%, then Mancozeb 50% and finally MetCu(I)O 50%.

Concerning the separation of the means of the radii of mycelia of *Fusarium anthophilum* due to the application of botanicals+ *Trichoderma* species *in vitro*, the results are presented in Table 5. At 120 HAI, Alligator pepper 100% produced the highest significantly different inhibition of the pathogen followed by Tumeric 100%, then Tumeric 50% and Eucalyptus 100%. Tumeric 50% and Eucalyptus 100% were at par.

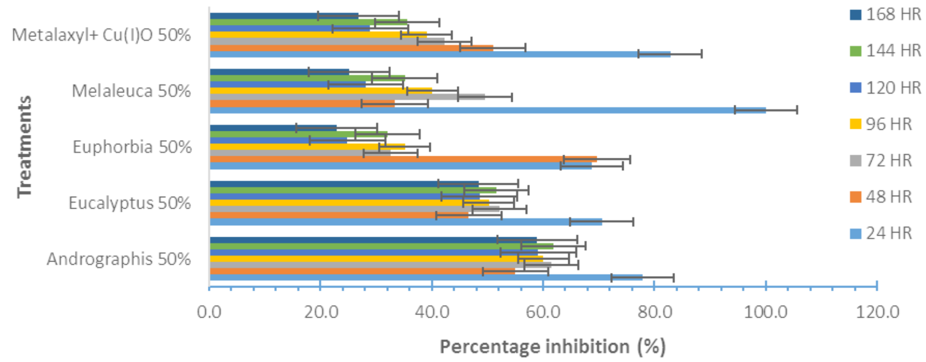

Figure 2. Percentage inhibition of mycelial growth of *Fusarium anthophilum* due to application of low concentration of plant extracts *in vitro* from 24-168 HAI

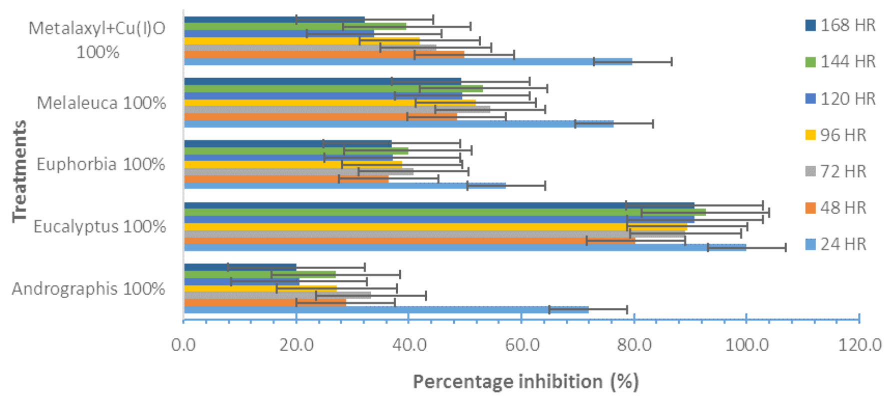

Figure 3. Percentage inhibition of mycelial growth of *Fusarium anthophilum* due to application of high concentration of plant extracts *in vitro* from 24-168 HAI

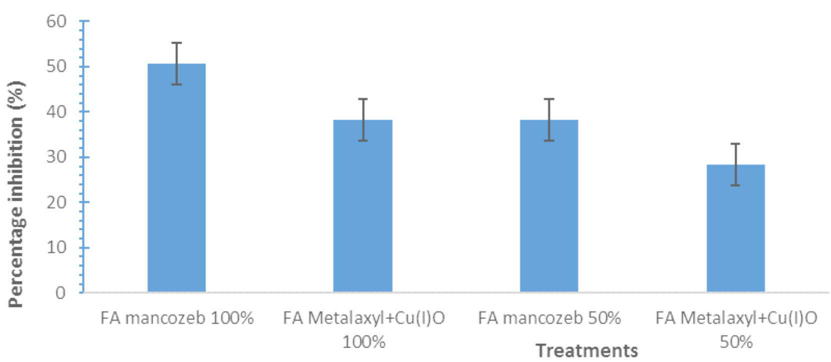

Figure 4. Percentage inhibition of mycelial growth of *Fusarium anthophilum* due to application of chemical fungicides+*Trichoderma* species at 120 HAI

FA = *Fusarium anthophilum*

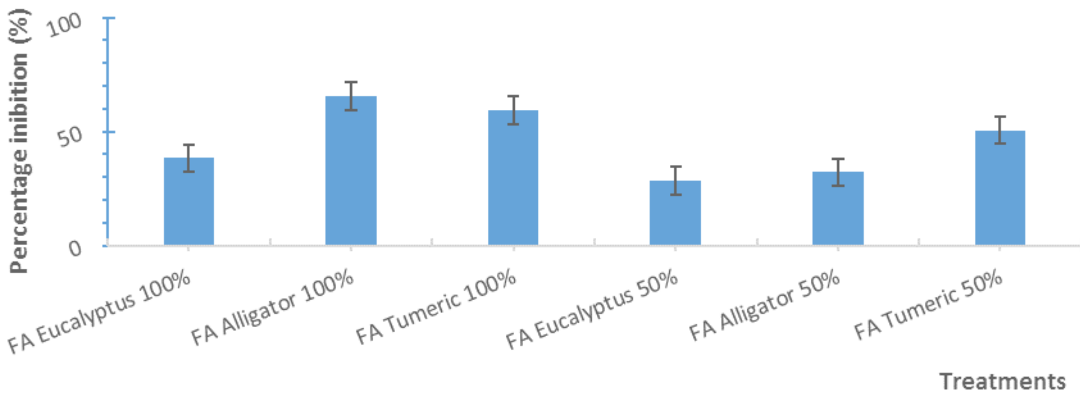

Figure 5. Percentage inhibition of mycelial growth of *Fusarium anthophilum* due to application of botanicals+*Trichoderma* species *in vitro* at 120 HAI

Table 1. Separation of the means of the radii of *Fusarium anthophilum* due to application of low concentration of plant extracts *in vitro*

TREATMENTS	72 HR	120 HR	168 HR
Control	4.3d	6.2c	9.0c
Andrographis 50%	3.2c	5.0b	7.0b
Eucalyptus 50%	1.0a	1.1a	1.1a
Euphorbia 50%	2.9c	4.6b	6.9b
Melaleuca 50%	2.2b	4.4b	6.7b
Metalaxyl+Cu(I)O 50%	2.8c	4.7b	6.1b
LSD	0.63	0.70	1.00
SED	0.29	0.30	0.40
CV%	13.00	9.10	8.70

Means followed by the same letter(s) are similar using DMRT (P≤0.05)

Table 2. Separation of the means of the radii of mycelia of *Fusarium anthophilum* due to application of high concentration of plant extracts

TREATMENTS	72 HR	120 HR	168 HR
Control	4.3d	6.2d	9.0e
Andrographis 100%	2.9c	5.0c	7.2d
Eucalyptus 100%	0.5a	0.6a	0.8a
Euphorbia 100%	2.7c	4.7c	6.0c
Melaleuca 100%	2.1b	3.5b	4.9b
Metalaxyl+Cu(I)O 100%	2.8c	4.9c	6.4c
LSD	0.48	0.69	0.99
SED	0.22	0.32	0.45
CV%	10.70	9.50	9.70

Means followed by the same letter(s) are similar using DMRT (P≤0.05)

Table 3. Separation of the means of the radii of mycelia of *Fusarium anthophilum* due to application of chemical fungicides+*Trichoderma* species *in vitro*

TREATMENTS	RANKING AT 120H
FA mancozeb 100%	1.33a
FA Metalaxyl+Cu(I)O 100%	1.67ab
FA mancozeb 50%	1.67ab
FA Metalaxyl+Cu(I)O 50%	1.93c
FA Control	2.67d
SED	0.21
LSD	0.47
CV%	13.80

Means followed by the same letter(s) are similar using DMRT (P≤0.05)

Table 4. Separation of the means of the radii of mycelia of *Fusarium anthophilum* due to application of botanicals+ *Trichoderma* species *in vitro*

TREATMENTS	RANKINGS AT 120H
FA Alligator 100%	0.93a
FA Tumeric 100%	1.10ab
FA Tumeric 50%	1.33abc
FA Eucalyptus 100%	1.67bc
FA Alligator 50%	1.83c
FA Eucalyptus 50%	1.93c
FA Control	2.67d
SED	0.26
LSD	0.57
CV%	19.70

Means followed by the same letter(s) are similar using DMRT (P≤0.05)

4. Discussion

The findings of this study on the possibility of utilizing plant extracts as alternatives to synthetic pesticides affirm those of Akanmu et al. [13] who showed that the extracts of *Jatropha curcas* and *Melia indica* significantly reduced the severity and the growth of *F. anthophilum, F. verticillioides* and *F. oxysporum*.

Ndifon et al. [12] revealed that dressing seeds and soil using ginger and garlic significantly controlled *Fusarium* wilt disease in *Solanum aethiopicum* crop. While Wavare et al. [14] reported that aqueous extracts of the flowers of marigold (*Tagetes erecta*) exhibited potential antifungal activity against *Sclerotium rolfsii*. Seed treatment (using *Pseudomonas fluorescens* + *Trichoderma harzianum* + marigold flower aqueous extract) proved effective in increasing seedling vigour index of chickpea in paper towel assay and also reduced collar rot disease incidence of chickpea (70.56%) under greenhouse conditions. These reports show clearly that plant extracts have the potential to act as pesticide agents against pathogens.

Another report by Oyelana et al. [15] revealed that leaf extracts of four *Ficus* species inhibited eight fungi species (including *Fusarium oxysporum* and *F. solani*), and two bacterial species (viz; *Pseudomonas* and *Klebsiella* spp.) isolated from infected *Dioscorea rotundata* tubers. This report corroborated the findings of this present study.

Botanicals may also have multiple effects on the systems as corroborated by Tamokou et al. [16] who reported that the crude extracts and compounds from *Vismia rubescens* exhibited both antibacterial, and antifungal activities. The effects varied among the microbial species (3 bacteria species and four yeast species).

Likewise, Kumari et al. [17] reported that aqueous extracts of neem cake and vermicompost inhibited the mycelial growth of *Helminthosporium pennisetti*, *Curvularia lunata,* and *Colletotrichum gloeosporioides* f. sp. mangiferae. Another report by Hussain et al. [18] revealed that six plant extracts (including *Azadirachta indica* and *Eucalyptus camaldulensis)* inhibited five fungi species (including *Aspergillus* and *Fusarium* spp.) by suppressing mycelial growth. Thus we can see that botanicals may be good substitutes for synthetic pesticides, even though most of them are not pest specific.

Moreover, Ali-Shtayeh and Abu Ghdeib [19] showed that many aqueous extracts of plants inhibited *Microsporum canis, Trichophyton mentagrophytes,* and *Trichophyton violaceum*. For instance, the extracts of *Capparis spinosa* and *Juglans regia* completely prevented the growth of dermatophytes like *M. canis* and *T. violaceum*.

Raji and Raveendran [20] reported that extracts from five plant species inhibited *Aspergillus niger.* Sneha et al. [21] reported that garlic and ginger inhibited *S. rolfsii*. These and more research on the efficacy of botanicals as plant pathogen control agents abound and strongly affirm the findings of this current study.

In the present study synthetic fungicides effectively controlled *F. anthophilum*. Ndifon and Lum [2] reported that all the synthetic fungicides utilized, gave higher inhibition of *A. niger* compared to all the plant extracts. The level of inhibition was more with Mancozeb than with Metalaxyl+Cu(I)O. Ndifon [22] reported that Mancozeb achieved 8-100% inhibition, but Mancozeb+Carbendazim achieved 36-100% inhibition of *Globisporangium ultimum*. This confirmed the findings obtained using Mancozeb+*Trichoderma* sp. Sneha et al. [21] reported that Mancozeb (i.e. Dithane M45) caused 100% growth inhibition of *S. rolfsii*, unlike Bavistin which failed to inhibit the growth of *S. rolfsii* at all concentrations.

These reports show that control of plant pathogen varies with the isolates and species of the pathogen, which agrees with the findings of this current study. It was noticed that in the presence of the biocontrol agent the synthetic fungicides failed to give 100% inhibition of the pathogen. This may be a pointer to some antagonistic effect or the biocontrol agent may be stimulating the pathogen as well as controlling it, etc.

Gwa and Nwankiti [23] controlled *Fusarium moniliforme* isolated from infected *Dioscorea rotundata* tubers using antagonistic isolates of *Trichoderma harzianum.* Ndifon [22] reported that all the biocontrol agents (isolates of *Trichoderma* and *Cladosporium* species) inhibited the mycelial growth of *G. ultimum* by 10%-90%.

While Al-Saeedi and AL-Ani [24] reported significant inhibition of seven soil-borne pathogenic fungi isolates (especially *Alternaria* sp.) by two isolates of *T. harzianum*. These findings agree with the current findings that *T. harzianum* is a good biocontrol agent against fungal pathogens. After all, Sharma et al. [25] reported that *T. harzianum* and *Trichoderma viride* are the most widely used species in the genus *Trichoderma.* In this genus, *Trichoderma* has been exploited for pest and pathogen control on about 87 different crops and about 70 soilborne and 18 foliar pathogens in India alone.

At more than 250 $\mu g\ mL^{-1}$ chlorothalonil; alone or in the presence of *Pseudomonas aeruginosa* (isolates GSE 18 and GSE 19) completely controlled *Phaeoisariopsis personata* late leaf spots of groundnuts [26]. This study confirmed the findings that combining different control agents can be used to manage fungi agents.

Concerning secretion or production of secondary metabolites, Kumar et al. [27] showed that some isolates of

Trichoderma species were endowed with abilities to produce significant amounts of chitinase and β-1,3-glucanase activities, which allowed them to out-compete or inhibit the test pathogens (viz., *Sclerotium rolfsii*, *Colletotrichum gloeosporioides,* and *Capsicum capsici*).

Meanwhile, Gajera and Vakharia [28] reported that among 12 isolates of *Trichoderma* species (i.e.; *T. harzianum*, *T. viride*, and *T. virens*), *T. viride* isolate 60 was the best biocontrol agent against *A. niger*, based on their lytic enzyme activities. De los Santos-Villalobos et al. [29] observed that one of the isolates (*T. asperellum* isolate T8a) was able to control *Colletotrichum gloeosporioides in vitro* and *in vivo.* This could be due to the involvement of enzymes (i.e., cellulases rather than chitinase or glucanase). These secondary metabolites may have been involved in the current trial, but the reason for the biocontrol agent not performing at its highest rate is not clear. Alternatively, the botanicals and synthetic agents may have affected the biocontrol agent negatively thus affecting the inhibitory ability of the treatments utilized.

Sanasam et al. [30] reported that plant extracts of garlic and turmeric inhibited *S. rolfsii.* These and more research on the efficacy of botanicals as plant pathogen control agents abound and strongly affirm the findings of this current study. In the present study synthetic fungicides effectively controlled *F. anthophilum*. Ndifon and Lum [2] reported that all the synthetic fungicides produced higher inhibition of *A. niger* compared to the plant extracts.

These reports show that control of plant pathogen varies with the isolates and species of the pathogen, which agrees with the findings of this current study. It was noticed that in the presence of the biocontrol agent the synthetic fungicides failed to give 100% inhibition of the pathogen.

5. Conclusions

Fusarium anthophilum is a major pathogen of white yams and cereals that produces dangerous mycotoxins. The management of *F. anthophilum* using chemical, biocontrol, and botanical measures revealed that *Eucalyptus, Andrographis, Melaleuca* and *Euphorbia* species inhibited *F. anthophilum* significantly. Combinations of Eucalyptus+, Alligator pepper+, Tumeric+, [Metalaxyl+Copper (I) oxide]+, and Mancozeb+*Trichoderma harzianum* isolate AIBN also successfully inhibited mycelial growth of *F. anthophilum.* These control measures can be effectively utilized to manage infections of *F. anthophilum,* while research on the control measures continues.

Conflict of Interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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