

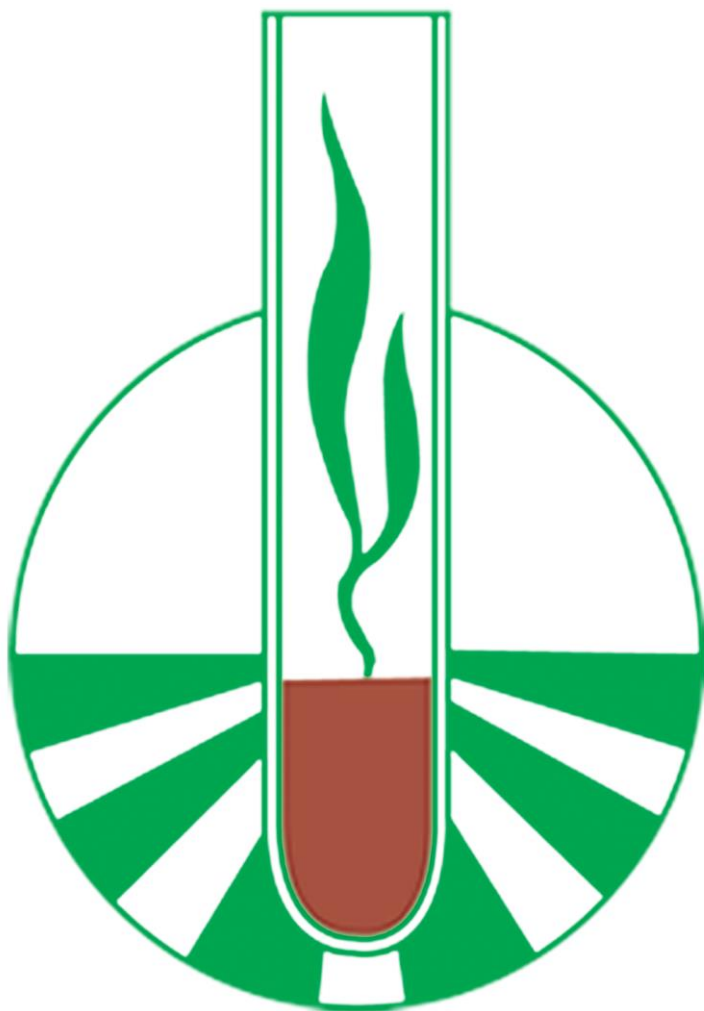
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Boni: Improved Tef Variety for Drought-Prone Areas of Ethiopia

Worku Kebede¹, Solomon Chanyalew¹, Tsion Fikre¹, Kidist Tolosa¹, Yazachew Genet¹, Mengistu Demissie¹, Kebebew Assefa¹, Habte Jifar¹, Solomon Mitiku², Kidu Gebremeskel³, Sewagegn Tariku⁴ and Zerihun Tadele⁵

¹Ethiopian Institute of Agricultural Research (EIAR), Debre Zeit Agricultural Research Center, P.O.Box 32, Debre Zeit; ²Amhara Regional Agricultural Research Institute (ARARI), Sirinka Research Center, P.O.Box:74, Woldia, Ethiopia; ³Tigray Agricultural Research Institute (TARI), Axum Research Center, P.O.Box30, Axum, Ethiopia; ⁴ARARI, Adet Agricultural Research Center, P.O. Box 8, Bahir Dar, Ethiopia; ⁵University of Bern, Institute of Plant Sciences, Altenbergrain 21, CH-3013 Bern, Switzerland
Corresponding author: workukebede121@gmail.com

Abstract

Tef [*Eragrostis tef* (Zucc.) Trotter] is extensively cultivated cereal crop in Ethiopia where it is annually grown by about 6.5 million smallholder farmers on about 30% of the total area allocated to cereal crops. However, the productivity of tef is very low compared to other cereals mainly due to little scientific research on the crop, widespread use of local varieties coupled with traditional cultural practices, and lack of drought tolerant varieties. A multi-environment field experiment was, therefore, carried with the objectives of identifying and releasing high yielding and farmer- and consumer-preferred tef variety for moisture deficit areas of the country. The drought tolerant tef genotypes tested were derived from two independent crosses of Dtt₂ x Dtt₁₃ and DZ-Cr-387 x Dtt₂. The parental lines Dtt₂ (drought tolerant tef2) and Dtt₁₃ (drought tolerant tef 13) were obtained by screening 5,000 ethylmethane sulfonate (EMS) mutagenized populations from an improved variety called Tsedey. Twelve candidate droughts tolerant tef genotypes from preliminary variety trials and a local as well as standard check varieties (Boset) were tested over two years (2018 and 2019 main cropping seasons) at five moisture deficit tef growing areas in Ethiopia (viz. Debre Zeit light soil, Minjar, Alemtena, Melkassa and Sirinka) using randomized complete block design with four replications. Late sowing combined with light textured soils was used to simulate terminal drought stress at Debre Zeit light soil and Minjar. The combined analyses of variance did not exhibit statistically significant difference for genotype by environment interaction. However, among the tested lines, the candidate line RIL 37 from Dtt₂ x Dtt₁₃ cross was found superior in grain yield over the standard check Boset variety (by 13.2%) and the local cultivar (by 27.6%). The candidate line was further evaluated in the variety verification trial during the 2020 main cropping season and approved for the release by the National Variety Release Committee in 2021 with name DZ-Cr-498 (RIL 37) or Boni.

Keywords: Boni, tef breeding, Drought tolerant tef (Dtt), drought tolerance, *Eragrostis tef*, moisture scarcity, tef

Introduction

Tef, [*Eragrostis tef* (Zucc.) Trotter] is a member of the Grass or Poaceae Family and belongs to Chlorodoideae sub-family. Tef is an allotetraploid ($2n=4x=40$) with estimated genome size 622 Mbp (VanBuren *et al.*, 2020), which is approximately 60% larger than the rice genome. It is self-pollinated with very low degree of out-crossing that ranges from 0.2% to 1.0% (Seyfu, 1997). Ethiopia is the center of both origin and diversity for tef (Vavilov, 1951). Tef represents a unique biodiversity component in the agriculture and food security systems of millions of poor farmers in Ethiopia. It is the most important cereal crop of Ethiopia, where the last two decades (1995 to 2015) have shown tremendous increases in both the total area under cultivation and the total production (CSA, 2015). Tef production increased from 1.7 million metric tons in 1995 to 5.25 million metric tons in 2015, which was equivalent to an average growth rate of 7.97% per annum. More importantly, tef yield has been increased by 5.06% per annum during the same period (CSA, 2015).

Tef plays an essential role in the Ethiopian food crop production system. Nearly seven million farmers grow the crop that occupies 22% of the total cultivated area (CSA, 2020), and it is second in terms of total production next to maize. Being produced by over 43% of all Ethiopian farmers and in lieu of the fact that it is

a very labour-intensive crop (Setotaw, 2013), tef production is a source of employment and livelihood for an estimated 25-30 million people. Furthermore, tef is the most commercialized crop in Ethiopia with approximately 36% of the total produced tef being marketed (Minten *et al.*, 2013).

Tef has an optimum amount of energy and protein compared to other common cereals (Baye, 2014; Nurse, 2015). The absence of gluten (Jeffrey, 2015) makes tef valuable for preparing dietary products for gluten intolerant people. It has been heralded as a super food or super grain and has high nutritional values (Spaenij-Dekking *et al.*, 2005; Provost and Jobson, 2014; Jeffrey, 2015). Furthermore, tef possesses additional nutritional advantages over many common bowls of cereal such as maize, barley, wheat and sorghum. For instance, tef, due to the low glycemic index (74) and high gelatinization temperature (68–800C), is a slow-digesting carbohydrate (Baye, 2014). Because of these nutritional properties, tef has attracted the interest of the western consumers and gaining global attention. Compared with other cereals such as maize and wheat, tef is also known to be tolerant to extreme climatic and soil conditions; hence, it is a favorite crop in the semi-arid areas with moisture limitations (Zerihun and Kebebew, 2012).

Despite its low yields as per the national average grain yield of 1.85 t

ha⁻¹ (CSA, 2020), tef remains to be very popular among Ethiopian farmers. This, among others, has been due to the fact that i) tef fetches higher prices than the other major cereals and therefore serves as a cash crop for many farmers (Bekabil *et al.*, 2013); ii) its straw also fetches high prices as it is the most preferred feed source for livestock and is used as construction material (Alemu, 2013). iii) tef is endemic and therefore little affected by epidemics of diseases and pests and can be stored for a long period of time without being attacked by storage pests, and iv) tef can be grown under drought stressed and water-logged conditions, and performs well on different soil types.

Not with standing its numerous relative advantages and economic importance, the productivity of tef in Ethiopia is low. Among the major yield limiting factors in tef are lack of cultivars tolerant to lodging and drought (Kebebew *et al.*, 2011), as well as small seed size. Yield losses in tef are estimated to reach up to 40% during severe moisture stress (Mulu, 1993). A yield reduction of 69% to 77% was when moisture scarcity occurred during the anthesis or flowering stage of tef plant (Abuhay *et al.*, 2001).

In Ethiopia, in order to increase tef productivity, more than 50 improved varieties have been developed and released by national and regional agricultural research institutes (MoA, 2020). Among these, recently released

varieties including *Quncho* (Kebebew *et al.*, 2013), *Kora* (Kebebew *et al.*, 2017), *Dagim* (Solomon *et al.*, 2017), *Tesfa* (Worku *et al.*, 2018) and *Bora* (Worku *et al.*, 2020) showed significant yield benefits. The majority of these varieties were designed for favourable and/or broad environments, not for challenging environment in terms of moisture scarcity.

The tef variety named DZ-Cr-387 RIL 355 (*Quncho*), has been promoted the national level for its farmers'- and consumers'-preferred traits such as high grain yield, white seed color, high biomass yield and good '*injera*' making quality. However, this variety was poorly adopted by tef growers in low moisture areas of Ethiopia due to poor performance under extreme environmental conditions. The level of yield reduction due to moisture stress warrants targeted breeding of tef for low moisture stress environments in Ethiopia (Mizan *et al.*, 2017). Accordingly, one of the primary goals of the National Tef Breeding Program in Ethiopia is to develop high yielding and drought tolerant tef varieties (Kebebew *et al.*, 2011).

Many different genotypes are typically evaluated in various environments (locations and periods) in plant breeding programs in order to identify and develop suitable genotypes for release. If a genotype or cultivar can adapt to a trait of economic importance in a wide range of conditions, it is considered stable. Only genotype and genotype by environment interaction are relevant to

meaningful cultivar evaluation and must be considered simultaneously for making selection decisions; the environmental component is typically the largest component in analyses of variance, but it is not relevant to variety choice exclusively (Yan and Kang 2003). Breeders might gain from information on the structure and nature of genotype by environment interactions (Yayis *et al.*, 2014).

As a result, a multi-environment national variety trial was initiated with the aim of identifying and release high-yielding, stable and farmer- and consumer-preferred tef variety for moisture deficient areas across the country. In this paper describes the performance of tef variety *Boni* (also known as DZ-Cr-498 RIL 37) which was recently approved for the release. Key beneficial features and morphological traits of this variety are presented.

Materials and Methods

Experimental sites and seasons

The field experiment was conducted for two years during the main cropping seasons of 2018 and 2019 in seven environments (namely, Debre Zeit, Minjar, Alemtena, Melkassa in 2018 and Debre Zeit, Minjar, and Sirinka in 2019) in the country's low moisture stress areas. At some of the locations such as Debre Zeit and Minjar low moisture stress was simulated by late

sowing in addition to the light textured soils of low water holding capacity.

Plant materials

Two independent crossings were made between Dtt_2 and Dtt_{13} , and DZ-Cr-387 and Dtt_2 at Debre Zeit Agricultural Research Center in 2013. Dtt_2 (drought tolerant tef 2) and Dtt_{13} (drought tolerant tef 13) were mutant lines obtained from screening 5,000 ethylmethane sulfonate (EMS) mutagenized populations of the tef variety *Tsedey* (DZ-Cr-37) (Blösch *et al.* 2019). These mutant lines had depicted excellent performance under moisture scarcity. The unique morphological difference between the *Dtt* and the original parental tef variety *Tsedey* (DZ-Cr-37) is the size and number of stomata. The stomata on the adaxial or upper side of the two *Dtt* lines are smaller both in size and number compared to the original parental tef line (Cannarozzi *et al.*, 2018). These small-sized stomata in the *Dtt* lines might contribute towards making the plants more tolerant to drought as less water is lost through transpiration. *Dtt* lines were tolerant to drought for three weeks, whereas the original *Tsedey* variety was badly injured. The *Dtt* lines were not only drought tolerant, but they also had shorter stomata than the *Tsedey* lines (Blösch *et al.*, 2019).

After a successful crossing, 400 F_2 populations were generated and substantially advanced to F_7 generations using the single seed descent method. Eventually, the

populations were reduced to few lines with best performance after seven generations of successive selection targeting seed color, standing ability, grain yield, and leaf area index. Hybridization and early generation testing, i.e., Observation Nursery and Preliminary Variety Trial were done at Debre Zeit Agricultural Research Center from where the national tef breeding program is coordinated.

Subsequently, at the National Variety Trial where a total of 12 genotypes including 10 selected drought-tolerant inbred lines from the two crosses, a local check or farmers' variety from each test site, and a standard check variety *Boset* were evaluated at five drought-prone areas in Ethiopia.

Experimental Design and Management

The performance of the twelve tef genotypes including 10 selected drought tolerant inbred lines from the two crosses as well as two controls (farmers' variety as a local check and improved variety *Boset* as a standard check) were tested at Debre Zeit light soil, Minjar, Alem Tena, Melkassa and Sirinka using Randomized Complete Block Design with four replications. *Boset* variety released in 2013 was used as a standard check since the variety is characterized as drought escaper due to its early maturing nature. The trial was conducted on the plot size of 2m x 2m with 10 rows per plot, and spacing of 1.5m between replications or blocks, 1m between plots within blocks and 20cm between

rows. All pre- and post-stand establishment cultural practices were performed as per the research recommendations of the respective test sites.

Data collection

Data on agronomic, yield and yield-related traits were collected both on plot and individual plant bases. Days to heading or panicle emergence using the sowing date as a reference, lodging indexes as well as grain and biomass yield were taken on plot basis. Data on individual plant traits such as plant height and panicle length were collected on the basis of five random samples of plants from the central rows of each plot, and the averages of five sample plants were used for analysis.

Data Analysis

Analyses of variance (ANOVA) of data from individual environments and combined over five locations and two years were made using R core Team (2021) software 4.2.0 version. The combined analysis of variance across the environment was done in order to determine the differences between genotypes across environments, among environments and their interaction. Bartlett's test of homogeneity of error variances was performed prior to making the combined analysis of variance over environments (years and locations). Mean comparison for significant differences in the analyses of variance were made using Least Significant Difference (LSD).

Results and Discussion

Field performance variations

According to the results of the combined analysis of variance over environments (Table 1), grain yield was highly significantly ($P < 0.0001$) affected by genotypes and environments, which accounted for about 7.88% and 41.13% of the total variance, respectively. However, the genotype by environment ($G \times E$) interaction effects on grain yield were not significant; indicating that the genotypes tested were performed similarly across the test environments. This, in other words, implies that the

genotypes tested did not exhibit differential adaptation to specific environments.

The genotype $\times$ location interactions were not significant, indicating that the genotypes performed consistently across locations in terms of grain yield. This is expected on the basis of the similar agro-climatic classification of the test locations (Kebebew *et al.*, 2003). If varieties perform similarly across locations, breeders may be able to reduce the cost of thorough varietal evaluation by eliminating unnecessary testing sites and altering breeding programs.

Table1. Sum of squares, mean squares and percent of variance explained by different sources of variation from the analyses of variance of grain yield of 12 tef genotypes tested at six environments

Source	Degrees of freedom	Sum of squares	Mean squares	Explained variance (%)
Genotypes	11	8219139.76	747194.52**	7.88
Environments	6	42885619.84	7147603.31**	41.13
Reps/Environments	21	16627723.17	791796.34**	15.94
Environment $\times$ Genotypes	66	7774627.29	117797.38 ^{NS}	7.45
Error	231	28749561.30	124457.00	27.57
Corrected Total	335	104256671.40		

*. ** denote significance at $P \leq 0.05$ and $P \leq 0.01$, respectively; NS = Not significant

Highly significant variations among the genotypes were observed in days to heading, days to maturity, grain filling period, plant height, panicle length, lodging index, shoot biomass yield and grain yield in all the study years and locations (Table 2). Similar significant results were reported for most traits in earlier studies (Hailu *et*

al., 2003a; Kebebew *et al.* 2003; Solomon *et al.*, 2009; Habte *et al.*, 2015, Tsion, 2016 and Habte *et al.* 2017). The presence of variations among genotypes for the traits indicates the higher chance of improving the crop through selection.

Table 2. Mean agronomic performance of tef genotypes evaluated in the national variety trial (Drought Tolerant) across locations and over years

Genotypes	Days to heading	Days to maturity	Grain filling period (days)	Plant height (cm)	Panicle length (cm)	Lodging index (%)	Shoot biomass yield (kg ha ⁻¹)	Grain yield (kg ha ⁻¹)
Standard Check (Boset)	41.00	83.79	42.79	89.94	36.54	81.08	11156.25	2131.38
Dtt₂ x Dtt₁₃ RIL 37	40.96	80.32	39.36	91.84	39.80	83.50	11810.27	2455.33
Dtt ₂ x Dtt ₁₃ RIL56	40.43	82.50	42.07	87.34	36.24	85.13	10417.41	2175.18
Dtt ₂ x Dtt ₁₃ RIL79	39.07	81.36	42.29	84.12	34.29	82.58	9714.29	2030.69
Dtt ₂ x Dtt ₁₃ RIL 80	39.21	78.46	39.25	85.28	34.30	83.83	10116.07	1975.18
Dtt ₂ x Dtt ₁₃ RIL 87	38.89	80.75	41.86	83.45	33.51	83.63	9171.88	1986.79
DZ-Cr-387 x Dtt ₂ RIL 98	41.68	83.36	41.68	90.44	38.20	80.92	10569.20	2157.57
DZ-Cr-387 x Dtt ₂ RIL15	42.46	83.96	41.50	92.89	39.39	76.67	12265.63	2217.03
DZ-Cr-387 x Dtt ₂ RIL 177	41.32	83.57	42.25	95.84	41.47	78.58	11312.50	2080.18
DZ-Cr-387 x Dtt ₂ RIL 199	41.14	82.96	41.82	93.22	39.86	80.00	10305.80	2121.76
DZ-Cr-387 x Dtt ₂ RIL 97	40.00	83.61	43.61	91.12	40.01	83.79	10705.36	2184.35
Local Check	43.32	85.86	42.54	96.93	40.99	80.17	10866.07	1778.77
Mean	40.79	82.54	41.75	90.20	37.88	81.66	10660.71	2107.85
LSD (0.05)	0.81	1.46	1.55	2.85	1.48	4.82	1666.80	211.33
CV (%)	3.79	3.34	7.04	6.01	7.42	10.37	29.70	19.04
R²	0.95	0.89	0.83	0.89	0.66	0.70	0.58	0.61

Averaged over environments, Dtt₂ x Dtt₁₃ RIL 37 reaches the panicle emergence stage in 40 days and physiological maturity in 80 days after sowing. These desirable traits can be suggested for fast-track release and to be used as parental lines for future tef breeding programs. From the average total plant height of 90 cm the panicle of Dtt₂ x Dtt₁₃ RIL 37 contributes to 40%. The relationship between plant height and panicle length indicates the possibility of increasing grain yield and biomass yield by improving either of the two traits (Table 2).

The average grain yield of Dtt₂ x Dtt₁₃ RIL 37 was (2455.33 kg ha⁻¹) and shoot biomass yield (11810.27 kg ha⁻¹) (Table 2), which is the highest grain yield and biomass yield recorded among tested genotypes across pooled environments. The genotype Dtt₂ x Dtt₁₃ RIL 37 ranked first in grain yield performance in four of the seven

environments (Debre Zeit and Minjar in 2018 and; Minjar and Sirinka in 2019). Similarly, three other best-performing genotypes DZ-Cr-387 x Dtt₂ RIL 97, DZ-Cr-387 x Dtt₂ RIL 15 and Dtt₂ x Dtt₁₃ RIL 87 ranked first in grain yield at Melkassa in 2018, Alemtena in 2019 and Debre Zeit in 2019, respectively (Table 3).

The average grain yield of Dtt₂ x Dtt₁₃ RIL 37 across the seven environments ranged from 1114 to 3051 kg ha⁻¹, with an overall mean of 2455 kg ha⁻¹ (Table 3). It performs very well in areas having an altitude 1200-1800m above sea level, thus being suitable for low rainfall and terminal low moisture stress areas of the country. Therefore, based on the two-year multi-location data, Dtt₂ x Dtt₁₃ RIL 37 has been selected for its high grain yield and moisture stress tolerance as well as other desirable traits. Consequently, the candidate line

was then tested in a variety verification trial during the main cropping season of 2020, and the National Variety Release Committee approved for release in 2021.

The current study's findings revealed that the range values for some traits are low when compared to the range values reported in prior tef researchers (Kebebew *et al.*, 2001b;

Habtamu, 2015 and Tsion, 2016). This could be due to the current study's use of drought-tolerant tef genotypes as experimental materials, as well as the fact that the experiment was conducted in a drought-prone area of the country, which are both different from the experimental plant materials and locations used in previous studies.

Table 3. Mean grain yield (kg ha^{-1}) performance of tef genotypes evaluated in national variety trial (for drought prone areas) across seven environments

Code No.	Genotypes	Mean grain yield (kg ha^{-1})							Mean
		2018		2019					
		Melkassa	DebreZeit	Minjar	Alem-tena	DebreZeit	Minjar	Sirinka	
1	Standard Check (Boset)	1691	2488	2361	1617	2056	2690	2016	2131
2	Dtt₂ x Dtt₁₃ RIL 37	2153	3051	2960	1698	2089	3003	2235	2455
3	Dtt ₂ x Dtt ₁₃ RIL56	1971	2697	2113	1727	1969	2545	2203	2175
4	Dtt ₂ x Dtt ₁₃ RIL79	1821	2704	2273	1453	1940	2131	1893	2031
5	Dtt ₂ x Dtt ₁₃ RIL 80	1502	2693	2311	1589	1717	2179	1836	1975
6	Dtt ₂ x Dtt ₁₃ RIL 87	1776	2364	1991	1538	2200	2015	2024	1987
7	DZ-Cr-387 x Dtt ₂ RIL 98	1871	2998	2280	1495	1907	2523	2029	2158
8	DZ-Cr-387 x Dtt ₂ RIL 15	2112	2789	2214	1764	2073	2553	2015	2217
9	DZ-Cr-387 x Dtt ₂ RIL 177	1754	2300	2437	1645	1862	2594	1970	2080
10	DZ-Cr-387 x Dtt ₂ RIL199	1731	2818	2191	1460	2055	2621	1976	2122
11	DZ-Cr-387 x Dtt ₂ RIL 97	2207	2513	2269	1471	2013	2609	2210	2184
12	Local Check	1426	2423	2188	1114	1256	2185	1861	1779
	Mean	1835	2653	2299	1548	1928	2471	2022	2108
	LSD (0.05)	429.3	664.5	642.9	402.9	389.8	673.2	345.2	211.3
	CV (%)	16.26	14.78	19.44	18.10	14.05	18.94	11.86	19.04

Genotype grain yield performance with respect to environment (Which Won Where)

The GGE polygon view of the 10 drought tef genotypes and two controls (local check and standard check Boset) tested in the seven environments is presented on Figure 1 polygon view helps to identify winning genotypes in different environments by visualizing

GEI (Yan and Kang, 2003) in MET and in estimating possible existence of different mega environments (Gauch, and Zobel, 1996; Yan and Rajcan, 2002; Yan and Tinker, 2005).

In the present investigation, the partitioning of GE interaction through GGE biplot analysis showed that AXIS₁ and AXIS₂ accounted for 55.08% and 19.73% of GGE sum of squares, respectively, explained 74.81% of the total variance (Figure

1). The polygon view was created by connecting the vertex genotypes codes (2, 6, 8 and 12) which were having the largest distance from the origin. These genotypes were the highest yielding in their respective environments or sector. The biplot is divided into four sections by the four rays with genotypes falling in all sections while the environments fall in two areas. According to the findings of Yan and Tinker (2005), the vertex genotypes were the most responsive genotypes, as they have the longest distance from

the origin in their direction. In this finding the genotype code "2" is the only one in vertices of the polygon in which all environments are contained except E5. Thus, genotype code "2" is the most productive in those six environments in terms of grain yield. The other genotypes 8, 6 and 12 on the vertices of the polygon not containing any of the seven environments are unfavorable in the seven test environments. The best performing genotype in grain yield was genotype code "2" being the furthest to the right.

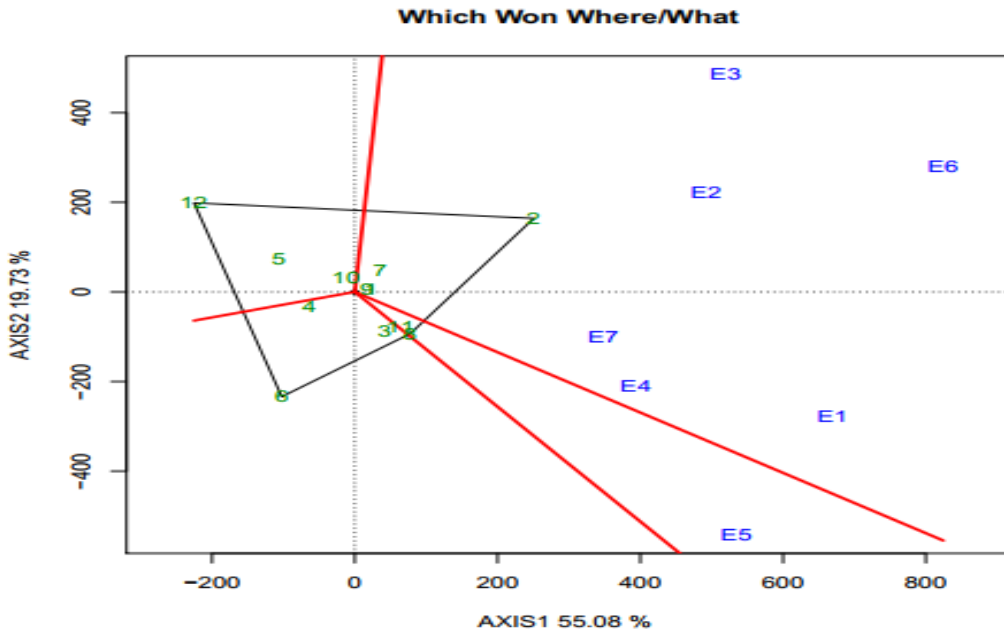


Figure 1. Adaptability and performance of tef test genotypes with respect to test environments. Genotype code is indicated in Table 2 and 3.

Genotypes Mean Yield and their Stability

Visualization of mean performance and stability analysis of genotypes is an important issue in crop genotype evaluation. The estimation of yield and

stability of genotypes were done by using the average environment axis (AEA) methods (Figure 2) (Yan, 2001 and Yan and Hunt, 2001). The line passing through biplot origin from lower right to upper left is the average environment axis (AEA) as defined by

the first two AXISs of the environments scores (Yan and Kang, 2003). The furthest from the arrow is the genotype with the highest yield ranking in a particular environment; the environment axis through the origin and that specific environment, genotypes closer to the environment along the axis are high yielding and *vice versa*. Genotype axis through the biplot origin and that genotype, along that axis are the rankings of the environments.

Genotypes located closer to the ideal genotype are more desirable than others. For selection, the ideal genotypes are those with both high mean yield and high stability. In this study, the genotype code "2" was ranked best in the entire tested environment and had the higher stability as well as higher mean yield across all tested environments. This result is in agreement with those obtained by (Akter, 2015) in rice and (Naheif, 2013) in wheat.

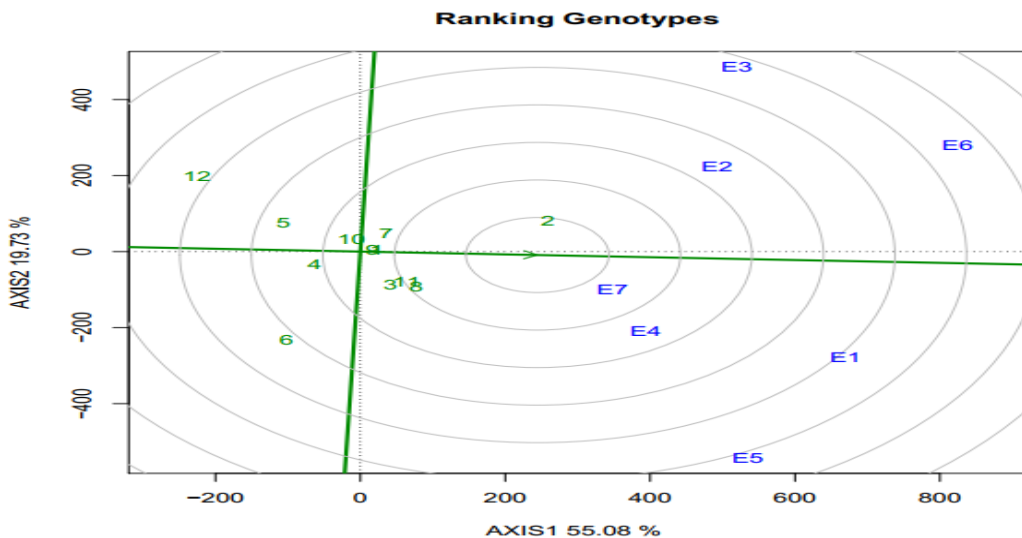


Figure 2. Ranking of tef test genotypes with respect to test environments. Genotype code is indicated in Table 2 and 3.

Description of the Candidate variety Dtt2 x Dtt13 (DZ-Cr-498 RIL 37) (Boni)

The distinctive pheno-morphologic and agronomic description of the genotype Dtt₂ x Dtt₁₃ RIL 37 selected as candidate variety is summarized in Table 4. The candidate line has got very loose panicle form which often correlated with high yield compared to

the compact panicle types (Seyfu, 1997) and the lemmas are yellowish green when immature and yellowish white when mature. In the current finding, Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37) belongs to the early maturity group (80 days to mature), which almost equally divided between the days taken to head and the grain filling period (i.e., the days from heading to physiological maturity). Furthermore,

the genotype produces good outputs, particularly in terms of grain yield,

and is comparable to standard checks in terms of biomass yield in general.

Table 4. Distinguishing phenologic, morphological and agronomic characteristics the candidate variety Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37).

No.	Characteristics	Description		
I	Qualitative traits	Yellowish green		
1	Basal stalk color	Yellowish green		
2	Panicle form	Very loose		
3	Lemma color	Yellowish green when immature and yellowish white when mature		
4	Anther color	Yellowish white		
5	Seed color	Very white		
II	Quantitative traits	Minimum	Maximum	Mean $\pm$ SE
1	Days to panicle emergence	27	49	41 $\pm$ 1.21
2	Days to maturity	62	88	80 $\pm$ 1.51
3	Grain filling period (days)	27	46	39 $\pm$ 0.92
4	Plant height (cm)	57	109	92 $\pm$ 2.72
5	Culm length (cm)	18	67	52 $\pm$ 2.6
6	Panicle length (cm)	33	44	40 $\pm$ 0.53
7	Biomass yield (t/ha)	6.5	20	11.33 $\pm$ 0.60
8	Grain yield (t/ha)	1.70	3.5	2.46 $\pm$ 0.110
9	Lodging index	62	100	83 $\pm$ 2.63
10	Harvest index (%)	13	40	26 $\pm$ 1.4

Distinguishing and beneficial features of the Candidate variety Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37) (Boni)

The candidate variety Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37) selected for release possessed the following noteworthy distinguishing characteristics.

- 1) It showed grain yield advantages of 13.19% and 27.55% over the standard check (Boset) and local cultivar, respectively.
- 2) Moreover, the selected genotype will be highly valuable in view of the prevailing climate change and thereby suitable for drought-prone areas since it is tolerant

to drought both at early stage during seedling emergence and also escapes terminal drought through its early maturing characteristics,

- 3) This genotype has also got immense farmers' preference and attention due the favorable combination of drought tolerance, early maturity and white caryopsis color

Conclusions and Recommendations

From the study we can conclude that, the evaluated drought tolerant tef genotypes showed significant variance for the studied traits in seven environments encompassing two years

(2018 and 2019 main seasons) and five tef growing sites in moisture stress areas of the country. The candidate variety Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37) had the highest mean grain yield, followed by genotype DZ-Cr-387 x Dtt₂ RIL 15 and DZ-Cr-387 x Dtt₂ RIL 97. In comparison, the genotype DZ-Cr-387 x Dtt₂ RIL 80 and local check had the lowest mean yield.

The candidate variety Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37) ranked first in four of the seven environments. GEI effects showed that genotypes performed similarly to the variations in the test environments. The genotype code "2" ranked best and most productive in all the test environments in terms of grain yield. The candidate variety Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37) has double advantage on moisture stress area or drought prone areas because tolerate drought conditions both at early stage during seedling emergence and also escape drought through early maturing.

Therefore, this genotype recommended for all moisture stress areas of Ethiopia. Considering the seven environments' data and field performance evaluation during the variety verification trial, the national variety releasing committee has approved the official release of candidate genotype, Dtt₂ x Dtt₁₃ (DZ-Cr-498 RIL 37), with the vernacular name of "Boni" for moisture stress areas of the country.

Author Contributions

Kebebew Assefa, Solomon Chanyalew and Zerihun Tadele conceived and supervised the research. Worku Kebede, Tsion Fikre and Yazachew Genet contributed to the research design and data interpretation. Worku Kebede, Tsion Fikre, Yazachew Genet, Kidist Tolosa, Mengistu Demissie, Habte Jifar, Solomon Mitiku, Kidu Gebremeskel and Sewagegn Tariku collected data and conducted phenotypic analysis. Worku Kebede, Habte Jifar and Kebebew Assefa analyzed and interpreted data. Worku Kebede and Kebebew Assefa drafted the manuscript and produced figures. All authors approved the final version of the manuscript.

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Traits Association in Durum Wheat Genotypes under Optimum and Low Nitrogen Conditions

Tesfaye Geleta Aga^{1*}, Fetien Abay Abera², Kebebew Assefa Abebe¹, Tesfaye Balemi Tufa¹, Bekele Geleta Abeyo³ and Negash Geleta Ayana¹

Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia

College of Dry Land Agriculture and Natural Resources, Department of Dry Land Crops and Horticultural Science, Mekelle University, Mekelle, Ethiopia.

International Maize and Wheat Improvement Centre (CIMMYT), Addis Ababa, Ethiopia

*Correspondence: tesfayegeleta@gmail.com

Abstract

Realizing the nature and degree of association between yield and yield related traits under various environment and conditions is a pre-requisite in any crop improvement. A total of 200 durum wheat genotypes obtained from different sources were tested at Debre-Zeit, Chefe-Donsa and Minjar under optimum and low nitrogen in 2020 season. The objectives were to assess the relationship between grain yield and other important traits, and to determine relationships among the various traits and their direct and indirect effects on durum wheat grain yield under optimum and low nitrogen (N) conditions. The Phenotypic and genotypic association of grain yield with grain filling period, number of seed per spike, biomass yield, harvest index, normalized difference vegetative index, hectoliter weight, and chlorophyll contents were significant and positive under both optimum and low N conditions. Biomass yield, number of seed per spike, normalized difference vegetative index, harvest index, and hectoliter weight were direct contributors to grain yield under both N conditions. Thus, these traits can be used as the primary selection criteria for grain yield in durum wheat under optimum and low Nitrogen.

Keywords: correlation analysis, durum wheat, optimum nitrogen, path analysis

Introduction

Durum wheat (*Triticum turgidum* var. *durum* Desf) is one of the oldest cultivated cereal species in the world (Royo *et al.* 2009). It has significant economic value and provides the raw materials for food industries in the nutrition of the global population (Sissons *et al.* 2005) and suitable for preparing traditional recipes in Ethiopia (Belay *et al.* 2013).

Currently, durum wheat has become a major cash crop, with pasta, burghul, and couscous industries paying 10 to 20% more for durum grain than for bread wheat (Sall *et al.*, 2019). Nutritionally, 100 gram of durum wheat contains 339 calories, 13.7 g of protein, 2.5 g of fat, 3.5 g iron, 34 mg calcium, 144 mg magnesium, and 508 g of phosphorus, as well as significant amounts of vitamins, lutein, and fiber for better health (Dan Brennan, 2021). Despite its importance, grain yield is a

complex quantitative trait and is governed by many minor genes and confounded by interactions of various traits due to the effect of environments and growing conditions (Singh and Diwivedi 2002). Use of primary and its related traits in phenotypic and genotypic correlations analysis would be important to select the right genotypes through indirect methods (Baye *et al.*, 2020). A correlation coefficient can be used to express how much and in what direction different variables influence the primary characteristics, but it does not indicate the relative importance of direct and indirect effects of yield components (Silva *et al.*, 2009). Path analysis, which involves the unfolding of correlation coefficients for analyzed traits, can be used to determine the direct and indirect effects of yield components (Baye *et al.*, 2020). In order to provide information regarding the proper cause and effect relationship between yield and other traits, correlation and path coefficient analysis could be employed as important tools. Plant breeders can increase the effectiveness and success of selection through better

understanding of the genetic relationship between grain yield and its components, which helps identify traits to be used in the future breeding (Wolde and Eticha, 2016) and (Yagdi and Sozen, 2009). Thus, information on the nature and magnitude of character associations between yield and yield related traits is a prerequisite in improving durum wheat under optimum and low nitrogen. Therefore, the objectives of this study was to estimate phenotypic and genotypic coefficient of correlations and to determine their interrelationships among various traits and their direct and indirect effects on durum wheat grain yield under optimum and low N conditions.

Materials and Methods

Description of the study area

The experiments were carried out at Debre-Zeit, Chefe-Donsa and Minjar experimental stations in 2020 growing season (Table 1).

Table 1. Geographical locations and climatic conditions description of the experimental sites

Descriptions		Locations		
		Debre Zeit	Chefe Donsa	Minjar
Altitude (m.a.s.l)		1900	2435	2257
Latitude and longitude		8° 44' N, 38° 58' E	8° 57', 39° 16' E	8° 46' N, 39° 16' E
Mean annual rainfall (mm)		984	1020	865
Temperature	Max. (°C)	26.84	20	28.77
	Min (°C)	11.39	8	12.3
Soil types		Black vertisol	Black vertisol	Vertisol
Agro- ecology		Mid altitude	Highland	Mid altitude

Source: DZARC, 2020

Experimental plant materials, design and layout

A total of 200 durum wheat genotypes were used in this study, of which 67 genotypes were obtained from Ethiopian Biodiversity Institute (EBI), 83 from International Maize and wheat Improvement Centre (CIMMYT), 13 from International Center for Agricultural Research in the Dry Areas (ICARDA), and 37 from Debre-Zeit Agricultural Research Center (DZARC) durum wheat breeding program (Appendix Table 1). A composite soil sample was taken from each site, and soil nitrogen analysis was done following standard procedures before planting. The fields that are low/very low in total nitrogen (TN) content were selected to establish the experiments following (Tadesse *et al.*, 1991) soil rating based on TN. Two sets of experiments (Set-I and Set-II) were conducted at each location, and the same genotypes were used for both sets of experiments. The plot size was 1 m x 1 m and the distance between rows, plots, blocks and replications was 0.2, 0.4, 0.5, and 1 meter, respectively. The genotypes were arranged in an alpha lattice design with two replications. The genotypes were assigned to plots at random within each block during planting. The optimum N environment received 92 kg/ha N in split applications at the time of sowing and tillering stage as top-dressing whereas none was applied to Low N environment. A recommended 10 kg/ha phosphorous in the form of

triple super phosphate (TSP) was applied under both optimum and low environments. Weeding was done manually, thus, the test fields were weed-free. The fungicide Nativo 300SC (200g/l Tebuconazole + 100g/l Trifloxystrobin) was used to control stem, leaf and yellow rust infestations, and all other crop management techniques were uniformly applied to all genotypes in accordance with the crop's recommendations.

Data collection

The data were collected for phenological, agronomic, physiological and quality traits. Days to heading (DH) was recorded by counting the number of days from sowing to the stage when 50% of the heads emerged within a plot and days to 90% physiological maturity (DM) was recorded by counting the number of days from sowing to physiological maturity on plot basis. Grain filling period (GFP) was obtained by subtracting DH from DM. Plant height (PH), number of fertile tillers per plant (NFT), spike length (SL), spikelet per spike (SPS), and number of seeds per spike (NSPS) were recorded from ten randomly sampled plants from the four central rows and their average data was taken. After the plants were mechanically harvested, data on above ground biomass yield (BM, t/ha⁻¹) and grain yield (GY, t/ha⁻¹) were collected and converted to a hectare basis. BM was measured in the field using a hanging balance during harvesting, whereas GY was calculated by weighing the threshed grain on an

analytical sensitive balance and adjusted to 12.5 percent moisture content. Harvest index (HI) was determined from the ratio of GY to BM. Thousand seed weight (TSW) was obtained by counting thousand grains using seed counter and weighing using analytical balance. A handheld green seeker was used to measure Normalized difference vegetative index (NDVI) during heading stage, and it was taken 50-60 cm above the canopy. Random plants were considered to record chlorophyll content (CHO) using SPAD-502 plus chlorophyll analyzer at flag leaf stage. Grain protein content (PC) was analyzed using Pertien protein analyzer and hectoliter weight (HLW) was measured by a portable hectoliter test weight kit(model).

Data analysis

The F-max ratio for homogeneity of variance was carried out to determine the validity of the experiment and to combine the data over locations (Domangue, 2015). Since the error variances for all traits were homogeneous, the data was pooled and analyzed across locations. Genotypic and phenotypic correlations between the traits were calculated from the mean of data over locations and replications using variances and covariance's matrix for the association of traits while path analysis was carried out for the traits that had significant correlations with grain yield both at the genotypic and phenotypic levels to determine the

direct and indirect contribution of the traits on grain yield following the procedures suggested by (Singh and Chaudhary 1977) and (Dewey and Lu, 1959) using R-software version 4.1.3 (R Core team, 2013). $r_{ij} = p_{ij} + \sum_{ik} r_{pkj}$ Where, r_{ij} =mutual association between the independent variable 'i' and the dependent variable 'j' as measured by correlation coefficient. p_{ij} =component of direct effects of the independent variable (i) on dependent variable (j) as measured by the path coefficients.

$\sum_{ik} r_{pkj}$ =summation of components of indirect effects of independent trait (i) on the given dependent trait (j) through all other independent variables (k).

The influence of the remaining unknown factor was measured as the residual effect. It was calculated as; $\sqrt{1 - R^2}$ where, $R^2 = \sum p_{ij} r_{ij}$.

Results and Discussions

Genotypic and phenotypic correlation coefficients under optimum N

Genotypic and phenotypic correlation coefficients of the characters are presented in Table 2. In this study, majority of the genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients demonstrating strong inherent association between the characters, and the environment that modify the phenotypic expression of the characters. However, the

phenotypic correlation coefficients of some traits were equal and/or more than its equivalent genotypic correlation coefficients indicating that environmental and genotypic effects were similar. Tsegaye *et al.* (2012) also reported high genotypic than phenotypic correlation in durum wheat.

Correlation of grain yield with other traits under optimum N

GY had positive and significant correlation with GFP, NSPS, BM, HI, NDVI, HLW, TSW, and CHO at both genotypic and phenotypic level; and NFT correlated at phenotypic level (Table 2). This implies that, selection for these characters would leads to simultaneous improvement of GY in durum wheat. The results were comparable with the work of (Kumar *et al.* 2016); (Singh *et al.* 2012) and (Zerga *et al.* 2016) on bread wheat; and (Alemu *et al.* 2020) and (Baye *et al.*, 2020) on durum wheat on different characters. In contrast, DH, DM, PH, SL and PC where DH showed a negative genotypic and phenotypic association with GY and PC and DH had significant correlation at genotypic and phenotypic level in respective order. Meles *et al.* (2017) found negative genotypic and phenotypic correlation coefficients of GY with DH, DM and PC and Surma *et al.*

(2015) with PC. Negative correlation of GY with important traits, which is major limitation in plant breeding leads to undesirable selection probably associated to linkage or pleiotropic gene effect. Abinasa *et al.* (2011) emphasized the biparental mating, mutation breeding and diallele mating in breaking undesirable linkages to improve yield components with negative associations. On the other hand, an inverse association of DH and DM with grain yield is sometimes desirable when terminal heat and drought are anticipated (Mohammadi, 2019).

Correlation among yield related traits under optimum N

DH and DM revealed positive and significant correlation with PH, NFT, SL, SPS, BM and NDVI whereas they showed negative and significant correlation with GFP, NSPS, HI, and CHO at genotypic and phenotypic levels (Table 2). DM was negatively and non-significantly correlated to PC and HLW at both phenotypic and genotypic levels and the former had positively and negatively correlated with DH at genotypic and phenotypic levels respectively. DH was negative and significantly correlation with HLW and DM had positive significant correlation with TSW at both levels.

Table 2. Genotypic (upper diagonal) and phenotypic (below diagonal) correlation coefficients among sixteen variables of durum wheat genotypes under optimum N

Variables	DH	DM	GFP	PH	NFT	SL	SPS	NSPS
DH	1.00	0.88**	-0.76**	0.47**	0.46**	0.61**	0.40**	-0.62**
DM	0.83**	1.00	-0.36**	0.38**	0.22**	0.38**	0.37**	-0.40**
GFP	-0.69**	-0.19**	1.00	-0.41**	-0.61**	-0.68**	-0.29**	0.68**
PH	0.41**	0.32**	-0.32**	1.00	0.58**	0.70**	0.45**	-0.68**
NFT	0.38**	0.18**	-0.41**	0.48**	1.00	0.68**	0.18*	-0.78**
SL	0.55**	0.34**	-0.54**	0.65**	0.56**	1.00	0.59**	-0.70**
SPS	0.29**	0.26**	-0.17**	0.37**	0.14**	0.54**	1.00	-0.09ns
NSPS	-0.59**	-0.35**	0.59**	-0.59**	-0.60**	-0.60**	0.04ns	1.00
BM	0.40**	-0.32**	-0.29**	0.43**	0.53**	0.52**	0.29**	-0.40**
HI	-0.64**	-0.45**	0.55**	-0.52**	-0.41**	-0.57**	-0.25**	0.64**
NDVI	0.35**	0.24**	-0.31**	0.54**	0.47**	0.54**	0.33**	-0.44**
PC	-0.02ns	-0.01ns	0.01ns	0.13**	0.10*	0.06ns	-0.06ns	-0.09ns
HLW	-0.14**	-0.06ns	0.19**	0.02ns	0.11*	0.02ns	0.03ns	0.07ns
TSW	-0.002ns	0.18**	0.23**	0.35**	0.04ns	0.06ns	0.02ns	-0.19**
CHO	-0.52**	-0.32**	0.51**	-0.39**	-0.41**	-0.48**	-0.12*	0.65**
GY	-0.17*	-0.09ns	0.19**	-0.05ns	0.13**	-0.01ns	0.06ns	0.16**

**=Significant at 1% level, *=Significant at 5% level, ns=non-significant

Table 2.Continued

Variables	BM	HI	NDVI	PC	HLW	TSW	CHO	GY
DH	0.51**	-0.75**	0.53**	0.001ns	-0.17*	0.01ns	-0.59**	-0.17*
DM	0.39**	-0.57**	0.37**	-0.05ns	-0.12ns	0.19**	-0.40**	-0.14ns
GFP	-0.47**	0.70**	-0.55**	-0.08ns	0.17*	0.24**	0.63**	0.16*
PH	0.49**	-0.68**	0.67**	0.18**	-0.07ns	0.38**	-0.53**	-0.12ns
NFT	0.64**	-0.57**	0.65**	0.07ns	0.11ns	0.02ns	-0.62**	0.11ns
SL	0.61**	-0.70**	0.70**	0.07ns	-0.005ns	0.07ns	-0.62**	-0.04ns
SPS	0.35**	-0.41**	0.43**	-0.11ns	-0.07ns	-0.01ns	-0.27**	-0.01ns
NSPS	-0.53**	0.75**	-0.66**	-0.15*	0.06ns	-0.24**	0.75**	0.16*
BM	1.00	-0.41**	0.90**	-0.01ns	0.67**	0.12ns	-0.41**	0.60**
HI	-0.29**	1.00	-0.54**	-0.25**	0.44**	0.05ns	0.73**	0.48**
NDVI	0.75**	-0.32**	1.00	0.14*	0.40**	0.26**	-0.57**	0.39**
PC	0.07ns	-0.15**	0.16**	1.00	-0.17*	0.17*	0.16*	-0.22**
HLW	0.56**	0.39**	0.39**	0.02ns	1.00	0.21**	0.20**	0.96**
TSW	0.14**	0.06ns	0.23**	0.12*	0.19**	1.00	0.13ns	0.15*
CHO	-0.23**	0.55**	-0.26**	0.18**	0.19**	0.13*	1.00	0.26**
GY	0.64**	0.53**	0.40**	-0.06ns	0.79**	0.17**	0.25**	1.00

**=Significant at 1% level, *=Significant at 5% level, ns=non-significant

DH had non-significant positive correlation with TSW at genotypic and negative at phenotypic level (Table 2). The results were in agreement with (Baye *et al.*, 2020) who reported that, the correlations of DH and DM were positive and significant with PH, SPS

and BM. Similarly, (Mecha *et al.*, 2017) described that GFP, TSW, HLW and HI showed a negative and significant association with DH and DM.

GFP showed negative and significant correlation with PH, NFT, SL, SPS, BM and NDVI at phenotypic level and a significant positive correlation for the same traits at genotypic level but the correlation was significant and positive with NSPS, HI, TSW, HLW, and CHO at both levels suggesting that longer interval between DH to DM contributed for the increments of these traits. It had negative at genotypic and positive at phenotypic level but non-significant correlation with PC (Table 2).

Similarly, (Dabi *et al.* 2016) stated that highly significant and positive correlation of GFP with HLW and TSW at both genotypic and phenotypic levels. PH showed highly significant positive correlation with NFT, SL, SPS, BM, NDVI and PC and highly significant negative correlation with NSPS, HI and CHO at both genotypic and phenotypic level. The finding was in agreement with Tabassum *et al.* (2017) for HI in bread wheat. Moreover, PH had positive and negative non-significant correlation with HLW at phenotypic and genotypic level, respectively. Birkneh (2021) reported positive significant correlation of PH with SL and SPS. NFT had positive and significant correlation with SL, SPS, BM and NDVI and highly significant negative correlation with NSPS, HI and CHO at both level. Moreover, NFT had positive significant correlation with PC and HLW at phenotypic level and positive non-significant correlation at genotypic level (Table 2). Similarly, NFT showed a non-significant but

positive correlation with TSW at both levels. The result was in line with (Meles *et al.* 2017) that showed negative correlation of NFT with NSPS.

SL had highly significant positive correlation with, SPS, BM and NDVI and highly significant negative correlation with NSPS, HI and CHO at both levels whereas, it had positive non-significant correlation with PC, HLW and TSW at phenotypic level (Table 2). The results of this study are in agreement with (Seyoum *et al.* 2021) who reported a significant and positive correlation of SL with spikelet per spike. A contrasting finding was reported by (Zecevic *et al.* 2004) on the correlation of SL and NSPS in wheat.

SPS showed significant positive correlation with BM and NDVI and highly significant negative correlation with HI and CHO at both levels. NSPS exhibited significant positive correlation with HI and CHO, whereas BM, NDVI and TSW associated highly significantly and negatively with NSPS at both levels. It was observed that, negative significant and non-significant correlation of PC with NSPS at genotypic and phenotypic level, respectively, and had also positive non-significant correlation with HLW at both level (Table 2).

BM had significant positive correlation with NDVI, HLW and TSW at phenotypic level, and NDVI and HLW traits showed significant

positive correlation at genotypic level. However, HI and CHO were highly significant negative correlation with BM at both levels which is in line with the work of (Kumar *et al.*, 2018) who reported negative association of biomass and HI. HI showed highly significant positive correlation with HLW and CHO, highly significant negative correlation with NDVI and PC at phenotypic and genotypic level. NDVI revealed highly significant positive correlation with PC, HLW and TSW but negative significant correlation with CHO at both levels. PC had significant positive correlation with TSW and CHO at both levels. HLW had significant positive correlation with TSW and CHO at both levels.

Correlation coefficient under low N

Table 3 presents the genotypic and phenotypic correlation coefficient of GY, yield components and physiological traits for diverse durum wheat genotypes. Genotypic correlation coefficients were found higher than the phenotypic correlation coefficients for majority of the traits suggesting that characters association had not been mainly influenced by environmental dynamics.

Correlation between grain yields with other traits under low N

The correlations of GY with GFP, NSPS, BM, HI, NDVI, HLW and CHO were significant and positive at

both genotypic and phenotypic levels. Similarly, TSW showed highly significant correlation with GY at phenotypic level, demonstrating the importance of these traits for yield improvement. DH and DM showed negative and significant correlation with GY at both levels, this could be attributed to the high influences of environment and inherent variations among genotypes. Similarly, PH and SL negatively and significantly correlated with GY at genotypic level but non-significant at phenotypic level. NFT, SPS and PC were positively and non-significantly correlated with GY at phenotypic level.

Ivić *et al.* (2021) stated similar findings on the correlation of GY with HI, PH and PC under low nitrogen treatments. Talebi *et al.* (2010) indicated similar results for PH, BM, NSPS and SL but under low water regime the result was contrary in the HI of durum wheat landraces. The correlation of GY and PC was negative as it illustrated by various studies in durum wheat under drought environment. According to (Salsman *et al.*, 2021) and (Guttieri *et al.*, 2017) GY correlated negatively with DH, PH and grain PC. Moreover, (Khayatnezhad *et al.*, 2010) reported positive and significant correlations of GY with TSW, total plant weight and HI among durum wheat genotypes under dry conditions. Contrary to this result, (Russell, 2020) reported non-significant correlation of GY with all traits except number of spikes in

spring wheat grown under low N conditions.

Table 3. Genotypic (upper diagonal) and phenotypic (below diagonal) correlation coefficients among sixteen variables of durum wheat genotypes under low N

Variables	DH	DM	GFP	PH	NFT	SL	SPS	NSPS
DH	1	0.97**	-0.91**	0.53**	0.68**	0.73**	0.61**	-0.71**
DM	0.91**	1	-0.77**	0.53**	0.62**	0.68**	0.59**	-0.69**
GFP	-0.80**	-0.49**	1	-0.44**	-0.66**	-0.72**	-0.59**	0.63**
PH	0.41**	0.43**	-0.24**	1	0.54**	0.65**	0.53**	-0.64**
NFT	0.49**	0.45**	-0.38**	0.47**	1	0.78**	0.54**	-0.69**
SL	0.67**	0.62**	-0.53**	0.57**	0.58**	1	0.70**	-0.73**
SPS	0.42**	0.42**	-0.29**	0.43**	0.34**	0.63**	1	-0.27**
NSPS	-0.64**	-0.58**	0.51**	-0.42**	-0.45**	-0.56**	-0.001ns	1
BM	0.35**	0.39**	-0.17**	0.26**	0.39**	0.37**	0.22**	-0.28**
HI	-0.66**	-0.58**	0.54**	-0.36**	-0.24**	-0.42**	-0.18**	0.56**
NDVI	0.35**	0.34**	-0.24**	0.35**	0.39**	0.44**	0.31**	-0.34**
PC	0.16*	0.19**	-0.06ns	0.21**	0.10*	0.29**	0.01ns	-0.28**
HLW	-0.19**	-0.19**	0.14**	-0.11**	-0.01ns	-0.11**	-0.12**	0.06ns
TSW	0.08ns	0.20**	0.11*	0.40**	0.14**	0.19**	0.03ns	-0.41**
CHO	-0.34**	-0.26**	0.33**	-0.17**	-0.26**	-0.21**	-0.03ns	0.41**
YD	-0.22**	-0.14**	0.25**	-0.09ns	0.09ns	-0.06ns	0.01ns	0.19**

**=Significant at 1% level, *=Significant at 5% level, ns=non-significant

Table 3 Continued

Variables	BM	HI	NDVI	PC	HLW	TSW	CHO	YD
DH	0.48**	-0.79**	0.58**	0.20**	-0.43**	0.13ns	-0.43**	-0.22**
DM	0.51**	-0.74**	0.60**	0.23**	-0.40**	0.22**	-0.37**	-0.16*
GFP	-0.36**	0.76**	-0.50**	-0.13ns	0.42**	0.06ns	0.49**	0.27**
PH	0.26**	-0.61**	0.50**	0.29**	-0.34**	0.49**	-0.38**	-0.26**
NFT	0.57**	-0.47**	0.75**	0.29**	0.001ns	0.16*	-0.49**	0.08ns
SL	0.42**	-0.61**	0.60**	0.35**	-0.32**	0.20**	-0.37**	-0.14*
SPS	0.26**	-0.44**	0.31**	0.04ns	-0.53**	0.005ns	-0.21**	-0.13ns
NSPS	-0.47**	0.69**	-0.64**	-0.43**	0.08ns	-0.53**	0.51**	0.16*
BM	1	-0.16*	0.75**	0.29**	0.66**	0.21**	-0.21**	0.66**
HI	0.01ns	1	-0.35**	-0.32**	0.84**	-0.06ns	0.53**	0.62**
NDVI	0.53**	-0.01ns	1	0.34**	0.16*	0.40**	-0.38**	0.34**
PC	0.24**	-0.16**	0.25**	1	-0.02ns	0.21**	-0.02ns	-0.01ns
HLW	0.31**	0.41**	0.18**	0.05ns	1	0.29**	0.09ns	0.85**
TSW	0.24**	0.06ns	0.31**	0.20**	0.18**	1	-0.06ns	0.09ns
CHO	0.02ns	0.40**	-0.09ns	0.03ns	0.07ns	0.01ns	1	0.20**
YD	0.71**	0.69**	0.32**	0.05ns	0.54**	0.19**	0.28**	1

**=Significant at 1% level, *=Significant at 5% level, ns=non-significant

Correlation among yield related traits under low N

The present study showed negative and significant correlation of DH and DM with GFP, NSPS, HI, HLW and CHO at genotypic and phenotypic levels (Table 3). These traits had

positive and significant correlation with other characters at both genotypic and phenotypic level except TSW with DH. GFP had positive and significant correlation with NSPS, HI, HLW, TSW and CHO, while the other characters showed negative and significant correlation with GFP.

Similarly, (Mwadzingeni *et al.*, 2016) stated that DH and DM had positive and significant correlation with PH, SL, SPS, NSPS and TSW under drought stress condition. Yield contributing traits such as PH, NFT, SL, SPS, BM and TSW showed significant and positive correlation with each other at genotypic and phenotypic levels except SPS and TSW which showed non-significantly correlated to each other at both levels. Similarly, Lupini *et al.* (2021) reported negative correlation among PH and TSW with HI and positive correlation between PH and TSW in durum wheat evaluated under different nitrogen and water regimes. (Khayatnezhad *et al.*, 2010) also stated positive and significant correlation between PH and NFT, total plant weight and thousand seed weight, number of fertile tiller and total plant weight, and SL and grain per spike among durum wheat genotypes under water and dry conditions.

Most yield component traits showed positive significant correlation with NDVI and PC at both levels where SPS had non-significant correlation with PC. Yield component traits excluding NSPS and HI showed negative correlation but significant with CHO at genotypic level; and SPS and BM were non-significant at phenotypic level. PH, SL and SPS revealed negative while NSPS, BM and HI showed positive correlation with HLW at both levels. In line with this study (Ivić *et al.* 2021) reported negative correlation of HI with PC

under low N for winter wheat cultivars but in contrast to this result, (Kubota *et al.*, 2018) found positive correlation of HI with PC of spring wheat cultivars only under low N but negative correlation under high N condition for the same traits. NDVI had positive and significant correlation with grain PC and HLW at both levels. Moreover, this trait exhibited negative significant at genotypic while positive and non-significant correlation at phenotypic level with CHO.

Path Coefficient analysis under optimum N

Path analysis partitions correlation coefficients in to direct and indirect effects which examines the cause and effect relationship between GY and other yield attributes and it provides clear picture of character associations for formulating efficient selection strategy. In this experiment, ten independent characters were selected as causal variables when GY is designated as dependent variable at genotypic and phenotypic level (Table 4 and 5).

Path analysis revealed that DH, GFP, BM, HI, NDVI, HLW and CHO had a positive direct effects with GY while NSPS, PC and TSW exerted negative and weak direct effect on GY at genotypic level. The maximum positive direct effect was observed for NDVI followed by HI, HLW and CHO (Table 4). Hence, direct selection based on these traits could be more effective for the improvement of GY in durum wheat. These findings

were in agreement with the result of (Tsegaye *et al.*, 2012) who stated small direct effect of BM on GY at genotypic level, and (Kumari *et al.*, 2020) who reported positive direct effect of HI and negative direct effect of NSPS and TSW on GY of bread wheat. In another study, (Nukasani *et al.*, 2013) described TSW had a direct but negative direct effect on GY. Bhushan *et al.* (2013) stated that positive direct effect of HI and

biological yield. In contrary, (Bhushan *et al.*, 2013) reported negative direct effect of DH on GY. The indirect effects of DH, BM and NDVI on GY via HI were negative. However, positive indirect effects of GFP, NSPS, HLW and CHO on GY were exerted through HI. On the other hand, DH, BM and HLW were showed positive indirect effects on yield through NDVI (Table 4).

Table 4. Estimates of direct (bold and diagonal) and indirect effects at genotypic level for durum wheat genotypes tested at the three locations under optimum N

Variables	DH	GFP	NSPS	BM	HI	NDVI	PC	HLW	TSW	CHO	Rg
DH	0.11	-0.08	0.06	0.05	-0.36	0.31	0.00	-0.07	0.00	-0.19	-0.17*
GFP	-0.09	0.11	-0.06	-0.04	0.34	-0.32	0.01	0.07	-0.05	0.20	0.16*
NSPS	-0.07	0.07	-0.09	-0.05	0.36	-0.39	0.02	0.03	0.05	0.24	0.16*
BM	0.06	-0.05	0.05	0.09	-0.20	0.52	0.00	0.28	-0.02	-0.13	0.60**
HI	-0.08	0.07	-0.07	-0.04	0.48	-0.32	0.03	0.18	-0.01	0.23	0.48**
NDVI	0.06	-0.06	0.06	0.08	-0.26	0.59	-0.02	0.17	-0.05	-0.18	0.39**
PC	0.00	-0.01	0.01	0.00	-0.12	0.08	-0.13	-0.07	-0.03	0.05	-0.22**
HLW	-0.02	0.02	-0.01	0.06	0.21	0.24	0.02	0.41	-0.04	0.06	0.96**
TSW	0.00	0.03	0.02	0.01	0.02	0.15	-0.02	0.09	-0.19	0.04	0.15*
CHO	-0.07	0.07	-0.07	-0.04	0.35	-0.33	-0.02	0.08	-0.02	0.31	0.26**

Residual effect =0.27, R-square=0.93, **, * significant at 1% and at 5% probability levels respectively, rg: genotypic correlations of variables with the GY.

At phenotypic level, BM and HI had high direct effect on GY (Table 5). Therefore, these traits could be considered as important selection criterion in durum wheat improvement program hence direct selection of these traits for yield improvement would be effective under optimum nitrogen conditions. However, the other traits exerted weak and insignificant direct and indirect effect on GY in the present findings (Table 5). Similar results were reported by (Seyoum *et al.* 2021) and (Baye *et al.*, 2020). In this study, DH, NFT, HLW and NDVI exerted moderate to high positive indirect effect on GY while GFP, NSPS, HI and CHO showed moderate negative indirect effect

on GY through BM. Moreover, GFP, NSPS, HLW and CHO exerted moderate positive indirect effect but DH, NFT, BM and NDVI exhibited moderately negative indirect effect on GY via HI (Table 5). Although, the correlation between HLW and GY was strong and highly significant its direct effect was negative and had low magnitude indicating its indirect contribution to GY via BM and HI. The result also revealed that residual effect was 0.270 for genotypic and 0.174 for phenotypic path coefficients, demonstrating all traits evaluated in the present result explained about 73 and 82.6 percent of the variability in GY, respectively (Table 4 and 5).

Table 5. Estimates of phenotypic direct (bold diagonal) and indirect effects of different variables on GY of durum wheat genotypes tested at three locations under optimum N conditions

variables	DH	GFP	NFT	NSPS	BM	HI	NDVI	HLW	TSW	CHO	rp
DH	-0.026	-0.002	-0.005	0.010	0.353	-0.488	0.001	0.001	0.00001	-0.014	-0.17*
GFP	0.018	0.003	0.005	-0.010	-0.256	0.419	-0.001	-0.001	-0.001	0.014	0.19**
NFT	-0.010	-0.001	-0.013	0.010	0.467	-0.313	0.001	-0.001	0.000	-0.011	0.13ns
NSPS	0.015	0.002	0.008	-0.017	-0.353	0.488	-0.001	-0.001	0.001	0.018	0.16*
BM	-0.010	-0.001	-0.007	0.007	0.882	-0.221	0.002	-0.004	-0.001	-0.006	0.64**
HI	0.016	0.002	0.005	-0.011	-0.256	0.762	-0.001	-0.003	0.000	0.015	0.53**
NDVI	-0.009	-0.001	-0.006	0.007	0.661	-0.244	0.002	-0.003	-0.001	-0.007	0.40**
HLW	0.004	0.001	-0.001	-0.001	0.494	0.297	0.001	-0.008	-0.001	0.005	0.79**
TSW	0.000	0.001	-0.001	0.003	0.123	0.046	0.001	-0.001	-0.005	0.004	0.17*
CHO	0.013	0.002	0.005	-0.011	-0.203	0.419	-0.001	-0.001	-0.001	0.027	0.25**

Residual effect =0.174, R-square value= 0.97, **, * significant at 1% and at 5% probability levels respectively, rg: genotypic correlations of variables with the GY.

Path coefficient analysis under low N

Yield is a complex resultant character and influenced by several components and the environment. Due to internal modifications among the components, increase in one component results in a decrease in other component(s) and hence does not affect the resultant trait, yield. The results of genotypic and phenotypic path analysis under low N were presented in Table 6 and 7. Genotypic path analysis revealed the highest positive direct effect on GY observed in HLW followed by NSPS, BM and NDVI indicating, the importance of direct selection of these traits to identify high yielding genotypes. The higher positive direct effect has been reported for NSPS (Khan and Naqvi, 2012); (Oliveira *et al.*, 2021) and BM (Talebi *et al.*, 2010). All traits applied positive direct effect on GY except DM and PH had

negative direct effect with significant genetic correlations. Alternatively, DH, DM, PH, SL and NDVI had negative indirect effect on GY through NSPS whereas GFP, HI and CHO exerted positive indirect effect through this trait. The indirect effects of NDVI, HLW, DH and DM on GY through BM were positive. NSPS had negative indirect effect while DH, DM, SL and BM had positive direct effect on GY through NDVI. Positive indirect effect was exerted on GY by BM and HI through HLW while the indirect effects of the other traits were weak and insignificant (Table 6). The residual effect was 0.367, indicating that about 63.3 percent of variability in GY might be contributed by these eleven traits examined in the path analysis. This gives an impression that some other factors which have not been measured also contributed to the variability in GY.

Table 6. Estimates of direct (bold and diagonal) and indirect effects at genotypic level for durum wheat genotypes tested at the three locations under low N

Traits	DH	DM	GFP	PH	SL	NSPS	BM	HI	NDVI	HLW	CHO	rg
DH	0.12	-0.01	-0.15	-0.05	0.10	-0.26	0.17	-0.12	0.18	-0.17	-0.03	-0.22**
DM	0.12	-0.01	-0.13	-0.05	0.09	-0.25	0.18	-0.12	0.19	-0.16	-0.03	-0.16*
GFP	-0.11	0.01	0.16	0.04	-0.10	0.23	-0.13	0.12	-0.16	0.17	0.04	0.27**
PH	0.07	-0.01	-0.07	-0.09	0.09	-0.23	0.09	-0.09	0.16	-0.13	-0.03	-0.26**
SL	0.09	-0.01	-0.12	-0.06	0.14	-0.27	0.15	-0.09	0.19	-0.13	-0.03	-0.14*
NSPS	-0.09	0.01	0.10	0.06	-0.10	0.36	-0.17	0.11	-0.20	0.03	0.04	0.16*
BM	0.06	-0.01	-0.06	-0.02	0.06	-0.17	0.35	-0.02	0.23	0.26	-0.02	0.66**
HI	-0.10	0.01	0.12	0.06	-0.08	0.25	-0.06	0.16	-0.11	0.33	0.04	0.62**
NDVI	0.07	-0.01	-0.08	-0.05	0.08	-0.23	0.26	-0.05	0.31	0.06	-0.03	0.34**
HLW	-0.05	0.01	0.07	0.03	-0.04	0.03	0.23	0.13	0.05	0.39	0.01	0.85**
CHO	-0.05	0.00	0.08	0.04	-0.05	0.19	-0.07	0.08	-0.12	0.04	0.07	0.20**

**, * significant at 1% and at 5% probability levels respectively, rg: genotypic correlations with the GY and Residual effect =0.367, R-square=86.5

The phenotypic path analysis result revealed direct and positive effects of DM, BM, HI and HLW whereas; DH, GFP, NSPS, NDVI, TSW and CHO were found to be negative direct effect on GY (Table 7). Chowdhry *et al.* (2000) and (Hussain *et al.* 2012) reported similar observations in agreement with the current study results for some of the traits. NSPS via HI and NDVI via BM exerted moderately positive indirect effect on GY. DH and DM were moderate indirect positive effect via BM and negative indirect effect via HI on GY.

On the other hand, GFP, NSPS, HLW and CHO had moderate positive indirect effect on GY through HI (Table 7). As the indirect contribution of various characters were low in magnitude, not considered worthy to be described. The residual effect was 0.148, indicating about 85 percent of the variation in yield was due to these ten characters examined even though there are some other factors, which were not measured in the present study.

Table 7. Estimates of phenotypic direct (bold diagonal) and indirect effects of different variables on GY of durum wheat genotypes tested at three locations under low N conditions

Variables	DH	DM	GFP	NSPS	BM	HI	NDVI	HLW	TSW	CHO	rp
DH	-0.496	0.289	0.182	0.011	0.254	-0.430	-0.021	-0.012	-0.002	0.003	-0.22**
DM	-0.451	0.318	0.112	0.010	0.284	-0.378	-0.020	-0.012	-0.004	0.002	-0.14*
GFP	0.396	-0.156	-0.228	-0.009	-0.124	0.352	0.014	0.009	-0.002	-0.003	0.25**
NSPS	0.317	-0.184	-0.116	-0.018	-0.204	0.365	0.020	0.004	0.009	-0.003	0.19**
BM	-0.173	0.124	0.039	0.005	0.727	0.007	-0.031	0.019	-0.005	0.000	0.71**
HI	0.327	-0.184	-0.123	-0.010	0.007	0.651	0.001	0.025	-0.001	-0.003	0.69**
NDVI	-0.173	0.108	0.055	0.006	0.385	-0.007	-0.059	0.011	-0.007	0.001	0.32**
HLW	0.094	-0.060	-0.032	-0.001	0.225	0.267	-0.011	0.062	-0.004	-0.001	0.54**
TSW	-0.040	0.064	-0.025	0.007	0.174	0.039	-0.018	0.011	-0.022	0.000	0.19**
CHO	0.168	-0.083	-0.075	-0.007	0.015	0.260	0.005	0.004	0.000	-0.008	0.28**

Residual effect =0.148, R-square value=0.98, **, * significant at 1% and at 5% probability levels respectively, rp: genotypic correlations with the GY

Conclusion

In present study, majority of the genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients, demonstrating strong inherent association between the measured characters and less influenced by environmental dynamics. Correlation coefficient analysis revealed that durum GY had a positive and significant association with GFP, NSPS, BM, HI, NDVI, HLW, and CHO at genotypic and phenotypic levels under both optimum and low N conditions. This showed that the traits were effective for direct selection of genotypes to improve grain yield.

Similarly, NFT identified as an important trait under optimum and TSW was under low nitrogen based on phenotypic correlation analysis to improve grain yield. In contrast, GY had a negative association with DH, DM, PH, SL, and PC at the genotypic and phenotypic levels under both optimum and low N conditions.

NDVI had the greatest positive direct effect on GY at the genotypic level, followed by HI, HLW, and CHO, while at the phenotypic level, BM and HI had the greatest positive direct effect on GY under optimum N. Indirect effects of BM via NDVI at the genotypic level and NDVI via BM at the phenotypic level, as well as NSPS via HI at the genotypic and phenotypic levels, were observed on GY under optimum N conditions. Under low N conditions, HLW, NSPS, BM, and

NDVI had the highest positive direct effect on GY at the genotypic level. Moreover, at the phenotypic level, DM, BM, HI, and HLW had a positive direct effect on GY. As a result of the strong correlation and positive direct and indirect effects of BM, NSPS, NDVI HI, and HLW on GY, breeders need to apply direct selection of these traits during breeding stages to develop new durum wheat varieties with improved yield under low N conditions.

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Appendices

Appendix Table 1 Durum wheat genotypes used for the experiment

NO	GENOTYPES	SOURCE	PEDIGREE/ ID/ACCESSIONS
1	FIGSDRYWET016	ICARDA	RUSS199/ID-82244
2	FIGSDRYWET078	ICARDA	AFG68::77/ID-90233
3	FIGSDWHOTCLD015	ICARDA	ETH732::91/ID-81510
4	FIGSDRYWET028	ICARDA	ETH64:112/ID-83807
5	DURUM_PANEL_UNIBO-054	ICARDA	D333/GAVIOIA/4/AVETORO//ALUINCO/D/EIOD/ID-MARJANA MOROCCO
6	FIGSDRYWET001	ICARDA	OMN87:113/ID-43315
7	DURUM_PANEL_UNIBO-048	ICARDA	INRA1807 /ID-CHAOUI MOROCCO
8	Land race	EBI	ETH CHEFE-9
9	Land race	EBI	ETH 208474
10	Land race	EBI	ETH 2368039
11	Land race	EBI	ETH 222796
12	FIGSDWHOTCLD009	ICARDA	ETH74::56/ID-79653
13	Land race	EBI	ETH 203762
14	FIGSDRYWET0144	ICARDA	IRNS382/ID-119026
15	DURUM_PANEL_UNIBO-081	ICARDA	ID-BRAVADUR,SW USA
16	FIGSDRYWET091	ICARDA	ETH731::112/ID-90482
17	FIGSDRYWET108	ICARDA	IRNS294/ID-98797
18	Land race	EBI	ETH 226804
19	ICARASHA2	ICARDA	Stj3/Ber/Lks4/3/Ter3
20	Land race	EBI	238498
21	Land race	EBI	ID-MU350/238498
22	Land race	EBI	ID-MU386/208215
23	Land race	EBI	ID-MU369/215411
24	Land race	EBI	ID-MU71/222859
25	Land race	EBI	ID-MU46/208746
26	Foka	DZARC	COCORIT-71/CANDEAL-II[1551][2837]
27	Bichena	DZARC	IUMILLO/COCORIT-71[1551]
28	Land race	EBI	ID-MU367/208316
29	Land race	EBI	ID-MU282/222408
30	Denbi	DZARC	AJAIA/BAUSHEN[3589]
31	Land race	EBI	ID-MU398/236988
32	Land race	EBI	ID-MU193/238531
33	Land race	EBI	ID-MU389/202012
34	Land race	EBI	ID-MU329/208162
35	Land race	EBI	ID-MU19/228862

NO	GENOTYPES	SOURCE	PEDIGREE/ ID/ACCESSIONS
36	Land race	EBI	ID-MU397/236269
37	Boohai	DZARC	COOT(SIB)/CANDEAL-II[40][115][1551][2837]
38	Land race	EBI	ID-MU375/222414
39	Land race	EBI	ID-MU274/210817
40	Land race	EBI	ID-MU320/222655
41	Quamy	DZARC	FLAMINGO,MEX/CRANE//FLAMINGO/3/HUIT
42	Land race	EBI	ID-MU295/8034
43	Land race	EBI	ID-MU56/238555
44	Land race	EBI	ID-MU77/222856
45	Land race	EBI	222413
46	Land race	EBI	222298
47	Land race	EBI	236987
48	Land race	EBI	222191
49	Land race	EBI	238133
50	Land race	EBI	7960
51	Land race	EBI	231538
52	Land race	EBI	138130
53	Land race	EBI	231541
54	Land race	EBI	231594
55	Land race	EBI	226958
56	Land race	EBI	204563
57	Land race	EBI	222415
58	Land race	EBI	8175
59	Land race	EBI	231573
60	Land race	EBI	222629
61	Land race	EBI	226963
62	Land race	EBI	231499
63	Land race	EBI	238138
64	Land race	EBI	238122
65	Land race	EBI	231597
66	Land race	EBI	208931
67	Land race	EBI	204573-1
68	Land race	EBI	222387
69	Land race	EBI	227009
70	Land race	EBI	226971-2
71	Land race	EBI	208261
72	Land race	EBI	7961
73	Land race	EBI	222568

NO	GENOTYPES	SOURCE	PEDIGREE/ ID/ACCESSIONS
74	Land race	EBI	231536-1
75	Land race	EBI	236974-1
76	Land race	EBI	222198
77	Land race	EBI	222382
78	Land race	EBI	238135
79	Land race	EBI	231584
80	Land race	EBI	204485
81	Land race	EBI	8356
82	Land race	EBI	231585
83	Land race	EBI	227007
84	Land race	EBI	238134
85	Land race	EBI	8333-2
86	CD15DZ_ELT/off/1084/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV 79/3/ACO89/5/2*S00TY.9/RASCON-37/6/1A.1D 5+1-6/...
87	CD15DZ_ELT/off/1024/2015	CIMMYT	JUPAREC2001*2/1M/10/KOFA/9/USDA595 /3/D67.3/RABI//CRA/4/ALD/5/HUI/YAV-1/16/...
88	CD15DZ_ELT/off/994/2015	CIMMYT	JUPAREC2001*2/RBC/5/MOHAWK/3/GUANAY//TILD-1LDTUS-4/4/ARMENT //SRN- 3/...
89	CD15DZ_ELT/off/253/2015	CIMMYT	BHA/5/MOHAWK/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/CF4205/4/YAZI-1...
90	CD15DZ_ELT/off/943/2015	CIMMYT	LILE/6/CF4205/4/YAZI-1AKAKI4//SOMAT3/3AUK/GUIL//GREEN /5/CANELD-9.1//...
91	CD15DZ_ELT/off/950/2015	CIMMYT	YAVA 79/9/ USDA 595/3 /D67.3 /RABI/ /CRA/4/ALO/5/HUI/YAV-1/6/ARDENTE /7/HUI/YAV 79/8/...
92	CD15DZ_ELT/off//248/2015	CIMMYT	CF420S/4/YAZI-1AKAKI-4//SOMAT 3/3/AUK/GUIL//GREEN/5/CANELD-9.1//SHAKE-3/...
93	CD15DZ_ELT/off/275/2015	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//SOMAT-3/3/AUK/GUIL//GREEN/5/CANELD-9.1//SHAKE-3/...
94	CD15DZ_ELT/off/982/2015	CIMMYT	ALTAR 84/STINT//SILVER-45/3/GUANAY/4/GREEN-14//YAV-10/AUK/10/CMH79.959/CHEN//...
95	CD15DZ_ELT/off/1029/2015	CIMMYT	JUPAREC2001*2/KHAPLI/4/INRAM-1805//SOMAT-4/INTER-8/3/SOOTY-9/RASCON-37//...
96	CDSS09B00191T-099Y-020M-6Y00M	CIMMYT	RBC/7/CMH83.2578/4/D88059//WARD/YAV79/3/ACO89/5/2*S00TY-9/RASCON-37/6/...
97	CDSS09B00067S-099Y-035M-3Y-0M	CIMMYT	STORLOM/3/RASCON-37//TARRO-2//RASCON-37/4/D00003A/5/1A.1D5+1-06/3*Mojo/3/AJAIA-12/...
98	CDSS09B00203T-099Y-066M-2Y-0M	CIMMYT	CIT71/5/MOHAWK/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/7/CMH83. 2578/4/D88059//...
99	ICD08-291-0AP	CIMMYT	otb4/3/HFN94N-8/Mrb5//Zna-1/4/5+j3//Dra2/Bcr/3/Ter-3
100	CDSS09B00190T-099Y-036M-18Y-0M	CIMMYT	RBC/HUALITA/5/MOHAWK/3/GUANAY//TILO-1/LOTUS-4/4/ARMENT//SRN-3/NIGRIS-4/3/...
101	CD15DZ_ELT/off/1103/2015	CIMMYT	KOFA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDENTE/7/HUI/YAV79/8/...
102	CD15DZ_ELT/off/1116/2015	CIMMYT	JUPAREC2001*2/1M/5/KOFA/4/DUKEM-1//PATAK-7YAZI-1/3/PATKA/7/YAZI-1/6/ALAS/...
103	CD15DZ_ELT/Off/1102/2015	CIMMYT	KOFA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDENTE/7/HUI/YAV79/8/...
104	CD15DZ_ELT/off/1057/2015	CIMMYT	KRON05/10/KOFA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/HAV-1/6/RADENTE/7/HUI/...
105	CD15DZ_ELT/off/999/2015	CIMMYT	JUPAREC2001*2/RBC/11/PLATA-10/6/MQUE/4/USDA/573//QFN/AA-7/3/ALBA/D/5/AVO/HUI/7/...
106	CD15DZ_ELT/off/1112/2015	CIMMYT	JURAREC2001*2/1M/7/CMH83.2578/4/D88059//WARD/YAV79/3/ACO89/5/2*S00TY-9/...
107	CD15DZ_ELT/off/1067/2015	CIMMYT	CHAM1/5/MOHAWK/3/GUANAY//TILO-1/LOTUS-4/4/ARMENT//SRN-3/NIGRIS-4/3/CANELO-9.1/6/...
108	CD15DZ_ELT/off/1094/2015	CIMMYT	STORLOM/3/RASCON-37/TARRO-2//RASCON-37/4/D00003A/5/1A.1D5+1-06/3*MOJO/3/AJAIA-12/...
109	CD13DZOS F6SR 2013 MS DZLS/22	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//SOMAT-3/3/AUK/GUIL//GREEN/5/CANELD-9.1//SHAKE-3/...
110	CD13DZOS F6SR 2013 MS DZLS/93	CIMMYT	KOFA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDENTE/7/HUI/YAV79/8/...

NO	GENOTYPES	SOURCE	PEDIGREE/ ID/ACCESSIONS
111	CD13DZOS F6SR 2013 MS DZLS/106	CIMMYT	RBC/HULITA/5/M0HAWK/3/GUANAY//TILO-1/L0TUS-4/4/ARMENT//SRN-3/NIGRIS-4/3/...
112	CD13DZOS F6SR 2013 MS DZLS/81	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//S0MAT-3/3/AUK/GUIL//GREEN/5/CANEL0-9.1//SHAKE-3/...
113	CD13DZOS F6SR 2013 MS DZLS/105	CIMMYT	RBC/HULITA/5/M0HAWK/3/GUANAY//TILO-1/L0TUS-4/4/ARMENT//SRN-3/NIGRIS-4/3/...
114	CD13DZOS F6SR 2013 MS DZLS/84	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//S0MAT-3/3/AUK/GUIL//GREEN/5/CANEL0-9.1//SHAKE-3/...
115	CD13DZOS F6SR 2013 MS DZLS/111	CIMMYT	RBC/5/ARMENT//SRN-3/NIGRIS-4/3/CANEL0-9.1/4/LIR0-3/L0TAIL-6/6/C F4 20S/4/YAZI-1/...
116	CD13DZOS F6SR 2013 MS DZLS/83	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//S0MAT-3/3/AUK/GUIL//GREEN/5/CANEL0-9.1//SHAKE-3/...
117	CD13DZOS F6SR 2013 MS DZLS/87	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//S0MAT-3/3/AUK/GUIL//GREEN/5/CANEL0-9.1//SHAKE-3/...
118	CD13DZOS F6SR 2013 MS DZLS/80	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//S0MAT-3/3/AUK/GUIL//GREEN/5/CANEL0-9.1//SHAKE-3/...
119	CD13DZOS F6SR 2013 MS DZLS/97	CIMMYT	K0FA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDEnte/7/HUI/YAV79/8/...
120	CD15DZ_ELT/off/251/2015	CIMMYT	CF420S/4/YAZI-1/AKAKI-4//S0MAT-3/3/AUK/GUIL//GREEN/5/CANELD-9.1//SHAKE-3/...
121	CD15DZ_ELT/off/1006/2015	CIMMYT	JUPAREC2001*2/RBC/6/STORLOM/3/RASCON-37/TARRD-2//RASCON-37/4/D00003A/5/...
122	CD15DZ_ELT/off/989/2015	CIMMYT	TRIDENT/3*KUCUK/7/CMH83 2578/4/D88059//WARD/YAV 79/3/AC089/5/2*S00TY-9/RASCON-37/6/...
123	CD15DZ_ELT/off/303/2015	CIMMYT	AGI22/2*AC089//2*UC1113/3/5*K0FA/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/...
124	CD15DZ_ELT/off/1035/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASCON-37/6/1A.1D 5+1-06/...
125	CD15DZ_ELT/off/1034/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASCON-37/6/1A.1D 5+1-06/...
126	CD15DZ_ELT/off/1038/2015	CIMMYT	WID22289/10/SAHEN-2/KIRKI-8//PROZANA-1/4/ADAMAR-15//ALBIA-1/LTAR84/3/SNITAN/9/...
127	CD15DZ_ELT/off/1115/2015	CIMMYT	JUPAREC2001*2/IM/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/ALAS/...
128	CD15DZ_ELT/off/1037/2015	CIMMYT	BOLENGA/10/K0FA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDEnte/7/HUI/...
129	CD15DZ_ELT/off/1069/2015	CIMMYT	CHAM1/4/INRAM-1005//SOMAT-4/INTER/8/3/SO0TY-9/RASCON-37//TILO-1/L0TUS-4/5/...
130	CD15DZ_ELT/off/1079/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASCON-37/6/1A.1D 5+1-06/...
131	CD15DZ_ELT/off/998/2015	CIMMYT	JUPAREC2001*2/RBC/11/PLATA-10/6/MQUE/4/USDA573//QFN/AA-7/3/ALBA-D/5/AVO/HUI/7/...
132	CD15DZ_ELT/off/1000/2015	CIMMYT	JUPAREC2001*2/RBC/11/PLATA-10/6/MQUE/4/USDA 573//QFN/AA-7/13/ALBA-D/5/AVO/HUI/7/...
133	CD15DZ_ELT/off/1025/2015	CIMMYT	JUPARE C 2001*2/IM/10/K0FA/9/USDA595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/...
134	CD15DZ_ELT/off/980/2015	CIMMYT	ALTAR.84/STINT//SILVER-45/3/GUANAY/4/GREEN-14//YAV-10/AUK/10/CMH79.959/CHEN//...
135	CD15DZELT/off/973/2015	CIMMYT	ALAM0:DR/4/ARMENT//SRN-3/NIGRIS-4/3/CANEL0-9.1/5/PLATA-6/GREEN-17//SNITAN/4/...
136	CD15DZELT/off/1117/2015	CIMMYT	JUPAREC2001*2/IM/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/ALAS/...
137	CD15DZELT/off/849/2015	CIMMYT	NASSIRA/10/PLATA-10/6/MQUE/4/USDA573//QFN/AA-7/3/ALBA-D/5/AV0/HUI/7/PLATA-13/8/...
138	CD15DZELT/off/306/2015	CIMMYT	AG1-22/2*AC089//2*UC1113/3/5*K0FA/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/...
139	CD15DZELT/off/846/2015	CIMMYT	AMRIA/6/ALTAR84/STINT//SILVER-45/3/GUANAY/4/GREEN-14//YAV-10/AUK/5/S0MAT-4/...
140	CD15DZELT/off/1239/2015	CIMMYT	GER0MTEL-3/8/ST0T//ALTAR84/ALD/3/THB /CEP7780//2*MUSK-4/6/EC0/CMH76A.722//...
141	CD15DZELT/off/889/2015	CIMMYT	GEROMTEL-3/7/ALTAR84/BINTEPE85/3/ST0T//ALTAR84/ALD/4/P00-11/YAZI-1/5/...

NO	GENOTYPES	SOURCE	PEDIGREE/ ID/ACCESSIONS
142	CD15DZELT/off/891/2015	CIMMYT	GEROMTEL-3/7/ALTAR84/BINTEPE85/3/ST0T //ALTAR84/ALD/4/P0D-11/YAZI-1/5/...
143	CD15DZELT/off/1235/2015	CIMMYT	TA5057/10/2*CMH85.797//DUKEM-12/2*RASC0N-21/9/USDA595/3/D67.3/RABI/...
144	CD15DZELT/off/1072/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASC0N-37/6/1A.1D5+1-06/...
145	CD15DZELT/off/664/2015	CIMMYT	GER0MTEL-3/10/CHEN-1/TEZ/3/GUIL//CIT71/CII/4/ S0RA/PLATA-12/5/ST0T//ALTAR84/...
146	CD15DZELT/off/745/2015	CIMMYT	CND0/VEE//PLATA-8/3/6*PLATA-11/6/PLATA-8/4/GARZA/AFN//CRA/3/GTA/5/RASC0N/9/...
147	CD15DZELT/off/790/2015	CIMMYT	AMRIA/6/ALTAR84/STINT//SILVER-45/3/GUANAY/4/GREEN-14//YAV-10/AUK/5/S0MAT-4/...
148	CD15DZELT/off/792/2015	CIMMYT	AMRIA/8/ST0T//ALTAR84/ALD/3/THBCEP7780//2*MUSK-4/6/EC0/CMH76A.722//BIT/3/...
149	CD15DZELT/off/801/2015	CIMMYT	GER0MTEL-3/6/S0MAT-3/PHAX-1//TILO-1/L0TUS-4/3/GUANAY/5/NETTA-4/DUKEM-12//...
150	CD15DZELT/off/802/2015	CIMMYT	GER0MTEL-3/9/GUANCAN INIA/GUANAY /8/GEDIZFG0//GTA/3/SRN1/4/T0TUS/5/ENTE/MEXI-2//...
151	CD15DZELT/off/935/2015	CIMMYT	C0RDEIR0/9/GUAYACANINIA/GUANY/8/GEDIZ FG0//GTA/3/SRN-1/4/TOTUS/5/ENTE/MEXI-2//...
152	CD15DZELT/off/981/2015	CIMMYT	ALTAR84/STINT//SILVER-45/3/GUANAY /4/GREEN-14//YAV-10/AUK/10/CMH79.959/CHEN//...
153	CD15DZELT/off/995/2015	CIMMYT	JUPARE C 2001*2/RBC/11/PLATA-10/6/MQUE/4/USDA573 //QFN/AA-7/3/ALBA-D/5/AV0/HUI/7/...
154	CD15DZELT/off/1032/2015	CIMMYT	JUPARE C 2001*2/KHAPLI/5/M0HAWK/4/DUKEM -1//PATKA-7/YAZI-1/3/PATKA-7YAZI-1/11/...
155	CD15DZELT/off/1081/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASC0N-37/6/1A.1D5+1-06/...
156	CD15DZ-ELT/off/1082/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASC0N-37/6/1A.1D5+1-06/...
157	CD15DZELT/off/1087/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASC0N-37/6/1A.1D5+1-06/...
158	CD15DZELT/off/1129/2015	CIMMYT	KR0N0S/10/K0FA/9/USDA595/3/D67.3/RABI//CRA/4/AL0/5/HUI/YAV-1/6/ARDENT/7/HUI/...
159	CD15DZELT/off/1131/2015	CIMMYT	CMH83.2578/4/D88059//WARD/YAV79/3/AC089/5/2*S00TY-9/RASC0N-37/6/1A.1D5+1-06/...
160	CD15DZELT/off/1144/2015	CIMMYT	ST0RL0M/3/RASC0N-37/TARR0-2//RASC0N-37/4/D00003A/5/1A.1D5+1-06/3*M0J0/3/AJAIA-12/...
161	CD15DZELT/off/1152/2015	CIMMYT	K0FA/9/USDA595/3/D67.3/RABI//CRA/4/AL0/5/HUI/YAV-1/6/ARDENT/7/HUI/YAV79/8/...
162	CD15DZELT/off/1159/2015	CIMMYT	T.DIC0CC0NPI164578/10/K0FA/9/USDA595/3/D67.3/RABI//CRA/4/AL0/5/HUI/YAV-1/6/...
163	CD15DZELT/off/1164/2015	CIMMYT	NASSIRA/10/PLATA10/6/MQUE/4/USDA573//QFN/AA-7/3/ALBA-D/5/AV0/HUI/7/PLATA-13/8/...
164	CD15DZELT/off/1176/2015	CIMMYT	CHAM-3/4/N0K-23//PLATA-6/GREEN17/3/S0RA /2*PLATA-12//SRN-3/NIGRIS-4...
165	CD15DZELT/off/1193/2015	CIMMYT	A624/5/SORA/2*PLATA-12/3/S0RA/2*PLATA-12//S0MAT-3/4/AJAIA-13/YAZI//DIPPER-2/BUSHEN-3
166	CD15DZELT/off/1516/2015	CIMMYT	JUPARE C 2001*2/IM/5/K0FA/4/DUKEM1//PATKA -7/YAZI-1/3/PATKA-7YAZI-1/6/ALAS/...
167	CD15DZELT/off/1244/2015	CIMMYT	JUPAREC2001*2/IM/5/K0FA/4/DUKEM 1//PATKA- 7/YAZI-1/3/PATKA-7YAZI-1/6/ALAS/...

NO	GENOTYPES	SOURCE	PEDIGREE/ ID/ACCESSIONS
168	CD15DZ-ELT/off/305/2015	CIMMYT	G 122/2*AC089/2*UC1113/3/5 *K0FA/5/K0FA /4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/...
169	Ude	DZARC	CHEN/ALTAR84//JO69
170	Mangudo	DZARC	MRF1/STJ2/3/1718/BT//KARIM,TUN
171	Tesfaye	DZARC	ARMENT//SRN-NIGRIS-4/3/CANED-9.1/4/TOSKA-26RASCON-37//SNITSN/5/PLAYERO
172	Alemtena	DZARC	Icasyr-1/3/Gcn//Sti/Mrb3
173	Mukiye	DZARC	STJ3//BICRE/LOUKOS-4/3/TER3
174	Yerer	DZARC	CHEN/TEZONTLE/3/GUILLEMOT//CANDEAL-II
175	D-2018	DZARC	CGS
176	Utuba	DZARC	Icajian42) Omruf1/Stojocri2/3/1718/BeadWheat24//Karim
177	Werer	DZARC	1346/LAHN//BICRE/LOUKOS-4
178	Asasa	DZARC	chorlito/yavaros//free-gallipoli/3/free-gallipoli/canadian-red/4/free-gallipoli/don-pedro/5/huitle
179	Cocorit 71	DZARC	RASPINEGRO-DE-AGUILASENANO/4*TEHUACAN-60//STEWART-63/3/ANHINGA
180	Dire	DZARC	CHEN/TE3/BUSHEN4/3/
181	Tate	DZARC	CD94523
182	Toltu	DZARC	4/B/R9096#21001(980SN Patho)
183	Bulalla	DZARC	DurumICARDA/Ethiopia
184	Hitosa	DZARC	CHEN/ALTAR-84
185	Obsa	DZARC	ALTAR84/ALTO-1/AJAYA
186	Bakalcha	DZARC	980SN Gedirfa/Gwerou #15 patho
187	Selam	DZARC	GERARDO/3/ND-61-130/LEEDS//COCORIT-71/4/HORA/5/HORA//COCORIT-71/CANDEAL
188	Malefia	DZARC	ALTAR-84/STERNA,MEX/LAHN
189	Breeding pipeline, DWNL p#2	DZARC	C F4 20 S/4/YAZI-1/AKAKI-4//SOMAT-3/3/AUK/GUIL//GREEN/5/CANELO-9.1//SHAKE-3/...
190	Breeding pipeline, DWNL p#5	DZARC	Yerer/UC11132...25Yellow/DZ2013mehF1 P#6/DZ2014meh F2 P#6-1
191	Breeding pipeline, DWNL p#13	DZARC	JUPARE C 2001*2/IM/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/ALAS/...
192	Breeding pipeline, DWNL p#15	DZARC	AG 1-22/2*AC089/2*UC1113/3/5*K0FA/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/...
193	Breeding pipeline, DWNL p#16	DZARC	BHA/15/MOHAWK/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/CF4 20S/4/YAZI-1/...
194	Breeding pipeline, DWNL p#18	DZARC	JUPARE C 2001* 2/RBC/5/MOHAWK/3/GUANAY//TILD-1LDTUS-4/4/ARMENT //SRN- 3/...
195	Breeding pipeline, DWNL p#20	DZARC	ALTAR 84/STINT//SILVER-45/3/GUANAY/4/GREEN-14//YAV-10/AUK/10/CMH79.959/CHEN//...
196	Breeding pipeline, DWNL p#21	DZARC	Icasyr-1/3/Gcn//Sti/Mrb3
197	Breeding pipeline, DWNE P#4	DZARC	Yerer/UC1113225Yellow/DZ2013mehF1 P#6/DZ2014meh F2 P#6-1
198	Breeding pipeline, DWNE P#5	DZARC	Yerer/UC 1113GPC Lr 1908001/59/ DZ 2013mehF1P#7/DZ 2014 mehF2 P#7-1
199	Breeding pipeline, DWNE P#6	DZARC	Yerer/UC 1113GPC Lr 1908001/59/ DZ 2013mehF1P#7/DZ 2014 mehF2 P#7-2
200	Breeding pipeline, DWNE P#13	DZARC	otb4/3/HFN94N-8/Mrb5//Zna-1/4/5+j3//Dra2/Bcr/3/Ter-3

Performance of Introduced Climbing Bean (*Phaseolus vulgaris* L.) Varieties for Registration in Ethiopia

Masreshaw Yirga¹, Yechalew Sileshi¹, Behailu Atero¹, Berhanu Amsalu²,
Abel Moges², Kidane Tumssa², Zeru Yimer⁴, and Dula Geneti⁵

¹ Ethiopian Institute of Agricultural Research, Jimma Research Center, P.O.Box 192, Jimma, Ethiopia,

² Ethiopian Institute of Agricultural Research, Melkassa Research Center, P.O.Box 436, Melkassa, Ethiopia

³ Ethiopian Institute of Agricultural Research, Pawi Research Center, P.O. Box 25, Pawe, Ethiopia,

⁵ Ethiopian Institute of Agricultural Research, Jimma Research Center, Haru Sub-center, Haru, Ethiopia

Corresponding author: E-mail: yirgamasresha@gmail.com

Abstract

Testing the adaptability of newly introduced crop varieties under potential growing agro-ecologies is an imperative component of a fast-track breeding approach in Ethiopia. A field experiment was conducted to evaluate the performance of climbing bean varieties for grain yield and other agronomic traits at four locations (Jimma, Haru, Assosa and Pawe) during 2019-2020 main cropping seasons. A total of 25 climbing bean varieties including standard check (Dandesu) were used in this study. The trial was laid down using 5x5 triple lattice design. Data was collected on 11 traits: numbers of days to 50% flowering, 95% maturity, pods per plant, seeds per pod, seed per plant, plant height (cm), common bacterial blight, angular leaf spot, floury leaf spot, hundred seed weight (g), and grain yield per plant (tha^{-1}). The data was subjected to statistical analysis using SAS software. The combined ANOVA revealed significant variation ($P \leq 0.01$) among varieties for most of the traits except for number of days to 95% maturity and hundred seed weight. The mean grain yield performance for the combined data was the highest for variety RWV 1272 (5.37 tha^{-1}) followed by G13607 (4.53 t/ha), and CAB2 (tha^{-1}). The three high yielding varieties had produced 117.4%, 83.4% and 54.7% yield increase over the standard check, Dendesu (2.47 tha^{-1}), respectively. In addition to their high yielding ability the varieties showed good resistance/tolerance reaction against common bacterial blight, angular leaf spot and floury leaf spot disease. The three varieties have medium seed size but have different seed color. The color of their seed is, brun purple for RWV1272; red for G13607; and white for CAB2, which have their own marketed demand and farmers' preference. The other major attributes of the varieties were acceptable cooking time of 81-88 minutes. The three varieties were planted under verification plot and evaluated by variety release committee for official registration. Based on their best performance in grain yield, disease reaction and acceptable quality in terms of seed size, color and cooking time, the two varieties RWV1272 and CAB2 were accepted by national variety release committee to be registered as commercial variety in Ethiopia since June 2022. The registered varieties are recommended for Southwest, West and other similar agro ecologies with high rain fall in Ethiopia. To exploit the high yield advantage of the varieties and partly solve the food self-sufficiency in the country, major emphasis should be given for early generation seed multiplication, well organized demonstration and popularization of the varieties to farmers.

Keywords: climbing bean, growth habit, Adaptation, Yield

Introduction

Common beans (*Phaseolus vulgaris* L., $2n = 2x = 22$) are the second most important crop in Eastern, Central, and Southern African agriculture. Ethiopia is one of primary beans growing regions in Africa. Common bean has been introduced by the Portuguese in the 16th century in Ethiopia (Imru, 1985). It has been known as an export crop and has probably been grown as a food crop for a much longer period. In terms of nutrition, common bean is often called the “poor man’s meat” rich in protein (about 22%) and good source of Iron and Zinc (Beebe *et al.*, 2000). The crop is a key component in intensifying production because it is easily intercropped and crop rotated with other crops and improve soil fertility through nitrogen fixation. In Ethiopia common bean covers 18.60% (1311, 583.58 hectares) of the pulse area coverage and 17.28% (about 552, 564.074 tons) of pulse production. National average productivity common bean in Ethiopia is generally low, 1.73 t/ha (CSA, 2021), this is because of lack of alternative improved bean type varieties, biotic and abiotic factors and poor extension services.

Depending on their growth habit common bean has classified in to four groups: Class I has a determinate growth habit (bush type bean); Class II-IV have an indeterminate growth habit, out of which class IIIb and class IV are referred to as climbing beans or pole beans. Climbing beans originated

from the medium to high-altitude regions of the Andes and Central America (Voysest, 2000). Climbing is a twinning, annual, herbaceous plant with various growth habits, morphological traits, and seed and pod characteristics. The crop is adapted to an altitude ranging from sea level to nearly 3000 masl (CIAT, 1986a).

Climbing beans in Ethiopia are mainly adapted in mid to highland areas and produced around homestead gardens and along the fences and sometimes intercropped with maize/pigeon peas. It can also be planted in the production fields by using supporting sticks (Berhanu *et al.*, 2019). Cropping land is getting shorter in Ethiopia, so, climbing bean which has high yield potential up to 4 to 5 tha^{-1} is becoming useful to maximize income per unit area. Even though, climbing beans are relatively high grain yield, there is a limitation of climbing bean improved variety in the country. Hence, alternative improved variety development of different common beans types across agro-ecology is important to increase production and productivity in the country.

Variety adaptation is one of the fast tracks variety development approach in common bean breeding program in Ethiopia. This approach requires introduction of commercial varieties from abroad and testing their performance for official registration of the best varieties for commercial production. A few numbers of varieties were released in this way so far. However, yield maximization and

development of disease resistant and tolerant varieties that meet the increased demand of the growing industries and market still remain as gaps in common bean technology development. Bearing in mind the above facts, the tested materials were introduced from International Centre for Tropical Agriculture (CIAT). Therefore, this study was conducted to evaluate, select and recommend adaptable commercial climbing bean varieties for potential climbing bean growing agro-ecologies in Ethiopia.

Materials and Methods

The experiment was conducted at Jimma, Haru, Assosa and Pawe during 2019-2020 cropping season. The description of experimental locations is stated in Table1.

Experimental Materials, Design and management

The field experiment was conducted using 25 introduced climbing bean varieties including the standard check variety (Dandesu). The tested climbing bean varieties were released commercial varieties in Burundi, Uganda, Rwanda and Tanzania (Table 2). The experiment was laid out in triple lattice design. Planting was done in a plot of 4 rows with 4m length and 10cm spacing between plants and 50cm between rows. Fertilizer NPS

(19%N, 38% P, 7% Sulfur, and the rest filler) at the rate of 121kg ha^{-1} was applied at planting. Supporting stick was used and the rest agronomic management was done as per the recommendation.

The candidate climbing bean varieties; RWV1272, G1360 and CAB2 along with the check Dandesu were tested under verification plot. The verification plot was planted at Jimma, Haru and Pawe research stations and on two farmer's field surrounding each research center. The trial was planted in a 10m X 10m single plot. All cultural practices for climbing were carried out as stated above. The verification plots were evaluated by variety release technical committee.

Data Collection and analysis

Data were collected both at plot and plant basis. Date of emergence, date of 50% flowering, date of 95% maturity, stand count at emergence, stand count at harvest, disease severity visual score (1-9 scale), plant height(cm), number of pods/plant, number of seed/plants, hundred seeds weight(g), and yield (tha^{-1}) were collected. The data analysis was done using SAS software. General linear mode of SAS was used to do the ANOVA and computation of the means.

Table 1. Descriptions of the experimental locations

Location	Altitude (m.a.s.l.)	Latitude	Longitude	Temperature		RF(mm)
				min	max	
Jimma	1,754	7°46'0" N	36°00'0"E	11.6°C	26.3°C	1,572
Assosa	1580	10° 03' 0" N	34° 59' E	14°C	39°C	1,275
Haru	1252	8°59' 0" N	35°47' 0"E	16°C	27°C	1227
Pawe	1120	11°19' 0"N	36°24' 0"E	16.3 °c	32.6 °c	1587

Table 2. Climbing bean varieties tested in four locations during 2019-2020

No.	Varieties	Source	Origin
1	NAKAJA	CIAT	Burundi
2	RWV 1129	CIAT	Burundi, Tanzania
3	VCB 81013	CIAT	Burundi
4	GASILIDA	CIAT	Burundi, Rwanda
5	MAC 70	CIAT	Burundi
6	Kinure	CIAT	Burundi
7	MUHHORO	CIAT	Burundi
8	GSZ 611	CIAT	Burundi
9	AND 10	CIAT	Burundi
10	Vuninkingi	CIAT	Burundi, Rwanda
11	G13607	CIAT	Burundi
12	IZO201543	CIAT	Burundi
13	Bihogo(MLV-206/96B)	CIAT	Burundi
14	RWV 1272	CIAT	Burundi, Rwanda
15	Nokia	CIAT	Burundi
16	Jaune volubile	CIAT	Burundi
17	NUV 30	CIAT	Burundi
18	NABE 12C	CIAT	Uganda
19	NABE 26C	CIAT	Uganda
20	NABE 29C	CIAT	Uganda
21	MAC 44	CIAT	Burundi,Uganda,Tanzania
22	NYIRAMUHONDO	CIAT	Uganda
23	G 2333	CIAT	Uganda, Rwanda
24	CAB 2	CIAT	Rwanda, Tanzania
25	Check (Dandesu)	Ethiopia,	Ethiopia

Results and Discussion

The results of the combined analysis of variance (Table 5) revealed that, the mean square due to location was significant ($P \leq 0.01$), indicating the distinct nature of the four test locations. The mean square due variety

was significant for most of the traits ($P \leq 0.01$) except for days to maturity and hundred seed weight, indicating varieties were responded differently for each trait. Mean squares due to location x variety were significant for most of traits except days to flowering and maturity, seed per pod, seed per plant and angular leaf spot, meaning

that varieties exhibited different relative performance in each location. Generally, the result for yield and related traits indicated that phenotypic variability for these traits is dependent on genetic factors, environmental variables and the interaction between varieties and environment.

The yield performances of 25 varieties for separate analysis are presented in Table 4. The maximum mean environmental grain yield across varieties was recorded at Haru in 2020 from the variety RWV 1272 (8.58 t ha^{-1}), while the minimum yield was recorded at Pawe in 2020 from the variety Jaune volubile (0.29 t/ha). The mean yield performance of the varieties at Jimma (4.60 t ha^{-1} of the two years) and Haru (3.98 t ha^{-1}) was relatively high, while mean yield of varieties at Pawe (2.12 t ha^{-1}) followed by Assosa (1.33 t ha^{-1}) was relatively low. So, Jima and Haru which are characterized by mid altitude with high in rainfall are found more suitable environment for climbing bean production compared to Assosa and Pawe. In most of the environments varieties RWV 1272, G13607 and CAB2 produced consistent and high grain yield over the check Dandesu. The mean yield performance across the five environments indicated that, maximum yield was recorded from varieties RWV 1272 (5.37 t ha^{-1}) followed by G13607 (4.53 t ha^{-1}), and CAB2 (3.82 t ha^{-1}), which exhibited a yield advantage of 117.4%, 83.4% and 54.7% over the standard check, Dandesu (2.5 t ha^{-1}), respectively.

The mean performance of the tested varieties across environment was also ranged widely for other agromorphological traits (Table 5). The earliest days to flowering (48) and maturing (98) was recorded from variety RWV 1129, and IZO201543, while the latest flowering (54) and latest maturing (150) was recorded from variety MLV-206/96B and Jaune volubile, respectively. The high yielding varieties RWV 1272, G13607 and CAB2 were relatively found medium maturing, which takes 106, 104 and 103 days to physiological maturity, respectively. The tallest plant height (243.8 cm) was recorded for the standard check Dandesu, while shortest height (144.8 cm) was recorded for the variety Jaune volubile. Highest range was also obtained for number of pod per plant (10 to 20), number of seed per pod (4 to 6), number of seed per plant (42 to 85), hundred seed weight (24 to 38 gm) and yield per plant (14 to 39 gm plant^{-1}), which played important role in the total variability of the tested climbing bean varieties.

The tested varieties also showed significantly different reaction against common bacterial blight, angular leaf spot and floury leaf spot. The varieties; RWV 1272, G13607 and CAB 2 also showed resistance/tolerance level of reaction against common bacterial blight, angular leaf spot and floury leaf spot. These three varieties were grouped under medium seed size and characterized by brun purple, red and white seed color, respectively. They have also fast cooking with 81, 88, and

82minutes of cooking time, respectively (Table 6). Therefore, these three varieties which have statistically considerable yield difference and other yield component traits were promoted to variety verification trial for registration. After evaluation the two candidate varieties by the national variety release committee, RWV 1272 and CAB2 were registered for production since

2022 for their high grain yield, good agronomic performance, acceptable quality, fast cooking time and high market demand. The registered varieties are recommended for Southwest, West and other similar agro ecologies with high rain fall in Ethiopia.

Table 3. Mean squares of the combined analysis of variance for yield and related characters of 25 introduced climbing bean varieties at five environments

Source	DF	DTF	DTM	PH	NPP	SPd	NSP	CBB	ALS	FLS	HSW	Yld(gm/pl)	Yld(t/ha)
Year	1	0.14ns	2145.5ns	13180.0**	313.5**	1.6ns	4114.0*	1.2ns	13.7**	8.7*	8381.1**	37.4ns	80.6**
Loc	3	2327.1**	9167.0**	142486.30**	1959.7**	13.8**	41125.4**	50.3**	67.3**	53.2**	4105.4**	2720.7**	160.7**
Rep	2	120.0**	43.7ns	15951.7**	158.6*	0.4ns	2056.8ns	3.6ns	7.6**	9.8**	9.6ns	310.3ns	59.8**
Block(Rep)	12	16.0**	738.3ns	5172.7**	15.8ns	1.5ns	834.6ns	3.8ns	1.8ns	1.5ns	21.4ns	149.5ns	2.7ns
Geno	24	20.0**	376.9ns	4972.9**	58.8*	2.7**	1712.7*	3.8*	2.8*	4.7**	31.6ns	218.2*	5.8**
L*G	72	23.40ns	387.30ns	3319.7**	53.2*	1.6ns	1279.3ns	3.6**	2.1ns	4.2**	55.3**	189.3*	3.7**
Y*G	24	21.6ns	509.2ns	1665.8ns	77.2**	2.5*	2255.6ns	2.3ns	1.8ns	4.4**	93.4**	246.3**	2.6ns

Where, * = significant at ($P \leq 0.05$) and **= significant at ($P \leq .01$), yr=year, loc=location, Geno=variety, DF=degree of freedom, DTF = days to 50% flowering, DTM = days to 95% pod maturity, PH = plant height, NPP =pod per plant, NSD= seed per pod, NSP= seed per plant, CBB=common bacterial blight, ALS= angular leaf spot,FLS=flory leaf spot, HSW=hundred seed weight, YLDpl= yield per plant, YLDha= yield per ha-1

Table 4. Mean grain yield performance (tha⁻¹) of 25 climbing bean varieties evaluated at 4 locations during 2019-2020

No.	Variety	2019	2020	2020			Overall yld(t/ha ⁻¹)
		Jimma	Jimma	Assossa	Haru	Pawe	
1	NAKAJA	4.98	4.47	2.79	4.99	1.33	3.69
2	RWV 1129	0.95	2.75	2.23	3.43	1.22	2.09
3	VCB 81013	3.79	6.19	2.26	3.92	1.36	3.53
4	GASILIDA	3.46	4.32	2.08	4.00	1.54	2.92
5	MAC 70	1.54	1.63	1.47	1.97	1.33	1.44
6	Kinure	4.62	3.61	2.82	2.00	1.48	2.76
7	MUHHORO	2.87	3.05	1.04	2.25	1.32	2.32
8	GSZ 611	5.33	6.60	2.64	3.50	1.37	3.93
9	AND 10	2.78	5.29	1.73	2.11	1.37	2.78
10	Vuninkingi	4.79	7.31	2.80	5.57	1.30	3.94
11	G13607	3.05	7.23	2.62	7.81	1.42	4.53
12	IZO201543	3.55	3.97	2.34	5.71	1.15	3.52
13	MLV-206/96B	3.36	5.91	3.13	3.88	1.15	3.60
14	RWV 1272	4.79	7.81	2.87	8.58	1.47	5.37
15	Nokia	5.29	8.39	2.02	3.94	1.43	4.20
16	Jaune volubile	0.45	0.64	1.55	2.37	0.29	0.88
17	NUV 30	5.60	3.84	2.23	4.83	1.32	3.55
18	NABE 12C	2.39	4.49	1.87	1.82	1.48	2.50
19	NABE 26C	1.90	3.10	1.30	4.04	1.38	2.54
20	NABE 29C	2.70	2.84	2.40	4.38	1.28	2.99
21	MAC 44	1.23	3.74	1.69	2.54	1.49	2.41
22	NYIRAMUHONDO	4.61	5.77	2.43	5.52	1.46	4.02
23	G 2333	2.81	2.86	0.57	1.28	1.56	2.08
24	CAB 2	3.75	5.45	2.73	4.16	1.46	3.82
25	Check (Dandesu)	2.20	3.00	1.36	4.84	1.37	2.47
Mean		3.31	4.57	2.12	3.98	1.33	3.12
CV		19.5	25.9	17.0	43.0	8.3	28.5
LSD		1.37	1.9567	0.76	2.8307	0.1831	1.12

Table 5. Mean grain yield and other traits of climbing bean varieties evaluated at 4 locations in 2019-2020

No.	Genotype	DTF	DTM	PH	NPP	SPd	SPP	CBB	ALS	FLS	HSW	Yld (gm/plant)	Yld (tha ⁻¹)
1	NAKAJA	49.3	98.7	200.5	11.9	5.0	52.4	4.5	4.5	2.3	27.6	23.7	3.69
2	RWV 1129	47.6	102.7	179.9	10.7	5.1	54.2	3.7	3.2	3.2	34.1	21.8	2.09
3	VCB 81013	49.9	104.5	218.1	16.3	4.9	73.0	4.2	3.6	2.3	26.3	23.9	3.53
4	GASILIDA	50.4	104.8	237.5	13.7	5.2	63.5	3.9	2.8	3.7	28.9	38.7	2.92
5	MAC 70	51.5	99.7	178.5	11.3	4.9	50.0	3.7	2.3	2.6	31.3	21.6	1.44
6	Kinure	50.0	103.5	186.8	14.0	5.1	62.1	4.2	3.7	2.3	30.0	22.7	2.76
7	MUHORO	50.5	103.7	187.2	12.3	4.5	45.9	4.2	3.5	2.6	30.3	22.6	2.32
8	GSZ 611	53.9	103.5	227.4	15.1	5.5	74.2	4.2	2.7	1.2	29.1	24.4	3.93
9	AND 10	52.5	105.0	204.8	12.2	6	69.2	3.3	3.2	2.8	28.7	18.2	2.78
10	Vuninkingi	51.1	106.0	226.7	12.8	5.7	66.1	3.2	2.3	1.9	26.7	22.4	3.94
11	G13607	52.1	103.7	216.7	18.9	4.7	78.8	3.9	2.9	1.8	30.2	18.9	4.53
12	IZO201543	49.8	97.8	183.3	15.0	4.4	53.8	3.9	2.7	1.7	28.4	17.5	3.52
13	MLV-206/96B	54.1	106.1	208.9	10.0	5.1	49.6	3.3	2.6	1.9	30.4	22.8	3.60
14	RWV 1272	50.8	105.8	219.1	14.7	5.1	73.1	3.2	2.6	1.7	26.1	19.3	5.37
15	Nokia	50.1	101.3	198.9	14.6	5.4	70.6	3.4	2.5	1.9	24.3	23.9	4.20
16	Jaune volubile	48.9	150.5	144.9	12.6	4.4	53.8	4.0	3.0	3.8	28.3	14.5	0.88
17	NUV 30	49.9	100.7	202.3	15.1	4.9	73.2	3.7	2.9	1.2	25.9	18.1	3.55
18	NABE 12C	51.3	99.9	218.5	9.6	5.2	49.6	2.9	2.7	3.0	33.9	18.9	2.50
19	NABE 26C	50.0	102.0	190.7	12.2	4.5	50.3	3.9	3.2	2.9	31.7	17.6	2.54
20	NABE 29C	48.9	101.7	187.9	10.3	4.1	41.8	2.9	2.5	2.0	30.5	18.7	2.99
21	MAC 44	48.7	99.4	172.4	13.5	4.5	62.4	3.3	2.6	3.0	34.7	20.7	2.41
22	NYIRAMUHON O	51.5	104.3	241.0	19.2	4.9	85.1	2.5	2.5	1.5	25.9	20.4	4.02
23	G 2333	49.9	102.8	190.6	12.7	4.6	56.0	5.1	3.9	3.0	24.2	20.9	2.08
24	CAB 2	50.2	102.7	226.5	14.8	5.1	68.9	3.2	3.2	3.5	25.8	24.4	3.82
25	C1(Dandesu)	52.3	102.9	243.9	10.0	4.6	46.1	4.4	3.5	2.0	27.2	19.3	2.47
Mean		50.6	104.5	203.7	13.3	4.9	60.9	3.7	3.0	2.4	28.8	21.4	3.12
CV		8.8	24.7	22.4	44.8	24.2	50.7	39.2	41.4	54.0	18.0	52.6	28.49
LSD		NS	NS	34.7	4.6	0.9	24.0	1.1	1.0	1.0	4.0	8.7	1.12

Table 6. Seed Characteristics and cooking time of climbing bean Candidate and check varieties

No.	Variety	Seed color	Seed size	Cooking time (minute)	Decision of the committee (NVRC)	Year of release
1	RWV1272 (candidate1)	brun purple	medium	81	released	2022
2	G13607(candidate2)	red	medium	88	rejected	-
3	CAB2	white	medium	82	released	2022
5	Dandesu(check1)	red	medium	87	check	2012

Conclusion and Recommendation

Evaluating the performance of climbing bean varieties and recommending the adaptable once for suitable agro-ecologies can boost production and productivity of bean in Ethiopia. The combined analysis of variance (ANOVA) revealed significant variation ($P \leq 0.01$) among varieties for most of the traits considered. The mean yield performance across the five environments recorded maximum grain yield from variety RWV 1272 followed by G13607, and CAB2. The outstanding varieties were also showed resistance/tolerance to foliar disease and fast cooking time. Therefore, these three varieties which exhibited high grain yield and good agronomic performance were promoted to variety verification trial for registration. After evaluation, the two varieties RWV 1272 and CAB2 were registered for production since 2022 for their high grain yield, good agronomic performance, acceptable quality in terms of seed size, color, cooking time and high market demand. These varieties are suitable for Southwest, West and other similar agro ecologies

with high rain fall in Ethiopia. It is highly recommended to make available the initial seed, demonstration and popularization of these varieties in suitable agro-ecologies. In the future, major effort will have to be put into mind to multiplying early generation seeds, demonstration and promotion of these varieties.

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Evaluation and Stability Analysis of Climbing Bean (*Phaseolus vulgaris* L.) Genotypes in High Potential Areas of Ethiopia

Masreshaw Yirga¹, Yechalew Sileshi¹, Berhanu Amsalu², Abush Tesfay³, Behailu Atero¹, Abel Moges³, Kidane Tumssa², Abush Tesfay³, Solomon Bekele⁴, and Zeru Yimer⁵

¹Ethiopian Institute of Agricultural Research, Jimma Agricultural Research Center, P.O.Box 192, Jimma, Ethiopia, ²Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Center, P.O.Box 436, Melkassa, Ethiopia, ³International Institutes of Tropical Agriculture, Oyo Road, P.M.B. 5320, Ibadan, Nigeria, ⁴Oromia Agricultural Research Institute, Bako Agricultural Research Center, P.O.Box 21, Bako, Ethiopia, ⁵Ethiopian Institute of Agricultural Research, Pawe Agricultural Research Center, P.O.Box 25, Pawe, Ethiopia; Corresponding author: E-mail: yirgamasresha@gmail.com

Abstract

Climbing bean (*Phaseolus vulgaris* L.) is an important pulse crop to ensure food and nutritional security in Ethiopia. However, its productivity is below its potential due to use of low yielding local varieties, biotic and abiotic stresses in different growing environments. Limited research was done on climbing bean and a few varieties were developed so far. This study is therefore undertaken to evaluate and identify high yield potential and stable performance. The trial was conducted at Jimma, Metu, Haru, Bako and Pawe during 2019-2020 main crop seasons using randomized complete block design with three replications. The combined analysis of variance showed highly significant difference ($P \leq 0.01$) among genotypes (G), locations (L), year (Y) and their interaction (G x LxY) for most of the traits. Based on mean grain yield performance of the genotypes over environments, Genotype NUV-54 (G1) scored maximum grain yield (2.67 tha^{-1}) followed by Genotype NUV-76 (G15) (2.57 tha^{-1}), which exhibited a yield advantage of (23.61% and 18.14) and (18.98% and 13.72%) from the checks Dandesu (2.16 tha^{-1}) and Tibe (2.26 tha^{-1}), respectively. Stability view of GGE biplot showed that G1 and G15 exhibited the first and the second-highest mean grain yield and relatively ideal genotypes and moderate stability to stable across environments, respectively. These genotypes G1 and G15 are characterized by small seed size with red and white seed color, respectively. Fast cooking time is the other major attributes of outstanding varieties G1 (83 minute) and G15 (88 minute). The performance of these two genotypes also showed resistance to common bacterial blight; angular leaf spot and floury leaf spot. These two promising genotypes were promoted to verification plot for official release. Based on the gain yield performance, disease resistance and quality, the National Variety Release Committee (NVRC) approved the release of the first candidate varieties NUV-54 (G1) for commercial production since June 2022. The variety is recommended for Southwest, West and other similar agro ecologies with high rainfall areas of the country.

Keywords: Climbing bean, Yield, GGE, NUV 54

Introduction

Common bean is an important pulse in terms of production and area coverage

in Ethiopia. The national area coverage and production is estimated as 311,583.58 hectares and 552,564.074 tons, respectively (CSA,

2021). The production and utilization of common bean has increased due to the rising of global demand and the expansion hunger particularly in vulnerable subset of small holder farmers in the country. Nutritionally, common bean is rich in dietary protein, source of vitamins and essential minerals such as iron and zinc (which are key elements for mental development) and B-vitamins. It plays a critical role in cropping systems and soil fertility improvement via nitrogen fixation (Beebe *et al.*, 2000)..

Common bean is classified into four major groups by CIAT, depending on their growth habit. Class I has a determinate growth habit (bush type bean) while class II-IV has an indeterminate growth habit. Classes IIIb and IV are referred to as climbing beans or pole beans. Climbing beans originated from medium to high-altitude regions of the Andes and Central America (Voysest, 2000). The most outstanding characteristic of climbing beans is their high yield potential: up to 4 to 5 tonha⁻¹ versus 3 tonha⁻¹ for bush beans under optimal conditions (CIAT, 2004). The nature of their growth habit and yield potential allows significant harvests in areas where population pressure is high and arable land is scarce (Sperling and Muyaneza, 1995). Climbing beans are grown in East and Central African countries, including: Rwanda, Central Kenya highlands, Western Kenya, Burundi, and Eastern Democratic Republic of Congo and Southern, southwestern and Western

mid-highlands of Ethiopia (Ramaekers *et al.*, 2013; Raphaël, 2013; CGIAR, 2018; Berhanu *et al.*, 2019). The majority of these regions are characterized by high rainfall, high population density and land scarcity. Climbing beans are more common on altitudes of 1750-2300 meters above sea level (Woolley *et al.*, 1991).

Climbing bean in Ethiopia is mainly produced around homestead gardens, along the fences and sometimes intercropped with maize/pigeon peas. It can also be planted in the production fields, but it requires providing supporting sticks (Berhanu *et al.*, 2019). Therefore, climbing beans which have high grain yield can provide the best option for intensification and production where arable landholdings are diminished due to population pressure. Despite the potential of climbing beans to maximize income per unit area for small holder farmers, limited number of climbing bean varieties were released as compared to bush type beans. Hence, this study was conducted to evaluate the stability of high yielding climbing bean genotypes along with disease resistance and acceptable quality across different testing locations and thereby to identify and advance elite genotypes to variety verification trial and release..

Materials and Methods

The experiment was conducted in Jimma, Metu, Haru, Bako and Pawe during 2019-2020 cropping season.

The description of experimental locations is presented in Table1. A total of 17 climbing bean genotypes including two checks (Dandesu and Tibe) were evaluated as a national variety trial across five locations during 2019-2020 except at Pawe where the experiment was conducted in 2020 only (Table 2). The tested materials were introduced from International Centre for Tropical Agriculture (CIAT). The genotypes were arranged in randomized complete block design with three replications.

Planting was done in a plot of four rows with 4m length with regular spacing of 10 cm between plants and 50cm between rows. Fertilizer NPS at the rate of 121kg ha^{-1} was applied at planting. The plants were supported

with sticks starting from one month after planting and hands weeding along with manual digging were done to control weeds. Harvesting and threshing were done manually after physiological maturity.

Two candidate climbing bean varieties; namely, NUV-54 and NUV-76 along with two checks Dandesu and Tibe were tested under verification plot. The verification plot was planted at Jimma, Metu Bako and Pawe research stations and on two farmers field surrounding each research center. The trial was planted in a 10m X 10m single plot. All cultural practices for climbing were carried out as stated above. The verification plots were evaluated by variety release technical committee.

Table1. Description of experimental locations

Location	Altitude	Latitude	Longitude	Temperature		Annual rainfall
				Min(°C)	Max(°C)	
Jimma	1754	7°46'N	36°00'0"E	11.6°C	26.3°C	1572mm
Metu	1558	8°19' 0" N	35°35' 0"E	12.7°C	28.9	1829 mm
Haru	1252	8°59' 0" N	35°47' 0"E	16°C	27°C	1227mm
Bako	1650	9°6' 0" N	37°9' 0" E	13.3°C	28°C	1238mm
Pawe	1120	11°19' 0"E	36°24' 0"E	16.3 °C	32.6°C	1587mm

Table 2. Climbing bean genotypes tested at nine environments (at five locations for two years)

Genotype code	Genotype name	Location	Year	Environment code
1	NUV 54	Jimma	2019	JM19
2	NUV 27		2020	JM20
3	NUV20	Metu	2019	MT19
4	NUV 31		2020	MT20
5	NUV 40	Haru	2019	HR19
6	HUV219-9		2020	HR20
7	NUV 100	Bako	2019	BK19
8	NUV 115		2020	BK20
9	NUV 102	Pawe	2020	PW20
10	NUV 30			
11	NUV 90			
12	NUV42			
13	NUV 173			
14	NUV 56			
15	NUV 76			
16	Check 1(Dandesu)			
17	Check 2(Tibe)			

Agronomic characters such as days to flowering, days to maturity, plant height (cm), number of pods per plant, number of seeds per pod, number of seeds per plant, hundred seed weight (gm), yield per plant (gm plant^{-1}), and yield per hectare (Kg ha^{-1}) were recorded. Disease such as common bacterial blight, angular leaf spot, and floury leaf spot were also recorded. The scoring system was 1-9 scale (1=immune, 9=Susceptible, then 1-3=resistant, 4-6=moderately resistant and 7-9 = susceptible (Shrestha and Mishra, 1994). All the data including grain yield were collected from the middle two harvestable rows. All the data were subjected to combined analysis of variance (ANOVA) using SAS software. The data analyses for interpreting genotype by environment interaction were done by GGE stability analysis in R software.

The following ANOVA models have been used to test the performance of genotypes at each and combined locations, respectively (Singh and Ceccarelli 1996) as indicated below.

$$Y_{ij} = \mu + G_i + B_j + e_{ij} \text{ and } Y_{ijk} = \mu + G_i + E_j + GE_{ij} + B_{k(j)} + e_{ijk}.$$

Where, Y_{ij} = observed value of genotype i in block j , Y_{ijk} = observed value of genotype i in block k of environment j , μ = grand mean of the experiment, G_i = the effect of genotype i , B_j = the effect of block j , $B_{k(j)}$ = the effect of block k in environment j , e_{ij} = error effect of genotype i in block j , E_j = environment effect, GE_{ij} = the interaction effect of genotype i with

environment j , e_{ijk} = error (residual) effect of genotype i in block k of environment j . The stability of the tested genotypes was performed using GGE Biplot of GUI package in R software.

Results and Discussion

The result from the combined analysis of variance across the five locations is presented in Table 3. The pooled analysis of variance revealed that mean squares due genotype was significant ($P \leq 0.01$) for most of the traits except pod per plant and common bacterial blight, indicating genotypes were responded differently for each trait. Mean squares due to location was significant ($P \leq 0.01$) for all the traits considered, indicating the distinct nature of the five test locations. Mean square due to years differed significantly ($P \leq 0.01$) with respect to all the traits indicating that climate changes were observed during the study.

Mean squares due to location x genotype were significant for most of traits except pod per plant, seed per pod and seed per plant, meaning that genotypes exhibited different relative performance in each location. Non-significant genotype x year was observed for most of the traits except days to flowering, days to maturity, floury leaf spot, hundred seed weight and yield hectare⁻¹, indicating that genotypes showed consistent performance for most of traits in each year. Location x year interaction

revealed significant effect for all traits, meaning the location of genotypes performance varied in the two years, suggesting that climbing bean genotypes performed differently in every location in each year. Means squares due to genotype x location x year interaction found significant effect for days to flowering, floury leaf spot and hundred seed weight. Generally, the result for yield and related traits indicated that phenotypic variability for these traits is dependent on genetic factors, environmental variables and the interaction between genotypes and environment.

Based on the combined mean performance of the genotypes over environment, G1 scored maximum grain yield (2.67 t/ha) followed by G15 (2.57 t/ha), which exhibited a yield advantage of (23.61% and 18.14) and (18.98% and 13.72%) from the check Dandesu (2.16 t ha^{-1}) and Tibe

(2.26 t/ha), respectively (Table4). The performance of the tested genotypes also showed resistance to common bacterial blight, angular leaf spot and floury leaf spot. Highest plant height was recorded from genotype, G5 (291.37 cm) followed by G14 (269.88 cm), while the lowest was recorded from genotype G4 (213.57 cm). Separate analysis for each of the test environments showed consistently large variation among test genotypes for grain yield. Generally, based on the combined mean yield and other agronomic traits over 9 environments, G1 was relatively top-ranking genotype followed by G15. Moreover, G1 had also showed the highest yield across most of the environments than the two check varieties. Thus, G1 and G15 are the first and the second candidate varieties promoted for variety verification trial.

Table 3. Mean squares values of combined analysis of variance for yield and related characters of 17climbingbean genotypes evaluated at nine environments during 2019-2020.

Source	DF	DTF	DTM	PH(cm)	NPP	NSD	SPP	CBB	ALS	FLS	HSW (gm)	YLD _{pl} (gm/plant)	YLD _{ha} (t/ha)
yr	1	24350.7**	9676.9**	17817.4**	1664.3**	58.4**	65156.4**	9.7**	19.9**	23.5**	161.5**	3452.0**	196.1**
loc	4	8934.0**	21564.3**	1139**	5696.1**	90.7**	111505.7**	145.3**	49.0**	32.0**	8585.6**	5054.6**	104.6**
Geno	16	55.3**	118.8**	8493.9**	139.7ns	15.7**	3404.2**	1.3ns	1.6*	1.4**	903.1**	127.2**	1.3**
Loc*rep	10	22.5**	28.4*	1302.2ns	297.5*	8.1ns	14249.6**	4.7**	0.6ns	0.3ns	31.4ns	30.3ns	1.7**
Geno*yr	16	21.2**	26.5*	18.1ns	159.1ns	6.1ns	1596.2ns	1.0ns	1.1ns	1.8**	111.9**	23.9ns	0.6*
yr*loc	3	22986.5**	10192.8**	59697.0**	502.1*	21.0*	22690.5**	5.2**	9.5**	23.5**	2107.4**	5516.7**	96.5**
Geno*loc	64	15.1**	25.0**	2018.7**	136.2ns	7.7ns	1134.3ns	1.7**	2.5**	1.7**	79.9**	65.5**	0.8**
yr*geno	16	24.3**	20.7ns	1874.5ns	203.3ns	6.5ns	1603.1ns	1.0ns	1.0ns	1.5**	103.0**	16.2ns	0.6*
geno*yr*loc	48	12.9*	15.3ns	1602.4ns	151.8ns	7.8ns	1415.6ns	0.6ns	0.8ns	1.1**	60.3**	20.6ns	0.5ns

Where, * = significant at ($P \leq 0.05$) and **= significant at ($P \leq .01$), yr=year, loc=location, Geno=genotype, DF=degree of freedom, DTF = days to 50% flowering, DTM = days to 95% pod maturity, PH = plant height, NPP =pod per plant, NSD=seed per pod, NSP= seed per plant, CBB=common bacterial blight, ALS= angular leaf spot, FLS=floryleaf spot, HSW=hundred seed weight, YLD_{pl}=yield per plant, YLD_{ha}= yield ha⁻¹.

Table 4 . Mean grain yield performance (t ha⁻¹) of 17 climbing bean genotypes evaluated in five locations in 2019 and 2020 cropping season

		2019				2020					Overall mean (tha-1)
No.	Genotype	Jimma	Metu	Haru	Bako	Jimma	Metu	Haru	Bako	Pawe	
1	NUV 54	2.07	1.83	2.92	1.77	5.74	2.07	5.00	1.21	1.48	2.67
2	NUV 27	0.77	1.53	3.37	1.90	4.27	1.55	4.38	1.21	1.28	2.25
3	NUV20	1.30	1.23	2.73	2.06	4.82	1.99	3.96	1.62	0.94	2.30
4	NUV 31	0.37	1.50	2.47	1.37	3.06	1.82	3.75	1.13	1.35	1.87
5	NUV 40	1.17	1.28	2.01	1.05	4.96	1.97	3.13	1.44	1.71	2.08
6	HUV219-9	0.97	1.50	2.49	2.17	5.05	1.59	3.96	1.26	1.05	2.23
7	NUV 100	0.73	1.54	3.08	1.91	3.86	1.69	3.54	0.88	1.70	2.10
8	NUV 115	0.40	0.84	2.35	1.35	5.19	1.68	4.17	0.98	1.40	2.04
9	NUV 102	0.87	0.97	2.73	1.88	5.12	1.81	5.42	0.78	1.67	2.36
10	NUV 30	0.77	1.45	1.72	1.36	4.14	1.63	4.58	1.44	1.36	2.05
11	NUV 90	0.77	1.49	3.41	1.57	5.46	1.77	4.58	1.08	1.09	2.36
12	NUV42	0.47	0.92	2.17	1.48	3.41	1.58	3.96	0.90	1.54	1.82
13	NUV 173	0.43	1.51	3.19	1.46	5.64	1.89	5.75	1.13	1.65	2.52
14	NUV 56	0.43	1.31	2.07	1.06	3.81	2.23	3.75	1.08	1.70	1.94
15	NUV 76	0.60	1.91	3.28	1.80	5.90	2.03	5.71	0.70	1.21	2.57
16	Dandesu	0.57	1.14	2.83	1.70	5.52	1.48	4.42	0.83	0.97	2.16
17	Tibe	1.37	1.23	2.25	1.96	5.57	1.53	3.58	1.25	1.63	2.26
	mean	0.83	1.36	2.65	1.64	4.80	1.78	4.33	1.11	1.4	2.21
	CV	42.70	22.04	15.33	19.45	13.54	32.56	27.17	33.37	14.2	26.92
	LSD	0.59	0.50	0.68	0.53	1.08	ns	Ns	ns	0.33	0.32

Table 5. Mean grain yield performance (ton ha⁻¹) and other growth parameters of 17 climbing bean genotypes evaluated in five locations for the period 2019-2020

geno	Name	DF	DM	PH	NPP	spd	SPP	CBB	ALS	FLS	HSW	Yld(gm/pl ant)	Yld(t/ha)
1	NUV 54	56.63	105.85	256.77	15.17	4.97	68.43	3.07	2.41	1.44	29.34	17.80	2.68
2	NUV 27	52.15	101.26	240.36	12.89	5.55	68.55	2.85	2.67	1.37	29.36	16.07	2.25
3	NUV20	52.19	101.81	235.42	13.93	5.23	69.22	2.89	2.70	1.52	28.62	14.83	2.30
4	NUV 31	52.19	99.00	213.57	14.39	4.64	58.54	2.67	2.26	1.74	41.29	13.32	1.87
5	NUV 40	54.70	105.48	291.37	11.21	4.81	53.60	2.48	2.07	1.81	34.91	15.50	2.08
6	HUV219-9	54.37	99.59	253.37	13.43	7.10	83.52	2.74	2.48	1.15	25.31	15.95	2.23
7	NUV 100	52.41	100.26	221.85	13.59	6.79	69.98	3.04	2.70	1.15	28.56	13.71	2.10
8	NUV 115	53.37	101.59	246.78	10.57	5.21	52.65	2.70	2.56	1.22	29.35	13.61	2.04
9	NUV 102	54.44	100.22	246.43	15.17	5.55	74.99	2.44	2.44	1.00	26.32	17.75	2.36
10	NUV 30	52.22	102.48	245.23	10.45	5.00	46.00	2.70	1.96	1.52	42.43	15.34	2.05
11	NUV 90	52.70	100.81	256.23	14.00	6.08	79.34	2.89	2.48	1.22	24.47	15.30	2.36
12	NUV42	52.48	101.52	249.52	13.14	5.07	68.65	2.67	2.15	1.52	33.95	14.26	1.82
13	NUV 173	52.89	98.07	244.77	11.43	5.90	64.09	2.81	2.15	1.44	25.84	17.70	2.52
14	NUV 56	55.81	103.22	269.88	10.85	5.23	53.92	2.56	2.15	1.74	40.08	15.43	1.94
15	NUV 76	53.59	99.48	238.24	13.00	7.21	82.64	2.67	2.07	1.00	25.55	16.30	2.57
16	Dandesu	54.67	99.67	263.27	14.29	6.23	78.23	3.11	2.56	1.15	27.39	20.50	2.16
17	Tibe	53.85	100.07	256.88	21.55	5.64	78.75	2.81	2.67	1.00	29.76	21.29	2.26
	mean	53.57	101.20	248.82	13.47	5.66	67.71	2.77	2.38	1.35	30.74	16.16	2.21
	CV	5.64	3.76	14.50	89.88	48.23	57.75	31.59	37.4	51.72	15.71	31.21	26.92
	LSD	1.62	2.04	19.31	NS	1.46	20.94	NS	0.48	0.37	2.58	2.70	0.32

GGE Biplot and stability analysis of the test genotypes across environments

The GGE biplot method consists of a set of biplot interpretation methods to evaluate genotype and test-environment (Yan, 2007). The analysis showed that genotype G1 performed best at Jimma and Metu followed by G15. The check Tibe (G17) better performed at Jimma and Pawe. Pawe. Genotype G4, G7, G14, and G12 did not perform best in any of the environments (Figure 1). Mean vs. Stability” view of GGE biplot is an efficient tool to compare genotype based on mean performance and stability across environments within a mega environment (Yan *et al.*, 2007). Mean vs. stability view of GGE biplot is presented in Figure 2. G1 showed higher mean grain yield but had less stability across environment. Genotype-15 scored the second-highest mean grain yield performance and relatively stable across environments. Besides according to Yan and Hunt (2001), the GGE Biplot explains a small portion of the total variation that can contribute to this discrepancy.

The “which-won-where” view of the GGE biplot is an effective feature for mega-environment analysis (Yan *et al.*, 2007). Therefore, in this study based on the mean yield performance of climbing bean genotypes, all environments and genotypes fall into a four sector (figure 3). The Biplot contains a polygon drawn on genotypes that are furthest from the

biplot origin so that all other genotypes are contained within the polygon and these genotypes located on the vertices of the polygon performed either the best or the poorest in one or more environments (Yan, 2006). Environments within the same sector share the same winning genotypes and environments in different sectors have different winning genotypes while, the genotypes within the polygon and nearer to origin were less responsive than vertex genotypes (Yan and Tinker, 2006). Besides the high fluctuation in the performances of the genotypes, the significant interaction effect was observed over year by location. Yan and Tinker (2006) indicated the genotypes in the corner of the polygon are the best performing one in each set of environments within the angle of the polygon formed by the broken lines. In this assumption, the G1, G5, G4, and G13 performed best in their respective environments. Genotypes 1 performed well in JM19 and JM20 and moderately adapted to MT19, MT20, and BK20. Three vertex genotypes, G5, G4, and G13 had the highest yield in their vertex environments (MT20, PA20 and BK20), (PW20), and (BK19, HR19 and HR20 and, respectively. The other thirteen genotypes were fallen in sectors with their respective environment markers.

The ideal genotype is located in the first concentric circle in the bi-plot. An ideal genotype has the highest mean yield and stable across environments (Farshadfar *et al.*, 2012). Genotype

near to the concentric circle is G15 which can be desirable and benchmarks for evaluation of climbing

bean genotypes followed by G11, G9, and G17 (figure 4).

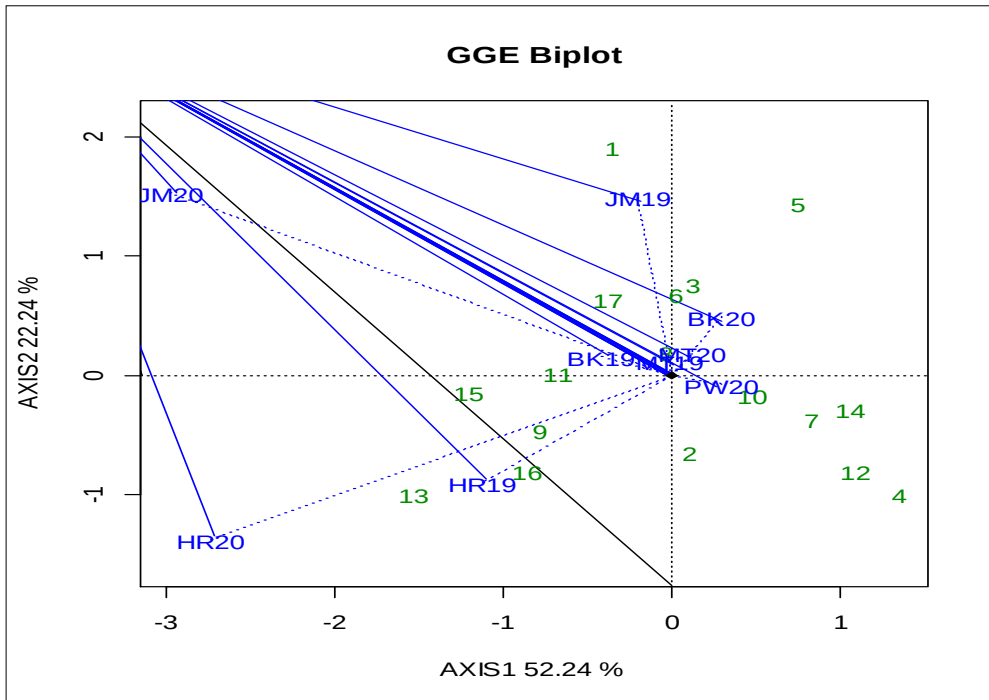


Figure 1. Mean grain yield performance and stability of genotypes based on the $G \times E$ data

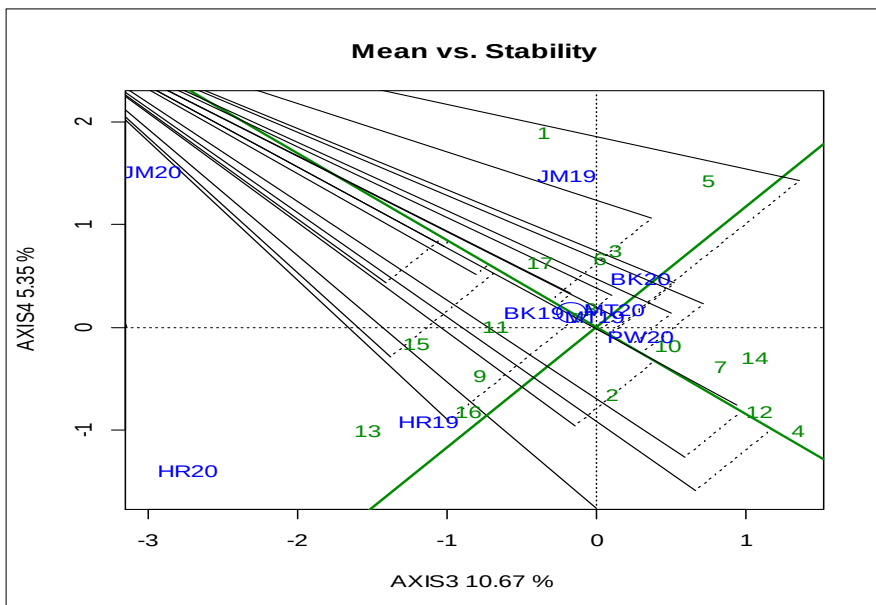


Figure 2. Mean grain yield performance and stability of genotypes based on the $G \times E$ data

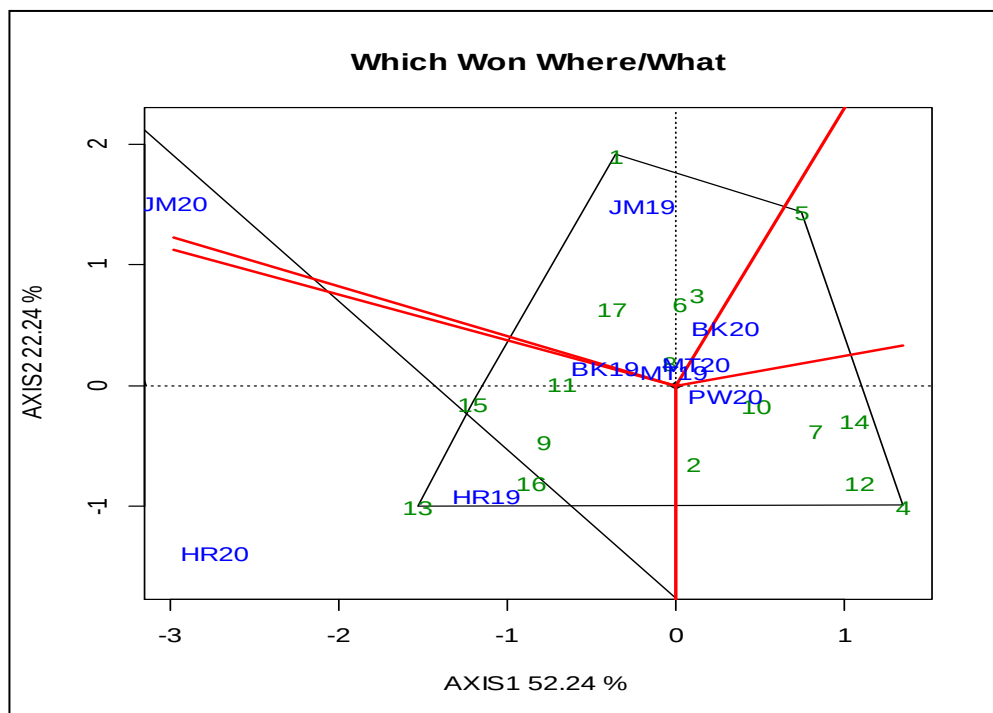


Figure 3. GGE bi-plot on genotypes using symmetrical scaling for mean lint yield and stability of 15climbingbean genotypes
Tested across seven environments

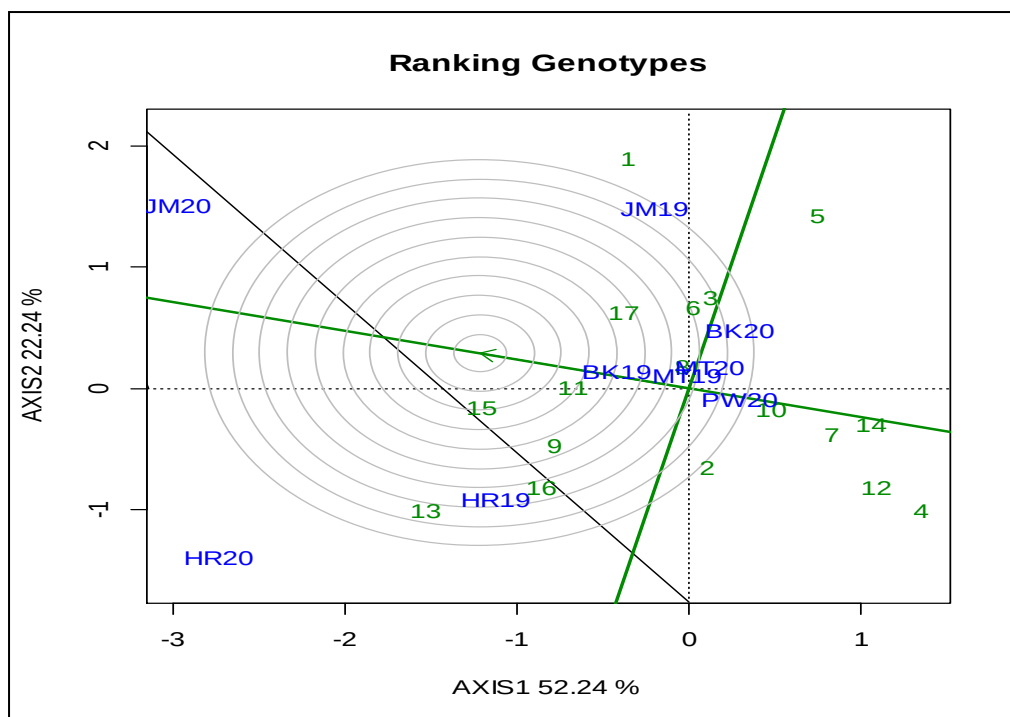


Figure 4. The average- environment view to rank genotypes to ideal genotypes

Important seed Characteristics and cooking time of candidate varieties

The candidate varieties NUV-54 and NUV-76 are characterized by small seed size with red and white seed color, respectively. Fast cooking time is the other major attribute of outstanding candidate varieties NUV-54 (83 minutes) and NUV-76 (88 minutes). Whereas, check varieties; Dandesu and Tibe were characterized by red seed color, medium and small seed size with their acceptable cooking

time (87 and 85 minutes), respectively (Table 6). Therefore, these two genotypes were promoted to variety verification trial and submitted to variety releasing committee as candidate varieties and evaluated by the technical committee in the 2021 cropping season. Finally, based on the gain yield performance, disease resistance/tolerance and acceptable quality, the national variety release standing committee approved the release of the first candidate varieties NUV-54 (G1) for commercial production purposes since June 2022.

Table 6. Seed Characteristics and cooking time of climbing bean Candidate and check varieties

No.	Variety	Seed color	Seed size	Cooking time (minute)	Decision of the committee (NVRC)	Year of release
1	NUV-54 (candidate1)	white	small	83	released	2022
2	NUV 76(candidate2)	red	small	88	rejected	-
4	Dandesu(check1)	red	medium	87	check	2012
5	Tibe (check2)	red	small	85	check	2004

Conclusion and Recommendation

The combined analysis of variance showed highly significant ($P \leq 0.01$) due to genotypes, location, year and their interaction for most traits. The mean yield performance of the genotypes showed that G1 (NUV 54) scored maximum grain yield (2.67 t ha^{-1}) followed by G15 (NUV76) (2.57 t ha^{-1}), which exhibited a yield advantage of (23.61% and 18.14) and (18.98% and 13.72%) from the standard check Dandesu (2.16 t/ha)

and Tibe (2.26 t/ha), respectively. The performance of the genotypes also showed resistance to foliar disease. These genotypes G1 and G15 are characterized by small seed size with red and white seed color, respectively. Fast cooking time is the other major attribute of outstanding varieties G1 (83 minutes) and G15 (88 minutes). Generally, G1 showed higher mean grain yield value than the other test genotypes and had moderate stability for some environments. Genotype G15 scored the second-highest mean grain yield and relatively a good stable candidate across

environments. Therefore, based on the gain yield performance, disease resistance and acceptable quality, the national variety release standing committee approved the release of the first candidate varieties NUV-54 (G1) for commercial production since June 2022. The variety is recommended for Southwest, West and other similar agro-ecologies with high rainfall areas of the country.

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Genetic Diversity of Shallot (*Allium cepa* var. *aggregatum*) Segregating Populations from Ethiopia Using Multivariate Analysis

Getachew Tabor¹, Gizachew Atinafu, Fekadu Gebretensay Menegistu,

Fasil Tadesse Tewolde, Yenenesh Asfaw, and Desta Fekadu

Ethiopian Institute of Agricultural Research, Debre Zeit Agricultural Research Center, P. O. Box 32,
Debre Zeit, Ethiopia; Corresponding author: gizachew.at@gmail.com getachewtf@gmail.com

Abstract

Shallot is an important traditional crop used for seasoning of various national cuisines. However, productivity of shallot is low partly due to lack of improved varieties that are adapted to diverse agro-ecologies of Ethiopia. It has been difficult to improve the genetic base of local shallot germplasm due to its vegetative propagation nature. However, some plants within the germplasm were found bolting and producing seeds providing the opportunity for broader genetic base. Therefore, the present study was initiated to characterize and classify some segregating genotypes so as to use them for future breeding program. The study was undertaken at Debre Zeit Agricultural Research Center. It comprised of sixty genotypes generated through natural out-crossing and three released varieties (Minjar, Huruta and DZSHT-005/-02/90 DZSHT-005/02) used as controls. The experiment was laid-out in augmented design with three blocks. Twenty bulbs of each genotype were planted on a ridge comprising two rows. The three control varieties were also planted in the same way but replicated at in each block. Data on yield and yield components, percent bolting and number of flowerstalks/plant were collected. Analysis of variance, cluster and principal component analyses were also undertaken on data recorded. The results of the study showed that the genotypes significantly differed in yield/plant, number of bolting plants and number of flowerstalks/plant. However, they did not differ in bulb diameter, bulb height and downy mildew severity. Eight genotypes had better yield/plant than all the three controls. Cluster analysis grouped the genotypes into seven clusters. Clusters I through VII comprised of 1(1.6%), 2(3.2%), 14 (22.2%), 10(15.9%), 5(7.9%), 22(34.9%) and 9(14.3%) genotypes, respectively. The genotypes within Clusters I through VI had atleast 87.5%, 85.2%, 85.0%, 85.8%, 82.9% and 84.1% similarity, respectively. Cluster III had the second highest mean for yield/plant, bulb diameter and number of bulb splits/plant. On the other hand, Cluster VII had the highest mean for yield/plant, bulb height and downy mildew severity. It had also high inter cluster distances with other clusters. The principal component analysis identified seven components, five of which contributed to 83.1% of the variation. Generally, the eight genotypes with better yield were recommended for further variety trials under different environments while maintaining the other genotypes as a source of for variation future for breeding activities.

Keywords: characterization, cluster analysis, germplasm, quantitative traits, principal component analysis

¹ Corresponding author: getachewtf@gmail.com

Introduction

Shallot (*Allium cepa* L. var. *aggregatum*) is a close relative of onion (*Allium cepa* L. var. *cepa*) and are no longer considered to be different species (Fritsch and Friesen, 2002; Rabinowitch and Kamenetsky, 2002; Brickell *et al.*, 2016). It is one of the most important vegetables used for seasoning local cuisines in Ethiopia. The largest producers of shallots are China and Japan, with more than 500,000 tons of shallot bulbs produced per year, followed by New Zealand, Mexico, Iran, Iraq, Cambodia, and Cameroon (FAOSTAT, 2018). Ethiopia produces about 374.7 thousand tons of onion and shallot on 48.4 thousand hectares of land (CSA, 2011).

Shallot is propagated mainly using vegetative bulbs and hence breeding endeavors of shallot were limited to clonal selection of genotypes or population collected from different parts of the country. Clonal selection often dealt with existing diversity of germplasm pool (Awale *et al.*, 2011; Ita *et al.*, 2016), with less possibility of further diversifying the genetic pool. According to Seifu (1981) Ethiopia is considered as the center of diversity for shallot. Getachew and Asfaw (2000) observed wide diversity among Ethiopian shallot accessions in growth habit, leaf width, sheath length, bulb shape, size and color, days to maturity, number of bulb splits and bulb yield/plant. Fasika *et al.* (2008) also studied forty-nine accessions

collected from Shewa, Gojam and Welo areas and reported highly significant phenotypic and genotypic coefficients of variance ranging from 7.6-41.6% and 4.4-27.9%, respectively. The genotypes varied in plant height, number of leaves and bulb splits/plant, bulb diameter, bulb yield, harvest index, total soluble solids, bulb dry weight and pungency. Similarly, Awale *et al.* (2011) reported high phenotypic and genetic variances among forty-nine accessions collected from Shewa, Harghe and Jimma areas for the above-mentioned traits as well as for days to maturity and sprouting of stored bulbs. Hasanah *et al.* (2022) reported that eleven shallot varieties originated from North Sumatra, Indonesia had high genetic diversity and categorized them into two main groups with dissimilarity coefficient of 76%. In addition, Noor *et al.*, (2012) confirmed the presence of significant genetic variability for important agronomic and morphological traits in Indonesia.

In Ethiopia, shallot variety improvement program was started in 1986 at Debre Zeit Agricultural Research Center (DZARC) with germplasm collected from major growing regions (Getachew and Asfaw, 2000). Currently, the center holds about 134 shallot accessions. So far, four vegetative propagated and two seed propagated varieties were released. Moreover, two seed propagated varieties from Melkassa Agricultural Research Center (MARC) and one seed propagated variety from Haramaya University were released

for production (MoANR, 2019). Some shallot plants within the germplasm holding of the DZARC were observed bolting, flowering and producing viable seeds providing an opportunity of natural out-crossing among plants and thus widening the germplasm base. Utilization of this opportunity, unequivocally, will have accelerated the development new varieties with better yield and quality.

Accessions collected from different parts of the country were characterized for morphological traits of growing plants as well as bulbs. Similarly, Josipa *et. al.*, (2021) reported that morphological characterization revealed phenotypic diversity in vegetative and reproductive traits in shallot genotypes of Croatia. Besides, descriptors of vegetative and bulb morphology were used to discriminate among different shallot genotypes in Croatia (Major *et. al.*, 2018). Method of data analysis is also crucial to efficiently utilize morphological data in diversity studies. The biplot analysis provides a useful tool of data analysis and allows visual appraisal of the structure of large data matrices. It specially reveals the principal component analysis, where the biplot can show inter-unit distances and indicates clustering of units as well as display variances and correlations of the variables (Gabriel, 1971). Moreover, Hanci and Gokce (2016) used principal components analysis for data reduction and estimation of

genetic diversity of onion breeding materials.

Genetic diversity is a critical component in breeding program of any crop. Selection of genetically diverse parents on the basis of divergence could be more promising to get hybrid varieties, and to create a broad spectrum of variability in segregating generation (Singh *et. al.*, 2020). Therefore, the objective of the present study was to characterize and classify some shallot genotypes generated from segregating populations for future breeding activities.

Materials and Methods

Description of the study area

The experiment was undertaken at DZARC, East Shewa zone, Ethiopia. The DZARC is located 47 km southeast of Addis Ababa at 08°44'N latitude and 38°58'E longitude. It has an altitude of 1860 m.a.s.l, annual min. and max. temperature of 8.9°C and 24.3°C, and annual rainfall of 851 mm (DZARC, 2008). The soil of the center is Alfisol soils with pH ranging from slightly acidic (6.1) to moderately neutral (7.9) (EARO, 2003).

Plant material and experimental design

Initially, the genotypes for the experiment were developed by planting the shallot accessions collected from different parts of Ethiopia at Kulumsa Agricultural Research Center (KARC). KARC has higher altitude (2200 m.a.s.l.) and cooler environment than DZARC, and allowed shallots to bolt, flower and out-cross naturally. Seeds of these accessions were collected and sown at DZARC to produce bulbs. The bulbs were selected for bulb size, color, and shape uniformity. The selection process was undertaken for three cycles and uniform bulbs were maintained by vegetative propagation.

The experiment comprised of sixty genotypes that were developed as described above. It was laid out using an augmented design with three blocks. Three improved shallot varieties (Huruta, Minjar and DZSHT-005-02/90) were planted at every block as controls. Twenty uniform bulbs of each genotype were planted on a ridge comprising two rows. All agronomic practices were undertaken as recommended by Getachew *et. al.* (2008).

Data collection

Based on the descriptors for allium developed by International Plant Genetic Resources Institute (IPGRI, 2001), data on yield/ per plant, weight, diameter and height of bulbs, and number of bulb splits/plant were recorded from five randomly selected

plants per genotype. Percent bolting was recorded as the proportion of bolted plants with respect to the total number of plants/ per plot and number of flower stalks/plant was a mean of flower stalks/ per bolted/ per plants. Downy mildew severity was recorded on plot bases using 1 to 5 scales.

Data analysis

Analysis of variance was undertaken using the control genotypes and the variance was used to separate means of the genotypes. Cluster analysis was done using the unweighted pair-group method with arithmetic average (UPGMA) employing Minitab statistical software (Minitab® 19.2020). Graphical representation of the cluster analysis (dendrogram) was constructed to elucidate the relation between genotypes. Principal Component Analysis was also undertaken and the subsequent Scree and biplot were generated using the same software.

Results and Discussions

Mean performance of quantitative traits

The genotypes significantly ($P < 0.05$) differed in yield/plant, number of bolting plants and number of flowerstalks/plant. However, bulb diameter, bulb height, number of bulb splits/plant and downy mildew severity were not significantly different among the genotypes (Table

1).Yield/ per plant ranged from 26.52 g in DZSHT-017-1/90 to 196.6 g in DZSHT-OP-100-2-3/90. Genotypes DZSHT-OP-005-1-2, DZSHT-OP-009-2/90, DZSHT-OP-100-2-2/90, DZSHT-OP-100-2-3/90, DZSHT-OP-255-2/90, DZSHT-OP-255-2-1/94, DZSHT-OP-255-2-3/90 and DZSHT-OP-41-4A had better bulb yield/plant than all the three controls. Inline with the present study, Awale *et. al.* (2011) and Fasika *et.al.* (2008) reported significant variations in morphological and yield parameters in shallot accessions collected from different parts of Ethiopia.

The bolting percentage of the genotypes ranged from no bolting in DZSHT-155-1B-1 to 100% in DZSHT-OP-005/02. Almost all the test genotypes, except DZHT-OP-051-1/90, had higher percent bolting than the control varieties, which were selected for their low bolting. Likewise, Wassu *et. al.* (2018) and Getachew (2018) reported that shallot genotypes had a potential of attaining

95% and 86-98% bolting, respectively. Similarly, Josipa *et al.* (2021) found that Croatian shallot accessions had bolting percentage ranging from 0 to 100% and classified them into four categories as: no (<10%), rare(15-30%), most(40-60%) and obligatory (70-100%) bolters. Moreover, Getachew (2004) reported that complete bolting was attained in some shallot genotypes that received vernalization at 8 or 12°C for 60 days.

Genotype DZSHT-OP-94-3/94 produced the highest (four) flowerstalks/plant than any other genotype. Sixteen (28%) of the test genotypes had about three flowerstalks/plant while bolted plants of the controls Huruta and Minjar had an average of one flowerstalks/plant. The high bolting was associated with low bulb yield/ per plant owing to more photosynthetic partitioning to flower stalks than to bulbs (Wallace *et. al.*, 1993).

Table 1. Bulb and bolting characteristics of sixty three shallot genotypes generated from open pollinated accssions

Genotype Code	Genotype	Bulb yield/ plant	Bulb diameter (mm)	Bulb height (mm)	No. bulb splits	Bolting (%)	No. flower stalks/ plant	Downy Mildew (1-5 scale)	Genotype Code	Genotype	Bulb yield/ plant	Bulb diameter (mm)	Bulb height (mm)	No. bulb splits	Bolting (%)	No. flower stalks/ plant	Downy Mildew (1-5 scale)
1	DZSHT-OP-005/02	41.93ghi	37.47	60.7	5.53	0.00q	0.00d	1.83	35	DZSHT-OP-155-1B	69.13c-i	48.23	59.8	5.25	43.99f-n	2.38abc	2.38
2	Huruta	38.6hi	36.07	58	4.93	0.97pq	0.67cd	2.17	36	DZSHT-OP-155-1B-1	61.63c-i	37.83	89.8	8.45	100a	2.78abc	3.88
3	Minjar	47.87ghi	39.4	70.7	5.33	4.17opq	1.1bcd	2.67	37	DZSHT-OP-155-1B-2	59.13c-i	52.23	67.8	3.65	76.39a-e	3.58a	3.88
4	DZSHT-OP-255-2/90	87.33b-f	40.3	73.2	5.78	29.09i-o	1.35a-d	1.38	38	DZSHT-OP-155-1B-3	54.33d-i	39.03	75.8	4.25	87.09abc	2.98ab	3.38
5	DZSHT-OP-255-2-3/90	94.73bcd	54.1	65.2	4.58	55.39d-i	1.25a-d	1.88	39	DZSHT-OP-19-3-1/94	63.03c-i	41.63	65.8	4.25	59.69c-h	2.58abc	3.38
6	DZSHT-OP-255-2-1/90	38.93ghi	50.9	69.2	8.38	39.79g-n	2.15a-d	2.88	40	DZSHT-OP-94-3/94	53.23f-i	40.23	69.8	3.45	34.69h-n	3.78a	3.38
7	DZSHT-OP-255-2-1/94	114.73b	50.7	49.2	7.38	62.99c-h	2.25abc	2.88	41	DZSHT-OP-19-3-2/94	48.23f-i	35.63	83.8	3.25	63.99c-h	3.38a	3.38
8	DZSHT-OP-255-2-3	61.73c-i	37.7	79.2	3.18	40.69g-n	1.75aa-d	1.88	42	DZSHT-OP-19-3-3/94	44.13ghi	35.23	61.8	3.85	54.09d-k	3.28ab	1.88
9	DZSHT-OP-41-4A	92.23b-e	54.1	59.2	8.38	52.89d-k	1.05bcd	4.38	43	DZSHT-OP-251-1B-3	36.43hi	37.23	53.8	2.65	79.69a-d	3.38a	2.38
10	DZSHT-OP-41-4A-1	72.23c-h	45.1	75.2	5.38	37.49a-n	0.95bcd	2.38	44	DZSHT-OP-001-3-2/94	43.62ghi	41.83	66.5	3.78	13.66n-q	1.33a-d	0.63
11	DZSHT-OP-41-4A-2	59.23c-i	47.9	81.2	3.18	64.79c-h	1.15a-d	2.88	45	DZSHT-OP-005-1-2	89.82b-e	36.83	46.5	5.58	40.86g-n	1.23a-d	1.63
12	DZSHT-OP-41-4A-3	46.43ghi	38.7	69.2	5.78	25.39j-p	1.55a-d	1.88	46	DZSHT-OP-005-1-1	44.47ghi	40.13	83.5	4.18	45.61e-m	1.53a-d	1.38
13	DZSHT-OP-41-4A-4	53.63a-i	49.9	65.2	3.18	77.79a-e	1.15a-d	3.38	47	DZSHT-OP-005-1-3	40.92ghi	32.03	66.5	3.98	24.86j-q	2.23abc	2.13
14	DZSHT-OP-54-2	52.93f-i	41.7	59.2	4.58	56.99c-i	1.65a-d	1.38	48	DZSHT-OP-005-1B	68.22c-i	32.03	52.5	5.58	31.36i-n	1.43a-d	3.13
15	DZSHT-OP-54-2-2	39.83ghi	38.8	60.2	3.78	43.79f-n	1.95a-d	1.63	49	DZSHT-OP-009-2/90	89.52b-e	40.83	42.5	4.78	74.06a-f	2.83abc	3.13
16	DZSHT-OP-72-2-2/90	71.28c-i	43.2	58.2	3.68	98.44ab	2.7abc	2.38	50	DZSHT-OP-009-2/07	53.6f-i	44.27	55.3	4.93	33.63i-n	2.17abc	2.83
17	DZSHT-OP-79-1A	42.93ghi	43.7	75.2	3.78	16.49l-q	0.85bcd	1.88	51	DZSHT-OP-009-2-2/07	43.12ghi	34.03	52.5	5.18	20.26l-q	2.33abc	1.63
18	DZSHT-OP-79-1A-1	52.13f-i	41.3	85.2	4.38	21.59l-q	0.75bcd	1.88	52	DZSHT-OP-009-2-3	35.42hi	37.03	50.5	3.58	43.76g-n	1.53a-d	3.13
19	DZSHT-OP-79-1A-2	61.83c-i	40.1	79.2	5.18	22.09k-q	0.75bcd	1.88	53	DZSHT-OP-009-2-3/90	38.82ghi	26.43	60.5	3.78	32.46i-n	2.53abc	2.63
20	DZSHT-OP-79-1A-3	53.53f-i	41.7	53.2	4.58	20.59l-q	1.95a-d	1.88	54	DZSHT-OP-009-2-4/07	57.02c-i	39.43	70.5	4.38	0.76pq	1.03bcd	1.63
21	DZSHT-OP-91-3/94	75.73b-g	43.7	85.2	5.98	37.79g-n	1.75a-d	3.38	55	DZSHT-OP-009-02/07	53.6f-i	44.27	55.3	4.93	33.63i-n	2.17abc	2.83
22	DZSHT-OP-91-3-1/94	34.93hi	36.7	55.2	5.78	35.69h-n	2.45abc	1.88	56	DZSHT-OP-017-1/90	26.52i	39.83	62.5	3.18	39.96g-n	2.33abc	3.13
23	DZSHT-OP-91-3-4/94	57.63c-i	40.5	65.2	4.58	62.19c-h	2.35abc	3.38	57	DZSHT-OP-017-1-1/90	51.42f-i	41.43	58.5	4.18	15.56m-q	1.93a-d	3.13
25	DZSHT-OP-54-2-5	48.93f-i	35.23	75.8	3.25	61.39c-h	3.48a	3.38	59	DZSHT-OP-051-1-1/90	55.62d-i	38.03	68.5	4.98	1.06opq	1.43a-d	2.63
26	DZSHT-OP-91-3-5/94	67.13c-i	38.53	69.8	4.25	54.44d-j	2.53abc	2.88	60	DZSHT-OP-051-1-2/90	45.52ghi	50.03	66.5	3.58	26.76i-o	1.63a-d	1.63
27	DZSHT-OP-100-2/90	56.83d-i	36.03	61.8	3.85	69.09b-g	1.68a-d	2.88	61	DZSHT-OP-051-1/90	33.82hi	33.23	44.5	3.38	68.76b-g	2.13a-d	2.13
28	DZSHT-OP-100-2-1/90	73.73b-h	41.83	79.8	4.45	48.39e-l	3.78a	3.38	62	DZSHT-OP-051-1-4/90	28.52hi	40.43	38.5	3.18	65.66c-h	2.13a-d	0.63
29	DZSHT-OP-100-2-2/90	97.73bc	47.43	73.8	6.05	48.19e-l	2.88abc	2.38	63	DZSHT-OP-054-2-3	32.22hi	30.43	46.5	2.78	88.86abc	2.53abc	3.13
30	DZSHT-OP-100-2-3/90	196.63a	35.23	93.8	3.85	35.49h-n	2.28abc	3.88		Mean	56.85	40.14	66.1	4.55	42.82	1.98	2.4
31	DZSHT-OP-12/90	70.03c-i	42.03	85.8	5.25	59.69c-h	2.88abc	2.38		SE	21.1	7.02	1.5	1.9	14.93	1.34	1.21
32	DZSHT-OP-12-1/90	67.93c-i	43.03	69.8	3.65	56.39d-j	3.38a	3.38		CV (%)	23.38	10.75	14.02	25.4	22.88	43.39	31.4
33	DZSHT-OP-121-1-1/90	41.33ahi	48.83	65.8	3.45	75.39a-e	2.78abc	2.38		Significance	*	ns	ns	ns	***	***	ns
34	DZSHT-OP-12-1-2/90	48.73f-i	39.83	55.8	3.65	47.59e-m	2.48abc	2.88									

Cluster Analysis

Cluster analysis of the genotypes based on the seven variables grouped the genotypes into seven clusters. Similarity among the genotypes within and between clusters is depicted by the dendrogram (Fig. 1). Cluster VII had the lowest similarity (18.5%) with other clusters (Fig. 1). Genotypes within Clusters I through VI have at least 87.5%, 85.2%, 85.0%, 85.8%, 82.9% and 84.1% similarity, respectively. Ita *et. al* (2016) and Lina *et. al.* (2019) also reported that Indonesian shallot genotypes were divided into three major groups and differences within a group demonstrated the existence of diversity among genotypes. Cluster I has fourteen genotypes and is characterized by the lowest cluster means for bolting and downy mildew severity and also low means in other parameters (Tables 2 and 3). Clusters II and IV comprised ten and twenty two genotypes, respectively; they have moderate cluster means for all parameters. Cluster III consist of five genotypes and has the highest bulb diameter and number of bulb splits, and the second highest yield per plant. Cluster V has nine genotypes and is characterized by the lowest number of bulb splits and bulb yield/ per plant. On the other hand, Cluster VI consisted of two genotype (DZSHT-OP-72-2-2/90 and DZSHT-OP-009-2/90) and has the highest percent bolting and flowerstalks/ plant but the shortest bulb height. Cluster VII

consisted of only one unique genotype (DZSHT-OP-100-2-3/90) that has the highest bulb yield/plant, bulb height and downy mildew severity but the lowest bulb diameter, number of bulb splits and flowerstalks/plant than those in other clusters.

The three improved varieties (Huruta, Minjar and DZSHT-005/02), used as controls in the study, were assigned to the Cluster I despite the fact that the varieties were adapted to and released for different agro-ecological zones. The high similarity of the varieties could be attributed to similarity in bulb diameter, bulb height, number of bulb splits/plant, low bolting and number of flowerstalks/plant. Inclusion of other morpho-physiological parameters could help further differentiate the genotypes that could otherwise belong to the same cluster.

Results of cluster distance analysis (Table 4) showed that Cluster V had the highest intra-cluster distance followed by clusters II and IV indicating the presence of high genetic diversity within these clusters. The inter-cluster distance (D^2) ranged from 24.9 to 154.9. Cluster VII had the highest inter cluster distance with all the other six clusters, ranging from 94.9 with Cluster III to 154.9 with Cluster V (Table 4). Crossing genotypes in these clusters with genotype (DZSHT-OP-100-2-3/90) could result in high heterosis. Moreover, Cluster VI is distant from all clusters, except from cluster III.

Cluster V is highly distant from clusters I, II and III. Cluster III is also distant from clusters IV and I. The result indicated that hybridization between genotypes of these clusters could result in hybrid vigor and better recombinants in the population. The findings are in agreement with Singh *et.al* (2020); Ravindra *et.al* (2018) and Singh *et.al* (2013) who reported that onion genotypes belonging to distant clusters had wide spectrum of variation in segregates. Fitriana and

Susandarini (2019) studied twelve shallot cultivars from Indonesia based on sixteen characters. They classified the cultivars in to two clusters based on bulb skin color, bulb skin layering and bulb shape which had higher loading values as indicated by principal componenet analysis. Khandagale and Gawande (2019) also underlined the importance of bulb color for breeding program and as a criterion for classifying genotypes.

Table 2. Distribution of sixty three genotypes into seven clusters based on Euclidean distance

Cluster number	No. of genotypes	Percentage	Name of genotypes
I	14	22.2	DZSHT-OP-005/02, DZSHT-OP-79-1A-2, DZSHT-OP-009-2-4/07, DZSHT-OP-051-1-1/90, DZSHT-OP-41-4A-3, DZSHT-OP-94-3/94, DZSHT-OP-79-1A-1, DZSHT-OP-79-1A-3, DZSHT-OP-001-3-2/94, DZSHT-OP-017-1-1/90, HURUTA, MINJAR, DZSHT-OP-54-2-2, DZSHT-OP-79-1A
II	10	15.8	DZSHT-OP-255-2/90, DZSHT-OP-255-2-3, DZSHT-OP-100-2-1/90, DZSHT-OP-41-4A-1, DZSHT-OP-91-3/94, DZSHT-OP-009-2/07, DZSHT-OP-91-3-5/94, DZSHT-OP-005-1B, DZSHT-OP-155-1B, DZSHT-OP-051-1-2/90
III	5	7.9	DZSHT-OP-255-2-3/90, DZSHT-OP-41-4A, DZSHT-OP-100-2-2/90, DZSHT-OP-005-1-2, DZSHT-OP-255-2-1/94
IV	22	34.9	DZSHT-OP-255-2-1/90, DZSHT-OP-91-3-1/94, DZSHT-OP-12-1-2/90, DZSHT-OP-005-1-3, DZSHT-OP-009-2-2/07, DZSHT-OP-009-2/07, DZSHT-OP-009-2/07, DZSHT-OP-009-2-3/90, DZSHT-OP-41-4A-2, DZSHT-OP-54-2, DZSHT-OP-19-3-1/94, DZSHT-OP-005-1-1, DZSHT-OP-91-3-4/94, DZSHT-OP-12/90, DZSHT-OP-12-1/90, DZSHT-OP-54-2-2, DZSHT-OP-100-2/90, DZSHT-OP-54-2-5, DZSHT-OP-19-3-2/94, DZSHT-OP-009-2-3, DZSHT-OP-19-3-3/94, DZSHT-OP-017-1/90
V	9	14.3	DZSHT-OP-41-4A-4, DZSHT-OP-155-1B-2, DZSHT-OP-121-1-1/90, DZSHT-OP-051-1-4/90, DZSHT-OP-251-1B-3, DZSHT-OP-155-1B-3, DZSHT-OP-051-1/90, DZSHT-OP-155-1B-1, DZSHT-OP-054-2-3
VI	2	3.2	DZSHT-OP-72-2-2/90, DZSHT-OP-009-2/90
VII	1	1.6	DZSHT-OP-100-2-3/90

Table 3. Cluster means of seven traits in sixty three genotypes of shallot

Variable	Cluster							
	I	II	III	IV	V	VI	VII	Grand
Yield /plant (g)	48.7	68.0	95.8	45.9	40.9	86.1	186.9	56.8
Bulb diameter (mm)	39.1	42.1	47.3	38.3	40.8	42.5	34.2	40.2
Bulb height (mm)	6.9	7.0	6.1	6.6	5.9	4.7	9.0	6.6
No of splits/plant	4.4	4.7	6.3	4.4	4.0	4.4	4.0	4.5
Bolting (%)	13.8	34.8	48.4	45.7	76.9	90.8	25.8	42.7
Flower stalk /plant	1.8	1.9	1.9	2.1	2.2	3.2	1.3	2.0
Downy mildew (1-5 scale)	1.9	2.3	2.4	2.5	2.7	2.5	3.5	2.4

Table 4. Intra (diagonal) inter (off diagonal) cluster Euclidean distances (D^2) among seven clusters in shallot genotypes

Cluster	I	II	III	IV	V	VI	VII
I	17.7						
II	28.7	20.9					
III	59.0	31.4	19.2				
IV	32.0	24.9	50.8	20.8			
V	63.6	50.1	62.2	31.7	21.6		
VI	85.7	58.9	43.8	60.6	47.4	13.2	
VII	138.8	119.5	94.9	142.5	154.9	120.3	0.00

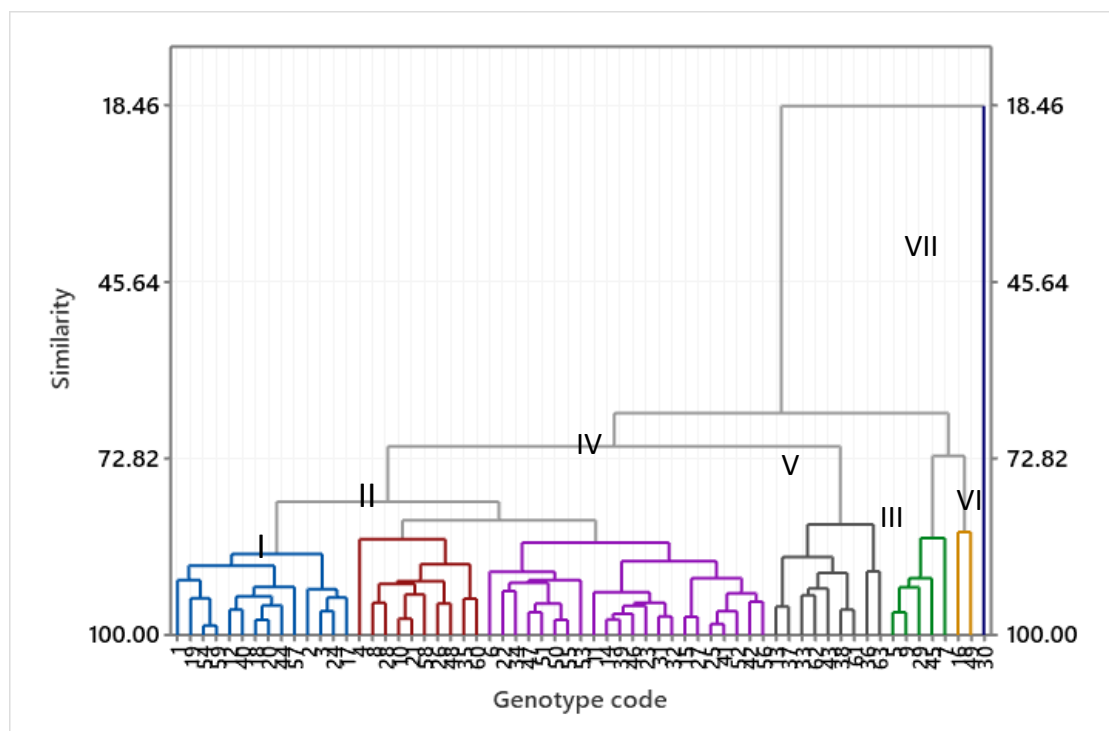


Figure 1. Dendrogram showing hierarchical clustering patterns of sixty three shallot genotypes for seven traits

Principal Component Analysis

The Scree plot showed that the first two components had Eigen values greater than unity, which could explain about 48.4% of the variability, whereas 83.1% of the variability is explained by the first five components (Fig. 2) i.e., the first five principal components are responsible for most of the variability. The coefficients of components indicated that bulb height, percent bolting, and number of flower stalks/plant were the major contributors to PC1; downy mildew severity, bulb diameter, number of splits/ plant

and yield/plant to PC2; downy mildew severity and bulb diameter to PC3; number of bulb splits and percent bolting to PC4 and bulb height and yield/plant to PC5. Bulb weight and yield/ per plant had large positive loadings on component 1 whereas downy mildew and percent bolting had large positive loadings on component 2. These results are partly in agreement with the result of Hanci and Gokce (2016) who examined genetic diversity of 87 onion genotypes and reported that 71.8% of the variations were accounted for nine principal components. In addition, Ravindra *et.al.* (2018)

reported five principal components with 78.5% variability in 58 onion accessions.

The bi-plot of components 1 and 2 (Fig. 3) showed that yield/plant was highly related with number of bulb splits/plant and to a lesser degree to bulb diameter. On the other hand, percent bolting, number of flowerstalks/plant and downy

mildew severity were unrelated to yield and yield components. Similarly, Singh *et. al.* (2020) observed seven principal components having 83.87% of total variability. Their results showed that bulb weight, marketable bulb percentage, total and marketable bulb yield were negatively correlated with, downy mildew infestation and percent bolters for 34 onion genotypes.

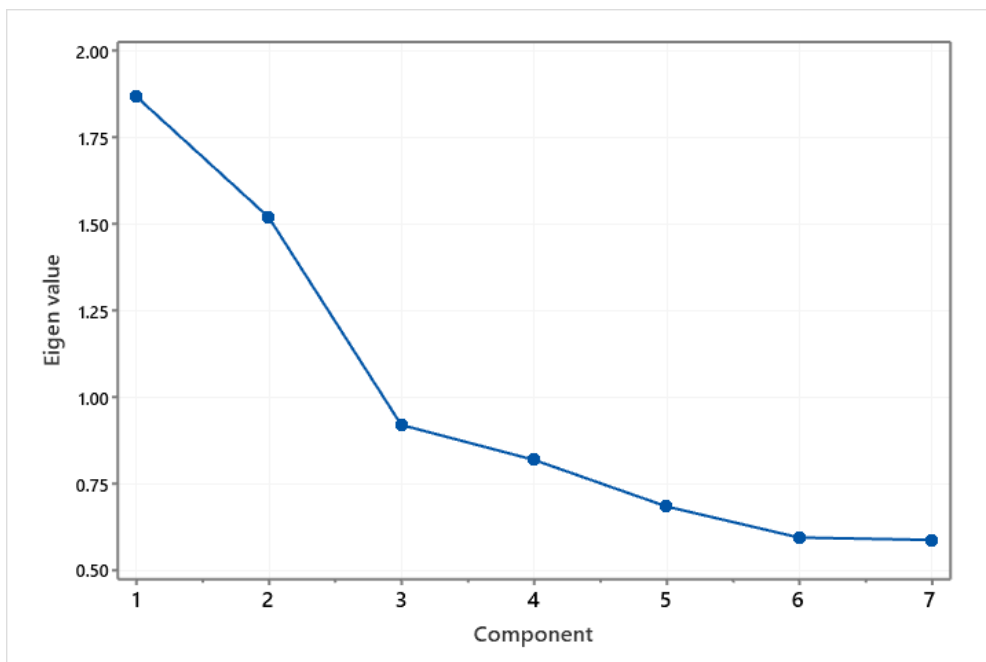


Figure 2. Scree plot of the seven variables

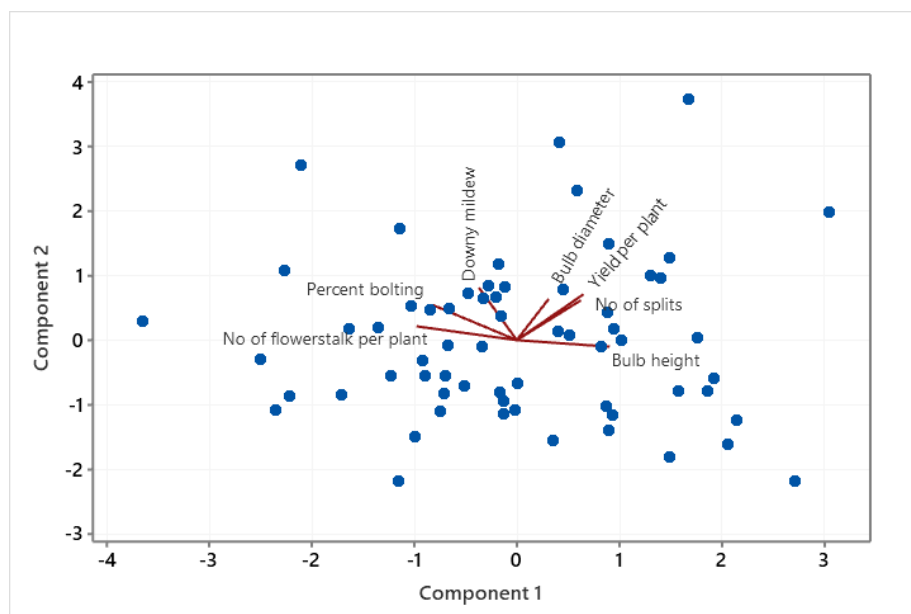


Figure 3. Bi-plot of principal components 1 and 2

Conclusions and Recommendation

Clonal selection of shallots slowed down the rate of variety development, with only a few varieties developed in the past three and half decades. Regeneration of shallots through true seeds provided an opportunity of natural out-crossing among plants and thus widening the genetic base. The present study was thus aimed at characterizing and classifying about sixty of the genotypes derived from segregating populations of shallot including three improved varieties used as controls for use in future shallot breeding activities. The results of the study showed that shallot genotypes significantly differed in yield/plant, percentage of bolting plants and number of flowerstalks/plant. However, they did not differ in

bulb diameter, bulb height and downy mildew severity. Eight genotypes had better yield/ plant than all the three controls. Cluster analysis grouped the genotypes into seven clusters based on their genetic similarities and differences using the the seven morphological traits. The principal component analysis also identified seven components, five of which contributed to 83.1% of the variation. Consequently, eight genotypes with better yield were recommended for further variety development trials under different environments while maintaining the other genotypes as sources genetic materials for future breeding activities.

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Performance of Newly Released Early Maturing Soybean (*Glycine max* (L.) Merr.) Variety, ‘Guda’ in the Major Growing Agro-ecologies of Ethiopia

Yechalew Sileshi¹; Masresha Yirga¹ ; Behailu Atero¹; Abush Tesfaye²;
Demelash Bosa³ and Mesfin Hailemaria²

¹Ethiopian Institutes of Agricultural Research, Jimma Agricultural Research P.O. Box, 192, Jimma, Ethiopia;;
Department of Field crop division; ² International Institute of Tropical Agriculture (IITA), Ibadan,
Nigeria; ³South Agricultural Research Institutes, Areka Agricultural Research, Department of Field crop
division; Corresponding author e-mail: yechalewss@gmail.com,

Abstract

Soybean is an affordable and valuable source of protein, oil, and other important nutrients. The current national average yield is 2.49 t ha⁻¹, which is low as compared to its potential due mainly to lack of varieties with wider adaptability to major agro-ecologies. Most of the released soybean varieties are medium to late maturity groups, and early maturing varieties are generally limited. Efforts have been underway to fill the gap through developing early maturing varieties. Jimma Research Center conducted a multi-location National Variety Trial (NVT) followed by a Variety Verification Trial (VVT) where candidate varieties were evaluated for release. Prior to release, the candidate was evaluated on a series of variety performance trails, including the NVT where 10 genotypes including the checks were tested in a randomized complete block design with four replications for two seasons across five locations. Combined data analysis revealed that the variety ‘Guda’ outperformed all the test genotypes including the checks. ‘Guda’ exhibited a 17 and 26% yield advantages over the recently released standard check, ‘Gazelle’ and the other check, ‘Nova’, respectively. In addition, the variety showed better tolerance to diseases. After a thorough evaluation of the NVT data and verification plots, the candidate genotype, HAR/PR142-15-SB, was officially released by the name “Guda” in the 2021 cropping season. Popularization of the new variety for farmers and fast inclusion of the new variety seed in the production system will play a significant role in increasing production and productivity of soybean in moisture deficit growing areas.

Keywords; - Soybean, early-maturing, performance trial, ‘Guda’, moisture stress

Introduction

The soybean is an important legume crop for food, feed, and soil fertility enhancement. Due to the seed composition of this crop, it is the most highly demanded crop at the global

level. Seeds of soybeans contain 38-42 percent protein, and 18-20 percent oil, and are rich in essential amino acids and unsaturated fatty acids (Zhang *et al.*, 2018). There is the potential for the crop to increase farmers' incomes and be used in various foods and feed

products as a protein source (Garrett *et al.*, 2013). Soybean was first introduced to the Sub-Saharan Africa (SSA) in the 19th century (Khojely *et al.*, 2018).

Production and utilization of soybean in Ethiopia is increasing since its introduction in the country. During the past seven years, soybean production have exponentially increased in terms of area of cultivation from about 31,854 ha and grain volume of 636,531 quintals in 2005/06 to 38,073 ha and 1,256,232 quintals in 2018/19 (CSA, 2005/06; CSA, 2018/19). In Ethiopia, soybean is gaining high importance in recent years. The current area under soybean cultivation is expected to increase in years to come due to the ever-increasing demand from domestic processing industries and export. Soybean productivity in Ethiopia average 2.49 metric tons per hectare (CSA, 2021), which is lower than the global average of 2.7 metric tons per hectare (FAO, 2021). One of the reasons for the low yield might be the lack of high-yielding varieties for specific agro-ecologies.

Since the inception of soybean research in Ethiopia, 36 soybean varieties have been developed and released for different agro-ecologies. However, most of the released varieties so far are medium to late-maturing groups. Although there are few early-maturing varieties like Nova and Williams, these varieties were

found to give low grain yield and biomass production. This necessitates the development of high-yielding early maturing varieties adaptable to the different agro-ecologies of the country. Despite the ever-increasing importance of soybean in Ethiopia, most of the area expansion, however, was in high rainfall areas, and soybean growing in moisture stress areas remains limited. Moreover, impacts of the global climate change has resulted in prolonged dry spell periods in most soybean-producing areas which in turn lower grain yield of popular varieties in the country. The aforementioned challenges and gaps call for continuous improvement and targeted breeding for early maturity varieties. As part of addressing the existing soybean production gaps and to widen soybean variety choices of early maturing varieties, a new soybean variety, 'Guda' was released from Jimma Agricultural Research Center in the year 2021.

Materials and Methods

Variety Guda was evaluated at various stages of variety testing, i.e. starting from observation nurseries, Preliminary Variety Trials (PVT), National Variety Trial (NVT), and verification trial. The national variety release procedure/system requires results of the NVT data for application and verification plots of the candidate varieties to evaluate candidate varieties against the standard checks.

Experimental locations and trail design

National variety trial

In this study, NVT trial was conducted at five locations representing the major soybean agro-ecologies in Ethiopia (Table 1) between 2018 and 2019 cropping seasons. The trial was planted in a 40cms by 5cms between row and within row spacing's respectively. The design used was RCB with four replications. NPS fertilizer was applied at the rate of 121kg per hectare at planting. All other cultural practices were carried out as recommended for soybean. A brief geographical and weather description of each test location is shown in the following Table1.

Verification plot

Verification plots are tested in a 10m x 10m plot at TiroAfeta Jima zone, Gofa, and Sirinka research testing sites and at two farmer's fields near each site. A variety release technical committee composed of breeder and pathologist experts evaluated the varieties. The technical committee thoroughly evaluated the application data of the NVT and visually evaluated the field performance of the candidate variety under verification plot along with checks. The technical committee makes its own decision about the candidate variety and presented its final decision to National variety release committee. And, the national variety release committee finally gave decision based on its assessment.

Table1. Description of the experimental locations.

Test location	Altitude (m.a.s.l)	Annual rainfall (mm)	Temperature (°C)	
			Min	Max
Mehoni	1571	600	18.0	25.0
Tiro-afeta	1768	1829	18.0	26.0
Gofa	1774	1298	13.1	28.0
Sirinka	1749	876	18.0	27.0
Humera	585	620	20.4	37.6

Plant materials

The trail involved 10 soybean genotypes of different genetic background and originated from different sources. As indicated in Table 2, four of the test genotypes were introductions from USA while the other four including the new variety, 'Guda' (HAR/PR142-15-SB) are recombinant inbred lines(RIL) developed by the breeding program of the Jimma Agricultural Research Center. The rest two genotypes, Gazelle and Nova were released early

maturing varieties included as checks (Table 2). Guda is homozygous line developed from a cross between Hardee an early maturing variety recommended in 1970 with promising line PR 142 through successive selection from segregating generations using a modified single seed descent method.

Table 2. Soybean genotypes and the corresponding seed sources used in the study.

No.	Genotype	Origin/ Source
1	Gazale	Early maturing check variety
2	PI200488	USA
3	JM-HAR/G99-15-SD-2	RIL-JARC
4	PI417116	USA
5	JM-PR142/G99-15-SB	RIL-JARC
6	PI506764	USA
7	JM-HAR/PR142-15-SB	RIL-JARC
8	Nova	Early maturing check variety
9	JM-DAV/PR142-15D	RIL-JARC
10	Delsoy 4710	USA

Results and Discussion

Based on the combined data analysis, the maximum grain yield (2.11 t/ha) was recorded from the newly released variety, Guda followed by the other two genotypes (JM-HAR/G99-15-SD-2 and JM-PR142/G99-15-SB) (Table 3). Results showed that the new variety, ‘Guda’ exhibited 17 and 26% yield advantages over the standard checks, Gazale and Nova, respectively (Table 3).

Days to maturity of the genotypes ranged from 86-102 days from sowing. Result showed that the days to maturity of the promising genotypes among the group including Guda(98) JM-HAR/G99-15-SD-2 (97 days), and JM-PR142/G99-15-SB (101days were found to be earlier in maturity than the standard check Gazelle (102 days).The finding indicate as there was , a positive trait in breeding for earliness. In most of the environments tested, the early maturing genotypes had also better grain yield. The maximum number of seeds per plant was obtained from the candidate

genotype, ‘Guda’ followed by the check variety Nova. The least number of seed per plant was recorded from the genotype PI506764. Furthermore, the two promising genotypes showed better tolerance reaction against soybean rust and bacterial blight (Table 3). In addition, the new variety Guda was better than the check (Nova) in hundred seed weight (Table 3).

In addition to the significant yield advantage of the new variety, Guda has comparable seed protein and oil content with the standard checks Gazale (Table 4).

The national variety release committee after thorough evaluation of the NVT data and verification plot finally accepted the candidate variety JM-HAR/PR142-15-SB and released by the name Guda since June 2021. The name Guda in Afaan Oromo language means big. This name was given tracing the big seed size of the variety main morphological characteristics of the candidate variety listed below (Table 4).

Table 3. Combined mean yield and related parameters of the test genotypes in the national variety trials.

Genotype	DTF	DTM	PH (cm)	NP	NSP	SH	RUST	CBB	HSW (g)	Yield (t/ha)	% Yield increase over check varieties	
											Gazella	Nova
Gazale	47.5	102	53.9	43.4	113.0	1.4	1.2	1.5	18.3	1.81	-	8
PI200488	42.6	86.6	38.4	31.5	80.0	2.5	1.3	2.1	18.2	1.41	-22	-16
JM-HAR/G99-15-SD-2	45.0	97.0	45.4	34.0	94.1	1.6	1.1	2.1	18.2	1.98	9	19
PI417116	41.9	85.5	30.8	26.2	57.2	2.8	1.0	1.4	19.1	1.11	-39	-34
JM-PR142/G99-15-SB	47.9	101.3	54.5	38.8	104.5	1.2	1.2	2.2	17.3	1.97	9	18
PI506764	41.1	88.8	29.6	23.5	56.8	2.2	1.3	1.9	18.4	1.30	-28	-22
Guda	45.0	97.5	56.5	43.5	113.4	1.4	1.3	1.7	15.7	2.11	17	26
Nova	43.6	86.3	54.5	50.2	129.2	2.1	1.4	1.7	12.9	1.67	-8	-
JM-DAV/PR142-15D	45.9	96.2	41.3	40.7	100.2	1.7	1.0	2.0	17.3	1.79	-1	7
Delsoy 4710	40.8	86.7	41.7	34.9	95.2	1.7	1.0	1.5	16.0	1.43	-21	-14
Mean	44.1	92.8	44.7	36.7	94.4	1.9	1.2	1.8	17.1	1.66		
CV	6.4	5.3	14.0	31.6	38.7	53.0	34.9	60.4	16.8	24.36		
LSD	5.5	9.6	12.2	22.7	71.5	1.5	0.8	NS	5.7	0.78		

DTF = days to 50% flowering, DTM = days to 95% maturity, PH = plant height, NPP = Number of pods per plant, NSP = Number of seeds per plant, HSW=hundred seeds weight (g)

Table 4. Mean seed protein and oil contents of the candidate variety compared with the two standard checks.

Seed composition	Nova	Gazale	Guda (JM-HAR/PR142-15-SB)
Protein	36.81	38.84	36.92
Oil	21.09	20.73	21.44

Table 5. Main morphological characteristics of the candidate variety

N o.	Candidates	Seed coat Color	Leaf Shape	Hilum color of the seed	Flower color	Morphological characteristics			
						Pubescen ce color	Pod color	Seed luster	Pubescen ce density
1	JM-HAR/PR142-15-SB(Guda)	Yellow	Inter media te	Black	Purple	Tawny	Light brown	1	Semi dense

Note; Seed luster scoring system was used a 1-5 scale (1=luster or attractive, and 5= unattractive).

The new variety, Guda can be adoptable from low to mid altitude soybean growing agro-ecologies, in areas with moisture deficit with annual rainfall rang of 300-620mm (Table 2). The variety could also be used for double cropping practices owing to its early maturing characters. Moreover, in high rainfall areas farmers plant soybean late due to overlap of other farm activities, mainly maize planting and weeding. Under such circumstances, farmers can harvest reasonable yield if they plant early maturing soybean varieties like Guda late in the season, which otherwise is hardly possible for medium and late maturing varieties to cope under such practices.

Conclusion and Recommendation

The newly released soybean variety Guda is an early maturing variety having mean days to maturity of 98

days, higher seed yield, better tolerance to major foliar diseases of soybean, and seed quality attributes as compared to the standard varieties studied. Hence, the variety has the potential to increase productivity and production in its current adaptation zones and similar moisture-deficit growing agro-ecologies. It's, therefore, worth to recommend the new variety for demonstration and popularization under small-scale farmers and for commercial production. Importantly, the impact of variety development can be realized if enough quantity of seed is multiplied and distributed to users in both quality and quantity. Towards that end, all actors and stakeholders in the soybean value chain should be engage in seed production and supply. Likewise, as owner of the variety, the breeding program of JARC need to regularly maintain the true-to-typness of the variety and continuously produce initial (breeder and pre-basic) seeds in a required quality and quantity.

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Distribution and Abundance of Wild Sunflower (*Verbesina encelioides*) and its Impacts on Plant Biodiversity in The Central Rift Valley of Ethiopia

Amare Fufa¹, Taye Tessema¹, Zelalem Bekeko² and Tewodros Mesfin¹

¹Ethiopian Institute of Agricultural Research, Addis Ababa, P.o.box 2003, Ethiopia

²College of Agriculture and Environmental Science, Haramaya University, Dire Dawa, P.o.box 138, Ethiopia; Amare Fufa; email: amarefufa@gmail.com

Abstract

Wild sunflower (*Verbesina encelioides*) is a newly identified emerging invasive weed with adverse consequences that require management efforts. Surveys were conducted in the Central Rift Valley of Ethiopia during the main rainy season of the year 2020. The research aimed to determine the geographic distribution of wild sunflower, generate data on the quantitative measures, the threats posed by the weed to native plant biodiversity, and assess the influence of some environmental factors on wild sunflower. A total of 220 sampling points were assessed across 22 different sites. Ecological indices were used to assess the distribution and diversity of the weed species. The significance of nine key variables: rainfall, temperature, altitude, species abundance, richness, diversity, and the density, frequency, and dominance of wild sunflower, were assessed using principal component analysis. A total of 42 taxa that belong to 18 plant families were recorded. Wild sunflower was found in 68.64% of the total sampling points. The infestation was more prevalent at low altitudes, such as Fentale, Boset, and Adama. On the roadside, wild sunflower was the dominant weed species. It has also been observed in different crop fields, like common beans, onions, and tef. Principal component analysis showed that the first two of the nine principal components (largely wild sunflower density and frequency) accounted for 77% of the variation in the data set. Rainfall, altitude, and temperature were among the environmental factors that influenced wild sunflower distribution. The highest density of wild sunflower (54.19 plants m⁻²) was observed to significantly reduce the diversity of other plant communities ($H' = 2.47$). Thus, practical and effective measures are required to prevent and control the spread of this exotic invasive weed to other parts of the country where it has not yet been introduced.

Keywords: Distribution; invasive species; land use types; principal component; *Verbesina encelioides*

Introduction

Ethiopia is endowed with a wide range of biological and ecological diversity. Its vast biological and ecological

multiplicity is due to its diverse temperature, soil, altitude, and topography (EARO, 2004). However, abiotic and biotic factors are threatening the country's biological

diversity. The biological invasion of invading alien species being the greatest threat to the native biota. Invasive alien plant species are one of the most serious ecological problems, as they cause a significant part of the extinction of native species (Pragya, 2017). They endanger biodiversity, habitat composition, ecosystem functioning, and human interests by displacing native species, resulting in a decline in native flora and fauna of biodiversity (Hulme, 2007; Crawl *et al.*, 2008; Rezene, 2008; Taye *et al.*, 2009; Rezene *et al.*, 2012).

In Ethiopia, over 35 invasive alien weed species have been identified as established or potentially emerging invaders (Rezene *et al.*, 2012). Parthenium weed (*Parthenium hysterophorus* L), Water hyacinth (*Eichhornia crassipes*), and Mesquite (*Prosopis juliflora*) are the most prominent plant invaders in the country. They resulted in a significant reduction of crop yields, biodiversity, and economic losses in several parts of the country (Tamado, 2001; Firehun *et al.*, 2007; Edward, 2013; Firehun *et al.*, 2014; Ilukor *et al.*, 2014). Besides the already established invasive alien weed problem, the problem of emerging invaders is becoming important due to a lack of comprehensive understanding of the invading weeds and the current shifting dynamics of weeds in crops, non-crops, and cropping systems, as well as environmental weeds (EIAR, 2016).

Wild sunflower (*Verbesina encelioides*(Cav.) Benth. & Hook. F. Ex A. Gray) is one of the recently

identified emerging invasive weeds in Ethiopia. It is thought to have originated in Mexico and the United States, and is widely distributed in many parts of the world (Walther, 2004; Feenstra and Clements, 2008; Jain *et al.*, 2008; Sayari *et al.*, 2016). Though the source of the introduction is not exactly known, its rare presence was noted during the study of weed flora in agricultural fields in eastern Ethiopia as early as 1998 (Tamado and Milberg, 2000). Arne and Quentin (2017) reported that wild sunflower has been found in a number of Ethiopian localities with establishing dense stands, and that the weed's possible introduction pathway could be as an ornament and accidentally as a contaminant.

Wild sunflower is an aggressive weed that invades huge habitats like roadsides, farming fields, residential areas, and grazing lands, competes with native plants and reduces biodiversity (Sade *et al.*, 2007; Taleb *et al.*, 2011; Mohammad, 2014; Goyal *et al.*, 2019). Its aggressiveness and fast growth capacity outcompetes native plants and prevent them from growing (Walther, 2004; Goyal *et al.*, 2019). It competes with its neighbors through allelopathic interference; for example, it has a higher competitive ability than co-occurring species such as *Amaranthus viridis* and *Senna occidentalis* (Mehal *et al.*, 2022). It is now a new and possibly emerging invader in Ethiopia having far-reaching consequences that necessitate efforts to contain the weed. However, knowledge about its ecological distribution and effects on plant biodiversity in Ethiopia, in general,

and in Ethiopia's Central Rift Valley, in particular, is lacking. Therefore, the objectives of this study were to: (i) determine the abundance and distribution of wild sunflower; (ii) generate data on the threats posed by the weed to native plant biodiversity; and (iii) assess the influence of some environmental factors on wild sunflower distribution in the Central Rift Valley of Ethiopia.

Materials and Methods

Description of the Study

Areas

The study was conducted in the Central Rift Valley of Ethiopia, which includes East Shewa and West Arsi. The East Shewa Zone is located from 38° 03' to 40° 05' E longitude and from 7° 04' to 9° 10' N latitude, covering a total area of about 13,766.5 km². Whereas, the West-Arsi Zone covers an area of approximately 12,938 km² and spans 38° 0' to 40° 00'E longitude and 6° 00' to 7° 35'N latitude. Based on the moisture index classification of climate, East Shewa is characterized by a semi-arid and sub-humid climate. Considering the long-term average seasonal rainfall, the area receives 458–718 mm of rain. According to the Food and Agriculture Organization (FAO) classification, Andosols, Vertisols, Rendzinas and Phaeozems, and Fluvisols are the dominant soil types found in the East Shewa Zone (Gizachew and Suryabhagavan, 2014). On the other hand, West Arsi receives 600 mm to 1400 mm of annual rainfall during the main rainy season. The average monthly temperature in the

zone varies between 15 and 20°C. Orthicluvisol, Eutric Combisols, and Vertisols are the dominant soils in West Arsi.

Sampling of the Species

Occurrence and

Environmental Data

The survey was conducted between August and October during the main season of 2020 when wild sunflower growth was at its peak. Initially, a preliminary field visit was conducted prior to the actual field assessment. A multistage sampling method was used to select eight districts based on the infestation level of the wild sunflower. Three sites were further selected from each district (except two districts where only two sites were examined in each) based on their accessibility to roads and wild sunflower occurrence along different land use types. In each site, ten quadrats (1m x 1m) were used for assessment. Thus, a total of 220 sampling points were examined from 22 sites. At each survey site, the occurrence of wild sunflower was noted and the geographic coordinates, latitude and longitude, as well as altitude, were also recorded by using a handheld Global Positioning System (Garmin GPS 60). Furthermore, the identity and quantity of other weed species in the quadrat was also recorded. Data recorded in all sites included altitude, species density, species richness, and wild sunflower density at different land use types. The long-term record of monthly rainfall and temperature of the study sites were obtained from National Metrology Agency. A summary of the description of the physical environment, and the

mentioned variables used in this study is given in Table 1.

Data analyses

Weed species distribution and abundance assessment

The data on weed species were summarized using: (1) frequency- the percentage of sampling plots in which a particular weed species is found. It explains how often a weed species occurs in the survey area, (2) abundance- the population density of a weed species expressed as the number of individuals of that species per unit area, and (3) dominance- the abundance of an individual weed species in relation to the total weed abundance. Wild sunflower density was calculated as the number of individuals of wild sunflower that occur per surface area of the sampling unit (plant per square meter). The formula used to calculate the frequency, abundance, and dominance of the species is described as follows:

$F = 100 * \frac{X}{N}$ where, F = frequency of particular weed species; X = number of samples in which a particular weed species occurs; N = total number of samples

$A = \frac{\sum W * 100}{N}$ where, A = abundance; $\sum W$ = sum of individuals of a particular weed species across all samples; N = total number of samples.

$D = A * \frac{100}{\sum A}$ where, D = dominance of a particular species; A = Abundance of the same species

$\sum A$ = total abundance of all weed species

Species diversity evaluation

Species diversity on the study sites was described by two parameters, richness and evenness, using the Shannon-Wiener Diversity Index. The formula is $H' = -\sum [Pi(\ln Pi)]$ where, H = Shannon-Wiener Diversity Index; Pi = proportional abundance of the i^{th} species. Then, using the calculated value of H, Evenness was calculated as: $E = \frac{H'}{\ln S}$ where, E = Evenness; S = Species richness (the number of species in a community).

Principal component analyses

Principal component analysis was performed on the mean values obtained for each variable (Table 1) using R software, Version 4.05 (R Development Core Team, 2018). It was used to identify the main factors that influence the distribution and abundance of wild sunflower. ANOVA was applied to investigate the relationship between the mean abundance of wild sunflower and diversity variables against land use types.

Correlation and regression analysis

The mean density of wild sunflower was used as the independent variable

and the density of broad-leaf and grass weeds as the response variables in the regression analysis.

Table 1. Description of variables used in principal component analysis

Variables	Variable code
Rainfall	Rainfall
Temperature	Temperature
Altitude	Altitude
Species abundance	Abundance
Mean density of wild sunflower	Density
Frequency of wild sunflower	Frequency
Dominance of wild sunflower	Dominance
Species richness	Richness
Shannon's diversity index	H'

Results and Discussion

Weed Species Community

A total of forty-two weed species from eighteen different families were identified (Appendix 1). The weed species communities were documented at twenty-two different sites along various land use types (roadsides, crop fields, fallow land, grazing land, and residential areas). The most diverse weed species were found on fallow land, followed by grazing land and residential areas (thirty-two, twenty-

four, and twenty, respectively) (Table 2). The most important families, based on the number of taxa, were Astraceae (9), Poaceae (7), and Fabaceae (4). These three families were also the most important in eastern Ethiopia (Tamado and Milberg, 2000). Annual weed species were more common than perennials in the study areas, except on roadsides where perennial weed species were dominant (Table 2). Fallow land accounted for 76.19% of the total weed species recorded, of which 62.50% were annual.

Table 2. Number of weeds by their family, species, and growth form (annual and perennial) across land use types in the Central Rift Valley of Ethiopia

Land Use Types	Family	Weed Species	Annual	Perennial
Crop field	8	15	13	2
Fallow land	15	32	20	12
Grazing land	9	24	15	9
Residential area	8	20	8	12
Roadside	8	17	7	10

Distribution and Abundance of Wild sunflower

Wild sunflower was recorded in all districts of the twenty-two sites surveyed. It was recorded in 68.64% of the total sampling points, being more common in the Fentale, Boset, Adama, Lome, and Dugda districts than in Adamitulu, Shala, and Liben districts (Table 3). The majority of the districts are located along main roads and railway routes where massive infrastructure development and agricultural investment activities take place. Roadsides are vulnerable to the spread of non-native plant species because roads and road maintenance are vectors for their spread (Hulme, 2009). Although the wild sunflower current distribution in Lome and Dugda districts was relatively moderate, its invading potential in these districts was high due to large crop production area coverage, particularly horticultural crop production on a small and large scale under both rain-fed and irrigation conditions. It is common for producers in these areas to cover their crop harvest, such as onions and

tomatoes, with various local materials, including invasive weeds, during transport to market. Moreover, continued agricultural activities may create a conducive environment for the invasive weed species. Such frequent movement of vehicles in and out of those areas along with continued and intensive farming practices could greatly contribute for the further expansion of invasive weed species in general and wild sunflower in particular.

On the other hand, the infestation of the weed was low in the Shala and Liben districts as compared to other surveyed districts. This might be due to the fact that these districts are relatively far from the main road, which is the main dispersal pathway of invasive weed species. Similarly, Wilson and colleagues (2009) reported that unintentional introductions of invasive species, such as those caused by mass dispersal, frequently involve the introduction of propagules into highly disturbed habitats, such as ports, roadsides, and commercial complexes, where the unaided establishment is more likely than in less disturbed habitats.

Table 3. Occurrence of wild sunflower in different districts in the Central Rift Valley of Ethiopia

Surveyed Districts	Number of sites	Total number of sampling points	Number of sampling points	
			Presence *	Absence
Adama	2(Site1&2)	20	15(75.00)	5
Adamitulu	3(Site3, 4&5)	30	19(63.33)	11
Boset	3(Site6, 7&8)	30	24(80.00)	6
Dugda	3(Site9, 10&11)	30	20(66.67)	10
Fentale	3(Site12, 13&14)	30	25(83.33)	5
Liben	2(Site15 &16)	20	9(45.00)	11
Lome	3(Site17, 18&19)	30	21(70.00)	9
Shala	3(Site20, 21&22)	30	18(60.00)	12
Total	22	220	151(68.64)	69

*values in parentheses are percentage presence out of total

With regard to the density of wild sunflower, it varied significantly

across an altitude gradient. It was more abundant between 500 and 1500

m.a.s.l. than between 1500 and 2000 m.a.s.l (Figure 1). At an altitude ranging from 1500 to 2000 m.a.s.l., the mean density of wild sunflower was significantly lower, as compared to its

density at lower altitudes, less than 1500 m.a.s.l. This indicates that the abundance of wild sunflower is greatly affected by altitude (Figure 1).

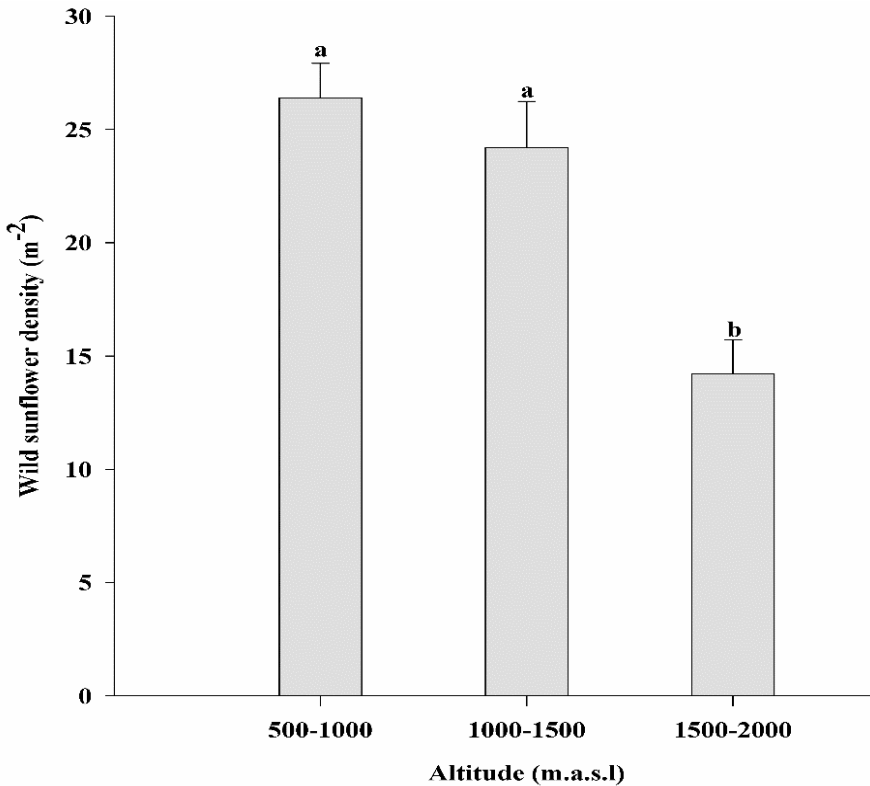


Figure 1. Distribution of wild sunflower along altitude gradient (LSD at $P \leq 0.05 = 2.13$)

Because of anthropogenic disturbances such as uncontrolled grazing and large-scale commercial farms, the distribution and abundance of invasive plant species, including wild sunflower, were significant in the low and mid-altitudes (Figure 1). Likewise, Dai *et al.* (2020) reported a lower density of invasive plant species in the high-altitude region. The number of weed species was observed low at higher elevations, which accounts for less available space, limiting the

growth of invasive species (Pathak *et al.*, 2019).

Wild sunflower had the highest mean density (53.47 plant m⁻²) on the roadside habitat, followed by the noxious invasive plant species, *Parthenium hysterophorus* (38.80 plant m⁻²) (Appendix 1). This could be because wild sunflower is a potential emerging invader that has taken over roadside vegetation and has the potential to spread to other land use

types or habitats. On the other hand, *P. hysterophorus* is already a well-established invasive plant species that is found beyond roadsides in a variety

of habitats. For instance, the mean density of *P. hysterophorus* in a crop field was higher than wild sunflower by two-fold (Appendix 1).



Figure 2. Wild sunflower infestation in a) field after wheat, b) Common bean field c) Onion seedling, and d) Tef, in the Central Rift Valley of Ethiopia.

Wild sunflower is widely distributed in different habitats of the Central Rift Valley of Ethiopia, including crop fields where the weed has infested many crop fields (Figure 2). The crop fields heavily infested by the weed in the study area were common bean, onion, and tef fields (Figure 2b-d).

Previous studies also showed that wild sunflower could be found in a variety of habitats, including crop fields, pasture land, roadsides, field borders, water course surrounds, and grasslands (Brunel *et al.*, 2010; Goyal *et al.*, 2019).

Factors Influencing the Distribution and Abundance of Wild sunflower

In order to better understand factors affecting the distribution and abundance of wild sunflower, a principal component analysis was computed. Table 4 shows a correlation matrix derived from principal component analysis. The mean density, frequency, and dominance of wild sunflower had a strong negative relationship with rainfall and altitude, on the other hand, they had a significant positive correlation with temperature (Table 4). The diversity and abundance of weed species were positively correlated with rainfall but inversely correlated with temperature. This might be due to the impact of high temperatures, which play a great role in contributing to climate change

and favoring the dominance of a few invasive species, like wild sunflower. Climate change can have an immediate impact on weed distribution through variability in selective pressures on weed species as well as an indirect impact through changes in the abiotic and biotic factors in an ecosystem (Ziska *et al.*, 2019). The abundance of weed species had a strong positive relationship with rainfall and a negative relationship with temperature. Moreover, species richness had a strong positive relationship with rainfall and a negative relationship with temperature and altitude. Walther *et al.* (2009), on the other hand, observed that climate change increases the abundance and distribution of some invasive species while decreasing or shifting the abundance and distribution of other native or invasive species, which may not result in changes in species richness.

Table 4. Correlation matrix of physical environment and species abundance and diversity indices

	Rainfall	Temperature	Altitude	Abundance	Density	Frequency	Dominance	Richness	Diversity
Rainfall	1.00								
Temperature	-0.63**	1.00							
Altitude	0.84***	-0.54**	1.00						
Abundance	0.56**	-0.65**	0.46*	1.00					
Density	-0.87***	0.62**	-0.91***	0.32	1.00				
Frequency	-0.84***	0.62**	-0.93***	0.32	0.97***	1.00			
Dominance	-0.78***	0.58**	-0.86***	0.14	0.93***	0.96***	1.00		
Richness	0.72***	-0.51*	-0.53*	0.25	0.29	0.29	0.22	1.00	
Diversity	0.52*	-0.52*	-0.10	0.11	0.38	0.38	0.42	0.58**	1.00

*significant at 0.05; ** significant at 0.01; ***significant at 0.001

With regard to principal component analysis, the first principal component accounts for 52.5% of the total variance, and the first two components explain around 77% of the total variance (Figure 3). As shown in Table 5, the variables most associated with the first principal component

were the wild sunflower frequency (0.422), mean density (0.421), and dominance (0.407), indicating these three variables vary together. In other words, if one increases, the others tend to increase as well. In the first principal component, on the other hand, precipitation and altitude had

almost parallel contrast with frequency, density and dominance. The second principal component was

highly associated with that of species richness and Shannon's diversity index (Table 5).

Table 5. Eigen vector of the first two principal components of variables measured in different land use types of the Central Rift Valley of Ethiopia

	*Prin1	**Prin2
Rainfall	-0.409	0.121
Temperature	0.300	-0.199
Altitude	-0.394	-0.247
Species abundance	0.146	0.319
Mean density of wild sunflower	0.421	0.026
Frequency of wild sunflower	0.422	0.026
Dominance of wild sunflower	0.407	-0.049
Species richness	0.117	0.632
Shannon's diversity index	0.179	0.617

*Prin1-first principal component; **Prin2- second principal component

The principal factors for site clustering were wild sunflower density and frequency, as evidenced by the high positive load of these variables on the first principal component, which accounted for 52.5% of the variation of the data set (Table 5). Figure 3b depicts the survey sites' positions on

the principal component dimensions. Sites on the right bottom (cluster 2) had an abundant distribution of wild sunflower. In contrast, sites on the right top (cluster 4) had a lower distribution of wild sunflower.

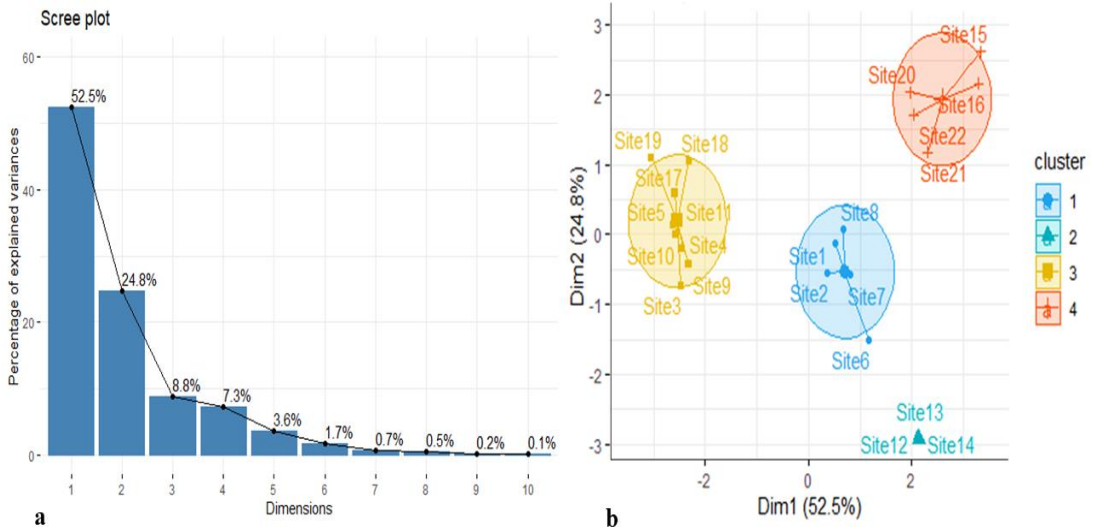


Figure 3. a) Scree plot b) Cluster plot of the 1st and 2nd axes from the PCA showing similarity of areas surveyed for the wild sunflower distribution in the Central Rift Valley of Ethiopia

Sites categorized in cluster 2 are those found in the Fentale district. The district is located in the lowland area of the Central Rift Valley of Ethiopia

and it is one of the climate change-prone areas that have been affected by climate-induced shocks, and beneficial plant species have become endangered

and have been replaced by unpalatable species as a result of declining rainfall, rising temperatures, and recurrent droughts (Mekuyie and Mulu, 2021). In general, climate-related variables are thought to be the dominant factors influencing species' presence or absence at spatial and temporal scales (Thuiller *et al.*, 2007).

Impact of Wild Sunflower on Herbaceous Plant Biodiversity

The five land use types had a significant impact on the abundance of wild sunflower and species diversity. Species diversity indices on fallow land and grazing land were the highest, while those in crop fields and roadsides were the lowest (Table 6). Species richness, defined as the number of plant species present in an area, was significantly ($P < 0.05$)

influenced by land use types. Likewise, land use types had varying effects on the Shannon diversity index and species evenness. As a result, the species richness of fallow land, grazing land, and residential areas was significantly ($P < 0.05$) higher than that of roadsides and crop fields, respectively (Table 6). In fallow land, the highest species evenness was observed followed by grazing land and residential areas with 0.96, 0.94, and 0.91 respectively (Table 6). All of the diversity indices in crop fields were comparatively lower. This could be due to weed management practices in crop fields. On the other hand, the highest species richness in fallow land may be due to less soil disturbance than in other land use types. This is due to the fact that disturbed soil or land favors the dominance of invasive plant species over stable land.

Table 6. Mean abundance of wild sunflower, Species richness, Shannon's diversity index, and Evenness (mean $\pm$ standard deviation) of weed species at different land use types

Land use types	Mean abundance	Species richness	Shannon's Index	Evenness
Crop field	13.47 ^e $\pm$ 2.13	14.05 ^e $\pm$ 2.81	2.47 ^c $\pm$ 0.31	0.87 ^b $\pm$ 0.08
Fallow land	25.21 ^d $\pm$ 2.25	31.41 ^a $\pm$ 2.16	3.25 ^a $\pm$ 0.21	0.96 ^a $\pm$ 0.11
Grazing land	34.14 ^c $\pm$ 3.16	24.64 ^b $\pm$ 1.74	3.00 ^{ab} $\pm$ 0.28	0.94 ^a $\pm$ 0.07
Residential area	42.23 ^b $\pm$ 4.12	20.32 ^c $\pm$ 2.18	2.79 ^b $\pm$ 0.19	0.91 ^{ab} $\pm$ 0.13
Road side	54.19 ^a $\pm$ 5.64	17.23 ^d $\pm$ 3.42	2.54 ^{bc} $\pm$ 0.37	0.89 ^b $\pm$ 0.09

Note: Different letters within a column indicate that the values are significantly different at p -value ≤ 0.05 .

The decrease in diversity indices, as wild sunflower mean abundance increased, indicated that the variation in weed species and community multiplicity decreased as wild sunflower infestation increased. Similarly, fallow land had a higher evenness index, indicating that weed species are more equitably distributed in low-disturbed habitats. When wild sunflower was present at its highest

mean abundance (54.19 plants m^{-2}), the plant community's diversity was the lowest ($H' = 2.47$), and the highest ($H' = 3.25$) when wild sunflower was present at its lowest mean abundance (13.47 plants m^{-2}). Consequently, as the diversity of the plant community increases, the mean abundance of the wild sunflower decreases, and vice versa (Table 6). This suggests that wild sunflower significantly reduces

the density and diversity of other plant species. Wild sunflower's aggressiveness and higher competitive ability prevent natural plants from growing (Walther, 2004; Goyal *et al.*, 2019). Due to allelopathic interference, wild sunflower competes with its co-occurring plant species (Mehal *et al.*, 2022). According to Kaur *et al.* (2021), the presence of certain compounds in wild sunflower may be responsible for its dominance in areas where it occurs; i.e., this dominance may be related to the allelopathic impact of this weed. Wild sunflower infestation on the field after wheat revealed that it grows in dense populations with few or no other plants present, indicating its significant impact on plant biodiversity (Figure 2a).

The mean density of weed species along land use types was used to develop regression equations against the dependent variable of broad-leaf and grass weed density versus wild sunflower density. The result revealed a strong negative relationship between wild sunflower density and broad-leaf

weeds (Figure 4a). Furthermore, wild sunflower was also negatively associated with grass weeds (Figure 4b). Figure 4 shows that the regression equation estimated by wild sunflower density explains 93.19 and 73.89% of the variability in broadleaf and grass weed populations per square meter, respectively.

When wild sunflower densities increased across land use types, there was a linear decrease in broad-leaf and grass weeds. Similarly, Million *et al.* (2021) also observed a negative association between the relative abundance of parthenium with species richness ($R^2 = 85\%$) and the index of Shannon diversity ($R^2 = 99\%$), respectively. The density of broad-leaf and grass weeds decreased linearly with each addition of wild sunflower plants m^{-2} by 0.78 and 1.20 plants m^{-2} , respectively (Figure 4a and b). Similarly, Taye *et al.* (2010) observed that as parthenium density increased, the density of broadleaf, grass, and sedges decreased.

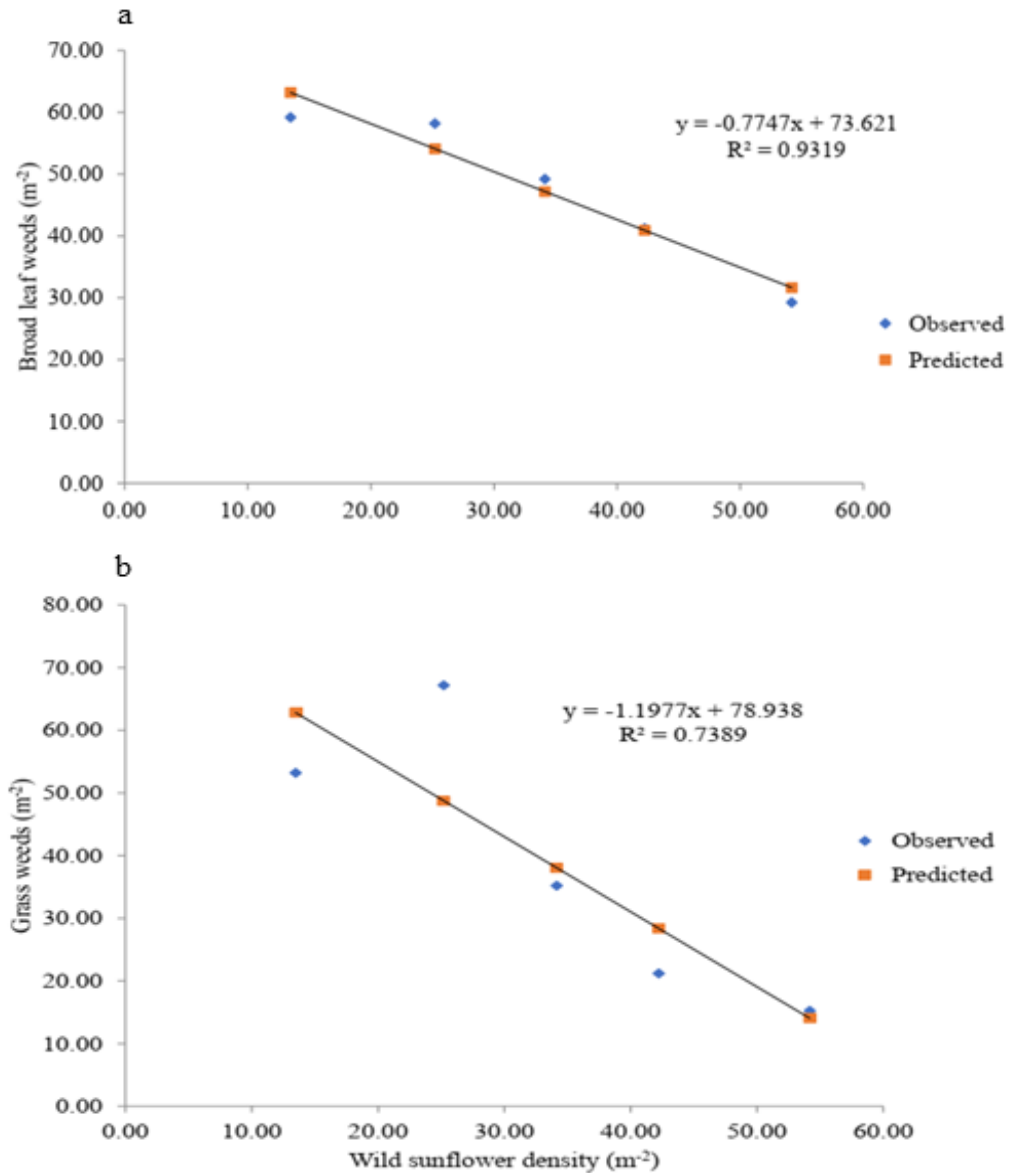


Figure 4. Regression of wild sunflower with a) broad-leaf weeds and b) grass weeds

Conclusion

This study described the distribution, abundance, and impact of wild sunflower in the Central Rift Valley of Ethiopia. It has documented the current distribution and abundance of the recently introduced wild

sunflower, a species that has spread rapidly and has the potential to threaten different crop and non-crop environments. Accordingly, the occurrence of wild sunflower at twenty-two sites across land use types was documented. The most abundant weed species across land use types were also identified. On roadsides, for

example, wild sunflower was the dominant weed species. Furthermore, it was widely distributed in different crop fields, like common bean, onion, and tef. The prevalence of the weed in farming fields indicated its potential to affect crop production. Rainfall, altitude, and temperature were among the environmental factors that influenced wild sunflower distribution. The study demonstrated that wild sunflower remarkably reduced the density and diversity of other plant species. Thus, if wild sunflower continues to grow unrestricted and unmanaged on an early note, it will have a significant impact on the country's agricultural and natural ecosystems. Given the current situation, it is critical that proper and effective measures for the prevention of this exotic invasive weed be implemented in order to control its spread from other areas of the country where it is not present at the moment.

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Appendix 1. Frequency, abundance and dominance of different weed species along land use system types in CRV of Ethiopia

Weed species	Family	Growth form	Frequency					Abundance					Dominance				
			RS	CF	FL	GL	RA	RS	CF	FL	GL	RA	RS	CF	FL	GL	RA
<i>Achyranthes aspera</i>	Amaranthaceae	Perennial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
<i>Alternanthera pungens</i>	Amaranthaceae	Perennial	18.00	0.00	0.00	0.00	3.21	3.21	0.00	0.00	0.00	0.00	1.52	0.00	0.00	0.00	0.00
<i>Amaranthus hybridus</i>	Amaranthaceae	Annual	0.00	12.00	7.80	12.00	0.00	0.00	8.00	4.30	0.00	3.00	0.00	1.75	0.88	0.00	0.84
<i>Amaranthus spinosus</i>	Amaranthaceae	Annual	0.00	0.00	16.00	12.80	0.00	0.00	0.00	9.00	0.00	4.98	0.00	0.00	1.97	0.00	1.40
<i>Anagalis arvensis</i>	Primulaceae	Annual	0.00	0.00	8.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00
<i>Argemone auchroleuca</i>	Papaveraceae	Annual	24.00	48.00	56.00	25.20	3.70	3.70	7.80	11.80	6.00	9.80	1.75	1.70	1.86	2.03	2.75
<i>Bidens pilosa</i>	Asteraceae	Annual	0.00	64.00	54.00	17.20	0.00	0.00	28.00	24.10	11.00	6.87	0.00	6.12	5.72	3.72	1.92
<i>Calotropis procera</i>	Apocyanaceae	Perennial	12.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	1.89	0.00	0.00	0.00	0.00
<i>Chenopodium spp</i>	Chenopodiaceae	Annual	0.00	65.00	32.00	0.00	0.00	0.00	8.00	20.86	0.00	0.00	0.00	1.75	5.28	0.00	0.00
<i>Commelina benghalensis</i>	Commelinaceae	Annual	0.00	0.00	35.00	0.00	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00	0.87	0.00	0.00
<i>Convolvulus spp</i>	Convolvulaceae	Perennial	0.00	0.00	15.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00
<i>Cynodon dactylon</i>	Poaceae	Perennial	0.00	0.00	65.00	31.32	28.67	0.00	0.00	17.00	18.20	24.00	0.00	0.00	3.71	6.15	6.72
<i>Cyperus esculentus</i>	Cyperaceae	Perennial	0.00	40.00	84.00	30.52	32.35	0.00	22.00	41.00	15.00	24.54	0.00	4.81	10.38	5.07	6.88
<i>Cyperus rotundus</i>	Cyperaceae	Perennial	54.00	55.00	65.00	30.12	12.80	12.80	23.00	31.40	12.80	24.60	6.06	5.03	5.63	4.33	6.89
<i>Cyperus sesquiflorus</i>	Cyperaceae	Perennial	0.00	0.00	60.00	30.92	0.00	0.00	0.00	21.00	15.80	24.60	0.00	0.00	4.59	5.34	6.89
<i>Datura stramonium</i>	Solanaceae	Annual	0.00	0.00	15.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	0.44	0.00	0.00
<i>Digitaria abyssinica</i>	Poaceae	Perennial	32.00	0.00	56.00	32.00	11.00	11.00	0.00	37.00	22.80	25.00	5.21	0.00	9.37	7.71	7.00
<i>Digitaria milaniana</i>	Poaceae	Perennial	40.00	0.00	48.00	32.00	7.00	7.00	0.00	32.00	22.40	9.80	3.31	0.00	8.10	7.57	2.75
<i>Echinochloa colona</i>	Poaceae	Perennial	0.00	0.00	45.33	0.00	0.00	0.00	0.00	8.00	0.00	0.00	0.00	0.00	1.75	0.00	0.00
<i>Eleusine indica</i>	Poaceae	Annual	34.00	65.00	60.00	26.52	13.00	13.00	11.00	10.00	19.23	2.00	6.15	2.40	2.53	6.50	0.56
<i>Eragrostis cilianensis</i>	Poaceae	Annual	0.00	0.00	35.00	0.00	0.00	0.00	0.00	6.00	0.00	0.00	0.00	0.00	1.31	0.00	0.00
<i>Euphorbia heterophylla</i>	Euphorbiaceae	Annual	0.00	0.00	0.00	12.00	0.00	0.00	0.00	0.00	3.00	2.43	0.00	0.00	0.00	1.01	0.68
<i>Galinsoga parviflora</i>	Asteraceae	Annual	42.00	90.00	60.00	42.12	12.00	12.00	38.00	33.20	13.00	13.80	5.68	8.30	7.94	4.39	3.87
<i>Guizotia scabra</i>	Asteraceae	Annual	0.00	95.00	72.00	43.8	52.00	0.00	33.00	43.12	12.80	14.86	0.00	7.21	7.51	3.75	4.16
<i>Lantana camara</i>	Verbenaceae	Perennial	36.00	0.00	0.00	0.00	44.00	4.60	0.00	0.00	0.00	7.00	2.18	0.00	0.00	0.00	1.96
<i>Leucus mertinicensis</i>	Lamiaceae	Annual	0.00	0.00	56.00	0.00	0.00	0.00	0.00	27.00	0.00	0.00	0.00	0.00	6.84	0.00	0.00
<i>Medicago polymorpha</i>	Fabaceae	Annual	24.00	0.00	0.00	9.20	2.17	2.17	0.00	0.00	2.12	3.20	1.03	0.00	0.00	0.72	0.90
<i>Nicandra physalodes</i>	Solanaceae	Annual	0.00	55.00	0.00	0.00	0.00	0.00	9.00	0.00	0.00	0.00	0.00	1.97	0.00	0.00	0.00

Note: RS-roadside; CF-crop field; FL-fallow land; GL-grazing land; RA-residential area; CRV-central rift valley

Appendix 1. Continued

Weed species	Family	Growth form	Frequency					Abundance					Dominance				
			RS	CF	FL	GL	RA	RS	CF	FL	GL	RA	RS	CF	FL	GL	RA
<i>Parthenium hysterophorus</i>	Asteraceae	Annual	86.00	45.00	62.00	52.00	38.80	38.80	27.00	44.80	33.80	20.60	18.37	5.90	11.34	11.42	5.77
<i>Plantago leoncelata</i>	Plantaginaceae	Perennial	0.00	0.00	65.00	0.00	0.00	0.00	0.00	7.60	0.00	0.00	0.00	0.00	1.66	0.00	0.00
<i>Portulaca oleracea</i>	Portulacaceae	Annual	0.00	45.00	38.00	28.00	0.00	0.00	21.00	22.00	5.00	4.30	0.00	4.59	5.57	1.69	1.20
<i>Prosopis juliflora</i>	Fabaceae	Perennial	12.00	0.00	0.00	0.00	4.00	4.00	0.00	0.00	0.00	0.00	1.89	0.00	0.00	0.00	0.00
<i>Ricinus communis</i>	Euphorbiaceae	Perennial	0.00	0.00	0.00	0.00	33.68	0.00	0.00	0.00	0.00	11.20	0.00	0.00	0.00	0.00	3.14
<i>Rumex abvssinicus</i>	Polygonaceae	Perennial	0.00	0.00	10.00	17.68	0.00	0.00	0.00	3.00	2.40	3.80	0.00	0.00	0.66	0.81	1.06
<i>Senna didimobotrya</i>	Fabaceae	Perennial	38.00	0.00	0.00	53.44	5.00	5.00	0.00	0.00	0.00	13.60	2.37	0.00	0.00	0.00	3.81
<i>Senna occidentalis</i>	Fabaceae	Perennial	44.00	0.00	28.00	0.00	4.80	4.80	0.00	7.00	0.00	0.00	2.27	0.00	1.77	0.00	0.00
<i>Setaria pumila</i>	Poaceae	Annual	0.00	0.00	52.00	21.32	0.00	0.00	0.00	26.80	16.20	22.00	0.00	0.00	6.79	5.48	6.16
<i>Setaria verticillata</i>	Poaceae	Annual	0.00	0.00	56.00	12.00	0.00	0.00	0.00	25.40	16.00	23.20	0.00	0.00	6.43	5.41	6.50
<i>Sorghum arundinaceum</i>	Poaceae	Annual	0.00	45.00	28.00	0.00	0.00	0.00	17.00	17.00	0.00	0.00	0.00	3.71	3.71	0.00	0.00
<i>Verbesina encelioides</i>	Asteraceae	Annual	92.00	23.56	64.00	92.00	53.47	53.47	14.13	25.49	34.20	43.12	25.52	2.77	16.32	14.37	13.60
<i>Xanthium spinosum</i>	Asteraceae	Perennial	36.00	0.00	64.00	54.56	12.24	12.24	0.00	14.67	1.80	2.43	5.79	0.00	3.71	0.61	0.68
<i>Xanthium strumarium</i>	Asteraceae	Annual	72.00	45.00	96.00	42.00	19.00	19.00	13.80	22.00	16.80	6.78	8.99	3.02	5.57	5.68	1.90

Note: RS-roadside; CF-crop field; FL-fallow land; GL-grazing land; RA-residential area

Impact of UV-B Radiation and Irrigation Frequency on Growth Performance and Tuber Yield of Different Sweet Potato (*Ipomea batatas* L.) Genotypes

Amsalu Gobena Roro^{1*}, Elsabet Worku², Selamawit Abera Kebede¹
and Andaragachew Gedebo Abite¹

¹ Hawassa University, College of Agriculture, School of plant and Horticultural Sciences, P.O.Box 5, Hawassa, Ethiopia

² Samara University, college of Dry Agriculture, Department of Horticulture P.O.Box 132, Semera, Ethiopia

*Corresponding author: Amsalu Gobena Roro; Email: amsalu_gobena@yahoo.com / amsalu@hu.edu.et

Abstract

Introduction: Sweet potato (*Ipomoea batatas* L.) is an important food security crop grown at different region of Ethiopia. However, its productivity is influenced by biotic and abiotic factors including Ultraviolet B (UV-B) radiation and moisture stress. . However, the level of damage varies based on the sensitivity of plants. Therefore, the present study was designed to study the impact UV-B radiation and irrigation frequency on growth performance, physiology and tuber yield of sweet potato varieties. The experiment was conducted under greenhouse conditions, at Hawassa University during January to May of the year 2016 and 2017. The experiment was laid out in complete randomized design in factorial arrangement with three replications. The experiment consisted of three different factors: 1) With and without UV-B radiation ($0.25 \text{ W m}^{-2} \text{ s}^{-1}$); 2) three irrigation intervals (daily, every three days and every seven days) and 3) two sweet potato varieties (Awassa-83 and Kulfo). The analysis of variance indicated that, vegetative growth, leaf water content, water use efficiency and tuber number per plant were significantly affected by combined effect of irrigation interval, UV-B radiation and variety. Extended moisture stress for three days with the involvement of UV-B radiation significantly reduced number of leaves by 30.5% (Awassa-83) and by 18.4% (Kulfo); leaf area by 49.4% (Awassa-83) and 53.6% (Kulfo) reduced stomata aperture by $3 \mu\text{m}$ and tuber yield by 50% as compared to daily irrigated crops and UV-B untreated varieties. Vegetative growth and yield reduction was stronger under combined effect than moisture stress alone or UV-B radiation alone. However, Kulfo variety had maximum water use efficiency ($36.26 \mu\text{mol mmol}^{-1}$) than Awassa 83 under extended moisture stress condition.

Key words: Awassa 83, Leaf water content, Stomata aperture, UV-B, Water use efficiency

Introduction

The climatic factors including solar radiation, precipitation and temperature are some of the abiotic components of the environmental factors that influences plant growth and development. Plants, due to their sessile nature, are potentially exposed to different environmental stresses including drought and Ultraviolet (UV) radiation. UV radiation is a part of non-ionizing region of the electromagnetic spectrum which comprises

approximately 8-9 % of the total solar radiation (Kovács and Keresztes, 2002). It is divided into three wavelength ranges: UV-C (200-280 nm) which is extremely harmful to organisms, but not relevant under natural conditions of solar radiation; UV-B (280-320 nm) is of particular interest because this wavelength represent only approximately 1.5 % of the total spectrum, but can induce a variety of signaling and damaging effects in plants; UV-A (320-400 nm) represents approximately 6.3 % of the incoming solar

radiation and is less hazardous parts of UV radiation (Hollósy, 2002). However, the effect varies based on the intensity, time of exposure, time of the day, angle of the sun, latitude and altitude. (Hollósy, 2002).

Under natural conditions, plants usually exposed to a number of environmental factors simultaneously, including inappropriate levels of CO₂, salinity, temperature, water, heavy metals and UV radiation (Tegelberg et al., 2008). The interaction between UV-B and other environmental factors may cause various responses in plants which can be additive, synergistic, or antagonistic (Alexieva et al., 2003). Water stress or soil drought is an important restricting factor, which always occurs in agricultural activity. Water stress, in particular, has been shown either to increase or mask the UV-B radiation effects (Nikolopoulos et al., 1995; Sullivan and Teramura, 1990). Previous report by (Feng et al., 2007) indicated that limiting the availability of soil moisture during the growth period was significantly reduced the negative effect of UV-B radiation on growth and yield of plants.

The response of plants to UV-B radiation can be altered by concurrent changes in other micro-climatic factors such as photosynthetic active radiation, nutrient status and water stress (CEN and BORNMAN, 1990; Murali and Teramura, 1985; Nogués et al., 1998). Furthermore, it has been reported that the effects of UV-B radiation are masked in the presence of nutrient deficiency or drought and the exposure of plant to UV-B might partially alleviate drought stress due to changes in epidermal anatomy or wax deposition, reduction in leaf area or increases water use efficiency through stomatal limitation to carbon assimilation (Allen et al., 1998; Laakso et al., 2000; Nogués et al., 1998). Ethiopia is located near the equator and about 50 % of the total landscape is characterized as a

mountainous region with elevation higher than 1500 m.a.s.l. (Chamberlin and Schmidt, 2013; Zeleke and Hurni, 2001). Thus, since UV-level depend on , the sun angle, altitude and latitude of the location , it is found that higher intensity of UV-B radiation is expected to reach ground surface at elevation from 1000 -2500 m.a.s.l altitude and (between 3-15°N and 33-48°E) latitude the region where more than 96% of the world sweet potato is produced (Sullivan *et al.*, 1992). Therefore, the purpose of this study was to investigate the effect of UV-B radiation and irrigation interval and compare their effect and interaction on growth, physiology, yield and adaptive mechanism of sweet potato varieties.

Materials and Methods

Description of the study area

The experimental study was conducted under greenhouse condition for two growing season of 2016 and 2017 from January to May each year at Hawassa University, Ethiopia. The site is located 7° 05' N latitude and 38° 30' E of longitudes which is 275 km far from Addis Ababa, the capital city of Ethiopia. Hawassa has an altitude of 1700 m.a.s.l. with the mean annual rainfall of 900 -1100 mm. The mean annual maximum and minimum temperature is 13 °C and 27 °C respectively. The Ultra violet- B radiation at field condition is 0.25 Wm⁻²s⁻¹ (Roro et al., 2016).

Experimental materials, treatment and design

Two sweet potato varieties (Hawassa-83 and Kulfo) were used for the experiment. The varieties were selected based on adaptability, high yield potential, diseases resistance, nutritional value and current wider distribution under farmer's production (Fekadu and Shemlis, 2017). Additionally, the description of the sweet

potato varieties used for the experiment were given in the table below (Table 1).

Table 1. Description of the sweet potato varieties used for the experiment

Variety	Adaptation area (m.a.s.l)	Days to maturity (days)	Yield (t/ha) at research field	Year of release and released by
Awassa - 83	1500-2500	150-180 days	36.6 t/ha.	AwARC of SARI in 1997/98
Kulfo	1200-2200	150 days	31.5 t/ha.	AwARC of SARI in 1995

The experiment was carried out in pots arranged in greenhouse. The experiment consisted three factors: two sweet potato varieties (Hawassa-83 and Kulfo), three level of irrigation frequency (Daily, Every three days and every seventh day interval), and two levels of UV-B radiation (with 0.25wm-2s-1 UV-B radiation and without UV-B irradiation). UV-B inflorescence tube (UVB-313, Q-Panel Co., Cleveland, OH, USA) was hanged above the top of plants (0.55 m). UV-B fluorescent tubes were wrapped with 0.13 mm thick cellulose diacetate polyester (Mylar type) transparent film to cut off the shortest wavelength below 290 nm (UV-C spectral region). The UV-B treatment was applied during the light period for five hours from 11:00 to 15:00hr. Water stress and UV-B treatments were started after the plants were well established (2weeks after planting). In order to fulfill the water requirement, the irrigation frequency were arranged as: daily irrigation of 50-200ml, every three days irrigation of 600-800ml and every seven days

irrigation of 1000-1200 ml per pot were applied depending on the field capacity. The amount of water to be added to the plant per pot to bring the soil in to field capacity was calculated using:

Amount of water to be added = Moisture content at FC-Actual moisture content) *pot depth (cm)*pot area (cm²). The treatments laid out in completely randomized design (CRD) with three replications. In each pot two cuttings of sweet potato vines each having 30 cm length and four- six nodes were planted. . The Physico - chemical properties of soil such as texture, PH and organic carbon, were measured using standard laboratory procedures at Hawassa University, college of Agriculture, plant and soil analysis laboratory . Moreover, bulk density, actual moisture content and moisture content at field capacity were determined in Melka Werer research center by taking twelve representative soil samples using soil core sampler.

Table 2 Physical and chemical properties of the experimental soil

Physical and chemical properties	Values
pH	7.6
Soil texture	Sandy loam
Bulk density (gm/cm ³)	1.018
Organic matter (OM %)	5.4
Organic carbon (OC %)	3.1
Total nitrogen (%)	0.11
Moisture content at FC (v/v %)	35.5
Soil moisture content (v/v %)	29.7

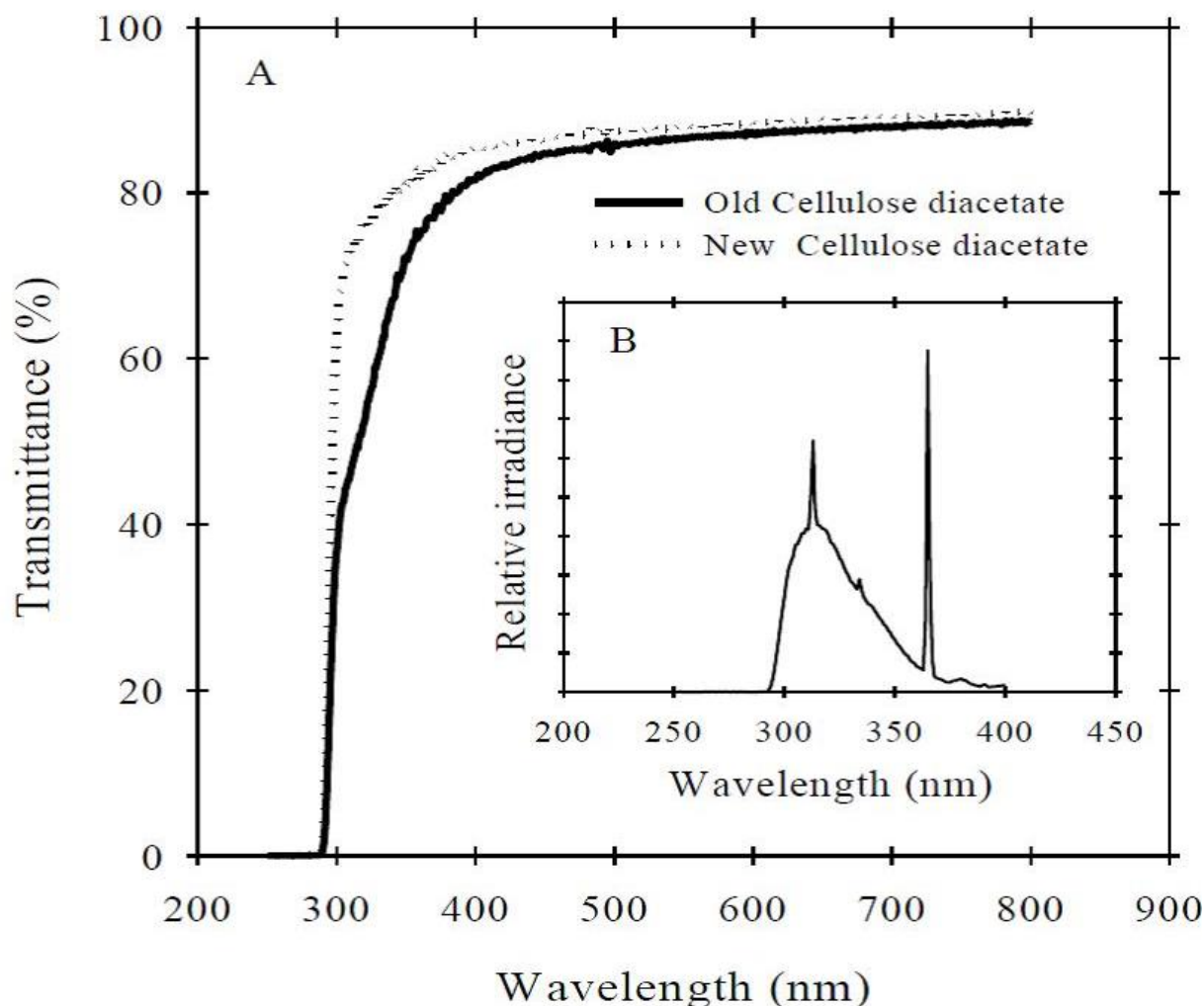


Fig 1. UV-B spectrum transmittance (%) of new (dotted line) and old (dash line) cellulose diacetate foil (A) and UV-B tube (Q-panel UV313) relative irradiance under new cellulose diacetate (B). UV treatments were delivered for 5 h centered around solar noon (11:00 - 15:00hrs). Lamps were adjusted to deliver daily exposure levels of $0.25 \text{ Wm}^{-2} \text{ s}^{-1}$.

Greenhouse Climate Condition

The daily minimum and maximum air temperatures and relative humidity for the greenhouse were recorded on randomly selected 25 days using mini data loggers (Testo 174, Version 5.0.2564.18771, Lenzkirch, Germany) (Table 3). Data logger was placed inside an open bucket to avoid direct sun and hanged close to the plant canopy (30 cm above the ground). The vapor pressure deficit of the greenhouse was

calculated based on the temperature and relative humidity recorded using VPD-Auto grow software (www.autogrow.com/wp-content/uploads/2016/03/VPD_HDCALC.xls). To full fill the light requirement of the crop, light intensity of approximately $350\text{--}400 \text{ } \mu\text{mol m}^{-2} \text{ s}^{-1}$, relative humidity at $70 \pm 5\%$ and ambient CO_2 level were maintained in greenhouse.

Table 3. Greenhouse daily climatic variables recorded during the experiment (average of 25 days) (VPD is vapor pressure deficit)

Hour	Temperature (°c)	Relative humidity (%)	VPD (KPa)
1:00 pm	36.6	22.8	4.74
2:00 pm	35.7	23.2	4.49
3:00 pm	33.5	23.4	3.96
4:00 pm	31.8	24.7	3.54
5:00 pm	27.5	30.3	2.56
6:00 pm	24.3	38.1	1.88
7:00 pm	22.9	44.0	1.56
8:00 pm	21.9	47.5	1.38
9:00 pm	21.0	49.1	1.27
10:00 pm	20.1	51.4	1.14
11:00 pm	19.3	53.6	1.04
12:00 pm	18.6	56.7	0.93
1:00 am	18.0	59.2	0.84
2:00 am	17.3	61.8	0.75
3:00 am	16.6	62.7	0.70
4:00 am	16.1	64.6	0.65
5:00 am	15.6	66.3	0.60
6:00 am	15.9	66.0	0.61
7:00 am	21.7	52.6	1.23
8:00 am	27.4	40.3	2.18
9:00 am	31.3	32.5	3.08
10:00 am	33.8	27.7	3.80
11:00 am	35.0	26.5	4.13
12:00 am	36.5	24.2	4.65

Data collection

Data like vine length, leaf number and leaf area were recorded every week interval for a total of 16 weeks. However, physiological parameters were collected at vegetative growth stage (90 days after planting) Finally, yield and yield related parameters like total tuber yield was recorded at final growth stage (150 days after planting).

Data Analysis

Data collected on growth, physiology and yield parameters were subjected to the analysis of variance (ANOVA) using the SAS (statistical software). General Linear Model in SAS software were used and mean separation was made using LSD at 5% probability level of the Statistical Analysis system(SAS), version 9, 2002).

Result and Discussion

Growth parameters

The result revealed that, all growth parameters were significantly influenced by the interaction of UV-B radiation, variety and irrigation intervals ($P \leq 0.05$). Result on (Fig 2) indicated that Hawassa-83 and Kulfo exposed to UV-B radiation for five hours without moisture stress significantly reduced rate of vine elongation by about 56.83% as compared to UV-B untreated plant (Fig 2A,2B and 2C). However, plant exposed to three days and seven days of moisture stress significantly reduced the rate of vine elongation by 29-30% and 10-12%, respectively. For both varieties vine growth rate was strongly affected by extension of irrigation from three to seven days' interval without the involvement of UV-B (Fig 1C). Data on Fig 1 D indicated that both genotypes treated with UV-B radiation and moisture stress inhibit vine length, but the reduction was

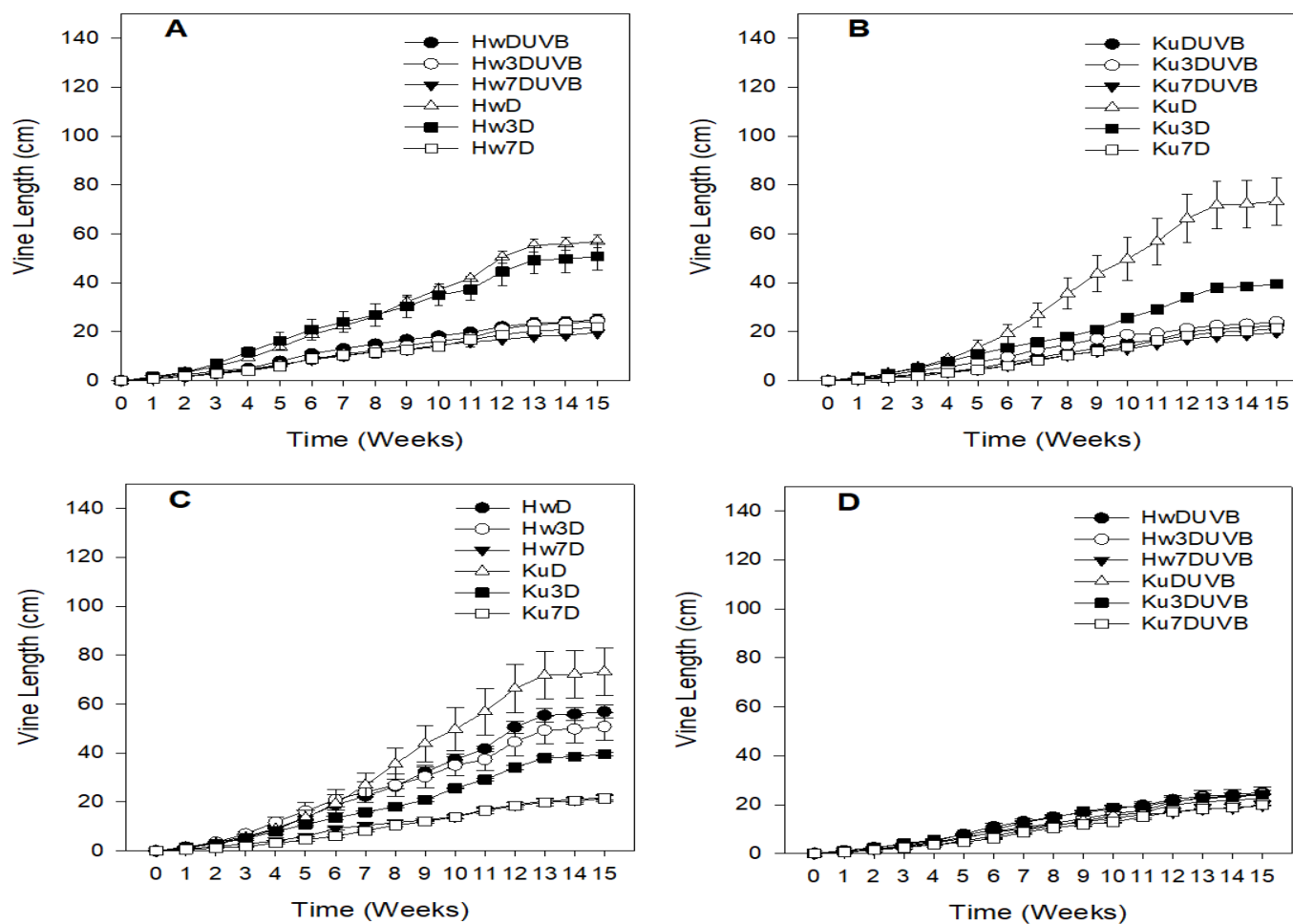


Figure 2. Impact of irrigation interval and UV-B irradiation on vine length of Hawassa-83 (A) and Kulfo (B) treated without (C) and with (D) $0.25 \text{ Wm}^{-2}\text{s}^{-1}$ UV-B radiation during the light period (11:00-15:00) under greenhouse condition. (where: HwD ,3D, 7D is Hawassa83 irrigated daily, at 3 days interval, and 7 days interval; : KuD ,3D, 7D is Kulfo irrigated daily, at 3 days interval, and 7 days interval; UVB is genotype treated with UV-B radiation)

Statistically different with in the treatments, suggesting that UV-B radiation have stronger effect in inhibiting vine length extension than effect of moisture . This might be due to moisture and UV-B radiation stress that has strong effect on growth, development and physiological performance of plants. Such reduction in growth might be related to the reduction in cell division, cell expansion and movements of stomata (Talukdar, 2013) .

Response of Leaf number, Leaf area and specific leaf area to irrigation interval and UV-B irradiation

In this study it was observed that leaf number and leaf area were significantly ($P \leq 0.05$) influenced by the interaction effects between irrigation interval, UV-B radiation and varieties. Extending the irrigation interval by three days and treating the plant with UV-B radiation for five hours significantly reduced number of leaves by 30.5% (Hawassa-83) and by 18.4% (Kulfo). Similarly, it was observed that irradiation of the varieties with UV-B for 5 hrs significantly reduced leaf area by 49.4% (Hawassa-83) and 53.6% (Kulfo) as compared to those untreated with UV-B radiation. From the result it was observed that reduction in leaf number and leaf area due to UV-B radiation was stronger on Awassa-83 than Kulfo variety. Maximum leaf area (3904 cm^2) was measured for Awassa-83 grown under daily irrigated condition without the involvement of UV-B radiation. However, with increasing the irrigation interval from daily to seven days, the expansion of leaf area did not show significant differences due to UV-B irradiation for both varieties (Table 4). Similarly, sweet potato variety irrigated daily and every three days interval significantly increased number of leaves per vine if UV-B irradiation is excluded (Table 4). The reduction in leaf number and leaf area might be related to stress induced due to UV-B

irradiation and moisture stress. Pervious study reveals that plant receiving ambient levels of solar UV-B at low , intermediate, and high latitudes can inhibit stem elongation and cause reductions in leaf area expansion in various plant species (Ballaré et al., 1996; Caldwell et al., 1998). UV-B irradiation could reduce cell expansion by changing turgor pressure or cell wall extensibility, and (Zavala and Botto, 2002) suggested that direct oxidation of indole acetic acid by UV-B irradiation reduces cell wall expansion.

Physiological parameters

The relationship between plant form and environment has played a central role in plant growth , development and physiology. The assessment of plant water status under drought conditions helped to identify genotypes that have better adaptation strategy to tolerate moisture stress at different geographic location. It was observed that irrigation of the sweet potato variety every seven days' interval gave higher leaf water content than those irrigated daily (Fig 3). Extending an irrigation interval from daily to seven days with or without the involvement of UV-B irradiation significantly increased Relative leaf water content in Kulfo than Hawassa variety (fig 3). Extending irrigation interval from daily to seven days without treating plant with UV-B irradiation, did not affect the relative leaf water content in both varieties. Relative water content of leaf was strongly sensitive to UV-B irradiation than genotypes. This suggested that genotype with higher leaf water content under moisture deficit might have potential to survive to tolerate drought. Adaptation to water deficit can be defined in relation to mechanisms that control leaf water status and cell turgor (Lambers et al., 2008). Moreover, maintenance of leaf turgor is critical to the continuance of growth and gas exchange in the face of declining water

availability(Cleland, 1971; FRANKS et al., 1995; Frensch and Hsiao, 1994). A genotype with the ability to minimize stress by maintaining turgid leaves and thick leaf epidermis in stressed environments will have

physiological advantages , this allows turgor dependent processes such as growth and stomatal activity, and to protect and maintain the photo system complex from damage(Lafitte, 2002).

Table 4 Impact of UVB irradiance (11:00-15:00), irrigation interval and their interaction on some growth parameter of sweet potato varieties grown under green house (n=3)

<i>Irrigation interval</i>	<i>UV</i>	<i>Variety</i>	<i>No of leaf</i>	<i>Leaf Area (cm²)</i>
Daily	+UV	Awassa -83	74.67 ^{cd}	1242 ^c
	-UV	Awassa -83	117.07 ^a	3904 ^a
	+UV	Kulfo	66.07 ^{def}	600 ^f
	-UV	Kulfo	109.47 ^{ab}	905 ^d
Three days	+UV	Awassa -83	71.87 ^{cde}	1201 ^c
	-UV	Awassa -83	103.40 ^b	2373 ^b
	+UV	Kulfo	65.40 ^{def}	339 ^e
	-UV	Kulfo	80.13 ^c	730 ^{ef}
Seven days	+UV	Awassa -83	62.93 ^{ef}	824 ^{de}
	-UV	Awassa -83	67.47 ^{def}	918 ^d
	+UV	Kulfo	58.53 ^f	218 ^g
	-UV	Kulfo	62.47 ^{ef}	255 ^g
P-Value		UV	<.001	<.001
		Var	<.001	<.001
		Irrign	<.001	<.001
		UV *Var	0.047	<.001
		UV* Irrign	<.001	<.001
		Var *Irrign	0.013	<.001

Means in the same column followed by the same letters are not significantly different at 5% level of significance

Physiological parameters

The relationship between plant form and environment has played a central role in plant growth , development and physiology. The assessment of plant water status under drought conditions helped to identify genotypes that have better adaptation strategy to tolerate moisture stress at different geographic location. It was observed that irrigation of the sweet potato variety every seven days' interval gave higher leaf water content than those irrigated daily (Fig 3). Extending an irrigation interval from daily to seven days with or without the involvement of UV-B irradiation significantly increased Relative leaf water content in Kulfo than Hawassa variety (fig 3). Extending irrigation interval from daily to seven days without treating plant with UV-B irradiation, did not affect the relative leaf water content in both varieties. Relative water content of leaf was strongly sensitive to UV-B irradiation than

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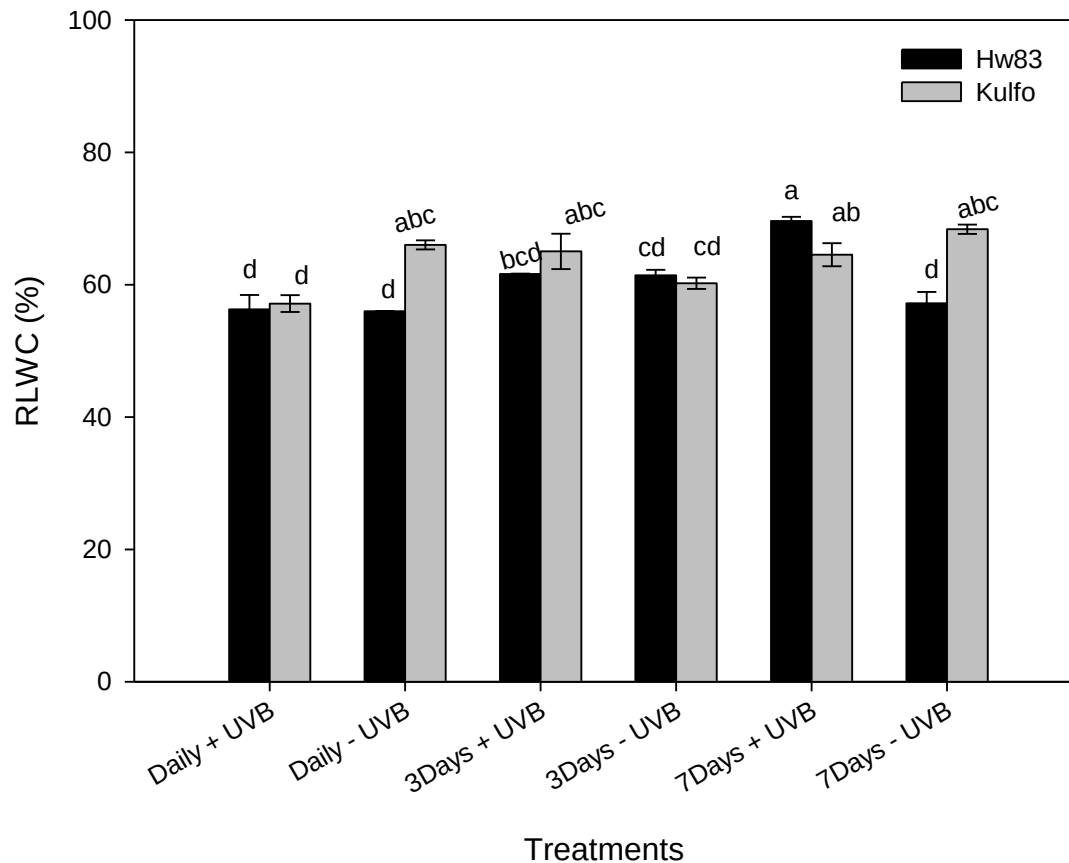


Fig 3. Relative Leaf water content(RLWC) of sweet potato varieties as affected by UV- B radiation and irrigation interval under greenhouse condition.(Bars with the same letter are not significant)

Exposing of Awassa-83 and Kulfo variety to UV-B radiation for 5 hrs. during the light period significantly reduced transpiration rate by 15.3 to 17.34 $\text{mmol m}^{-2} \text{s}^{-1}$ and 3 to 4 $\text{mmol m}^{-2} \text{s}^{-1}$ when each irrigation interval is combined with UV-B irradiation, respectively. Suggesting that Hawassa 83 is more sensitive to down regulate transpiration rate based on moisture level than Kulfo where UV-B irradiation is maximum.

Stomatal conductance is the measure of the rate of passage of carbon dioxide (CO_2) entering, or water vapor exiting through the stomata of a leaf. However, the rate of gas exchange can also be affected by the growth condition of the plant and genetic makeup of the plant. Previous report indicated that ,the response of stomata to environmental varies with leaf irradiance, leaf temperature, atmospheric water vapor pressure deficit and

CO_2 concentration(Buckley and Mott, 2002)(Cowan, 1982)(Yoo et al., 2009). In this study two sweet potato varieties were subjected to different moisture stress level and UV-B radiation in order to evaluate the gas exchange of each variety. From the result (Table 5) it was observed that, Awassa-83 irrigated daily and grown without UV-B irradiation treatment had the maximum stomata conductance than the rest of the treatments. Irradiation of Awassa-83 and Kulfo with UV-B radiation for 5 hrs during the light period significantly ($P \leq 0.05$) reduced stomata conductance of both genotypes and the effect was stronger when UV-B irradiation applied under extended moisture deficit condition. However, strong reduction in stomata conductance was observed in Hawassa 83 under UV-B irradiation than Kulfo (Table 5).

Table 5. Impact of UV-B irradiation during the light period (11:00-15:00), irrigation interval and their interaction on physiological parameters of sweet potato varieties grown under green house, (n=3)

Irrigation interval	UV	Variety	Transpiration rate (mmol m ⁻² s ⁻¹)	Stomata conductance (mmolm ⁻² s ⁻¹)
Daily	+UV	Awassa -83	9.67 ^{cd}	83 ^{ef}
	-UV	Awassa -83	24.97 ^a	187 ^a
Three days	+UV	Kulfo	7.70 ^e	153 ^{bc}
	-UV	Kulfo	12.16 ^b	166 ^b
	+UV	Awassa -83	8.88 ^{de}	93 ^e
	-UV	Awassa -83	9.58 ^{cd}	133 ^{cd}
	+UV	Kulfo	9.22 ^{de}	131 ^d
	-UV	Kulfo	11.09 ^{bc}	163 ^b
Seven days	+UV	Awassa -83	7.63 ^e	72 ^{fg}
	-UV	Awassa -83	11.55 ^b	86 ^{ef}
	+UV	Kulfo	8.02 ^{de}	66 ^{fg}
	-UV	Kulfo	7.64 ^e	60 ^g
P-Value		UV	<.001	<.001
		Var	<.001	<.001
		Irrign	<.001	<.001
		UV *Var	<.001	<.001
		UV* Irrign	<.001	<.001
		Var *Irrign	<.001	<.001
		var * Irrign * UV	<.001	<.001

Means in the same column followed by the same letters are not significantly different at 5% level of significance

Similarly, it was observed that the combination of UV-B irradiation and irrigation interval significantly influenced the rate of photosynthesis (Table 6). Although the exclusion of UV-B irradiation enhanced maximum photosynthesis rate under optimum irrigation frequency, exposing plant to three days and seven days significantly reduced photosynthesis by 0.61 $\mu\text{mol m}^{-2} \text{s}^{-1}$ and 1.64 $\mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. However, combining moisture stress with UV-B irradiation did not show significant influence on the rate of photosynthesis (Table 6). Such

reduction might be related to the lower efficiency of photo system II and photo system I due to UV-B irradiation induced loss of integrity of the thylakoids membranes, DNA damage, lower carbon dioxide fixation and oxygen evolution (Kataria et al., 2014). Similarly, the effect might be related to the negative effect UV-B radiation on morphological parameters and the reduction in leaf area and photosynthetic area (Dai et al., 1992)(Zhao et al., 2003).

Table 6. Impact of UV-B irradiance (11:00-15:00), irrigation interval (Irrign) and their interaction on photosynthesis rate of sweet potato varieties (Var) grown under green house (n=3)

Irrigation interval	UV-B	Photosynthesis rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Daily	+UV-B	2.68 ^{cd}
	- UV-B	3.91 ^a
Three days	+UV-B	2.71 ^c
	- UV-B	3.30 ^b
Seven days	+UV-B	2.40 ^{de}
	- UV-B	2.27 ^e
<i>P-value</i>	UV	<.001
	Var	0.038
	Irrign	<.001
	UV *Var	0.056
	UV* Irrign	<.001
	Var *Irrign	0.021
	var * Irrign * UV	0.339

Means in the same column followed by the same letters are not significantly different at 5% level of significance.

Many studies have indicated that mild drought has no obvious impact on plant growth and photosynthesis, even stimulation to a certain degree, but severe drought can lead to dramatic reductions (Chaves et al., 2009; Fereres and Soriano, 2007; Xu and Zhou, 2006). In this study it was observed that under optimum irrigation interval the rate of photosynthesis in both genotype was not significantly different, however, extending irrigation interval from daily to seven days interval strongly reduced photosynthesis rate in Hawassa 83 variety than Kulfo (Table 7). Kulfo genotype has potential to tolerate moisture stress for three days, but extending moisture stress up to seven days significantly

reduce the rate of photosynthesis by 1.09 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (Table 7). This result is in agreement with the work of (Kaewsuksaeng, 2011) who reported that photosynthetic rate declined linearly on different sweet potato varieties under reduced soil moisture conditions. It was suggested that stomatal closure is a key limitation for the drop in photosynthesis. Most experimental results have shown that the net photosynthetic rate (A), stomatal conductance (g_s), and mesophyll conductance (g_m) generally decrease with decreasing water availability, and an obvious reduction in photosynthesis occurs due to severe water deficit (Xu and Zhou, 2011).

Table 7. Impact of irrigation interval on photosynthesis rate of sweet potato varieties grown under greenhouse condition (n=3)

Irrigation interval	Varieties	Photosynthesis rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$)
Daily	Awassa-83	3.21 ^a
	Kulfo	3.37 ^a
Every Three day	Awassa-83	2.85 ^b
	Kulfo	3.16 ^a
Every Seven day	Awassa-83	2.38 ^c
	Kulfo	2.28 ^c
<i>P-value</i>	UV	<.001
	Var	0.038
	Irrign	<.001
	UV *Var	0.056
	UV* Irrign	<.001
	Var *Irrign	0.021
	var * Irrign * UV	0.339

Means in the same column followed by the same letters are not significantly different at 5% level of significance.

Water use efficiency (WUE) is one of an important physiological parameters that help to know the potential of the crop to withstand the moisture stress condition of the surrounding and help to regulate the irrigation frequency of agricultural crops. The scarcity of water resources is leading to limitation in productivity of the crop, but such problem can be alleviated by increasing crop water use efficiency, so that improving WUE of crops is becoming a main goal for agriculture and food security (Deng et al., 2006)(Medrano et al., 2015). In this study we investigated that the intrinsic water use efficiency of sweet potato varieties was significantly influenced ($P \leq 0.05$) due to the interaction between irrigation interval and UV-B radiation. Result on (Fig 4) indicate that Kulfo variety exposed to seven days of moisture stress had maximum intrinsic water use efficiency

($36.26 \mu\text{mol mmol}^{-1}$) as compared to other treatments with and without the involvement of UV-B radiation. Previous report indicated that genetic variability in WUE_i at different levels were associated with growth condition and the complexity of light interception, night transpiration, and respiratory losses (Medrano et al., 2015). According to (Hofmann et al., 2003) report, drought and UV-B radiation interacted synergistically resulting in a substantial increase of UV-B radiation-absorbing compounds, including phenolic (flavonols and glyco-sides), in drought-stressed plants. It was also reported that the combination of UV-B and water stress resulted in significantly increased WUE_i in different cultivars (Hofmann et al., 2003).

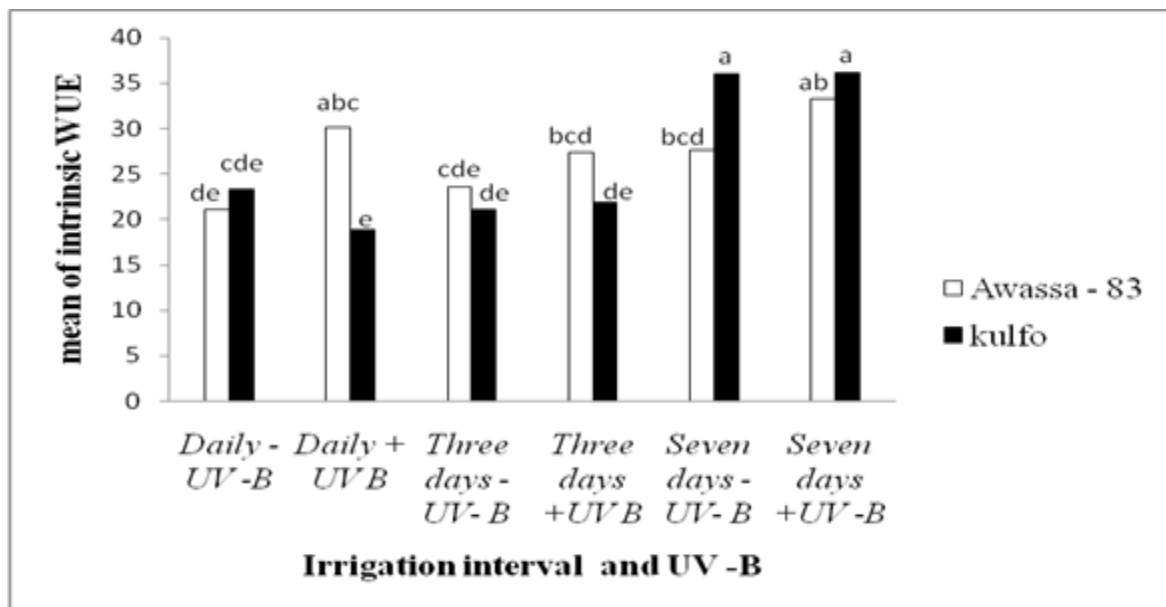


Fig 4. Effect of UV-B, irrigation interval and their interval on intrinsic water use efficiency of sweet potato varieties (Bars with the same letter are not significant different).

The analysis of variance revealed that the interaction between irrigation interval, UV-B radiation and variety did not significantly ($P > 0.05$) affect stomata number and stomata aperture on each sweet potato varieties.

However, stomata number and stomata aperture were significantly ($P \leq 0.05$) responded to the main factors like UV-B radiation and irrigation intervals.

Previous report indicated that Photosynthetic rate and productivity in many plant species can be reduced based on the dynamics of stomata movement and exposure time to UV-B irradiation. (Teramura and Ziska, 2006). Although, it is not clear whether changes in stomatal function play a major role in the UV-B-induced inhibition of photosynthesis, report indicated that exposure to UV-B radiation can modify the speed of stomatal opening and closing and reduce the rate of leaf transpiration (Day and Vogelmann, 1995; Middleton and Teramura, 1993; NEGASH, 1987). However, the response varies based on

the genotype and growth condition. In this study it was observed that, Hawassa 83 grown without UV-B irradiation gave the widest stomata opening (22.45 μ m) as compared to kulfo variety (Fig 6). (Nogués et al., 1999) suggest that High-UV-B irradiances affect stomata directly, by acting on the guard cell aperture control mechanisms. Similar finding by (Dai et al., 1992) also indicated that, exposure of rice varieties (*Oryza sativa* L.) to UV- B reduced both stomata number on the adaxial surface of leaf and on stomatal opening due to extended exposure UV- B.

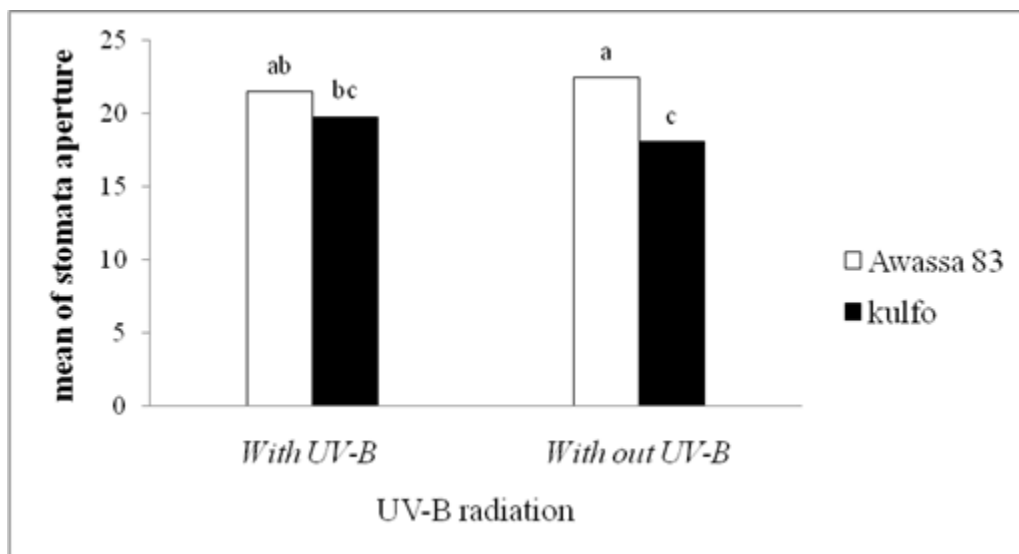


Fig 6. Stomata width as affected by UV-B radiation and variety (Bars with the same letter are not significant different)

Extended moisture stress up to seven day reduced the number of stomata by 2 per mm² leaf area as compared to regularly irrigated sweet potato plant. Such stomata reduction in number might be related to a reduction on the size of leaves due to moisture stress. As (Jagmail et al., 1990) illustrated as water deficit reduce the amount of stomata /mm² reducing leaf size and to temperature stress, by increasing stomatal number. The opening and closing of stomata is driven by a number of external environmental and internal signaling cues (Araújo et al., 2011) and significant variation in sensitivity and

responsiveness is known to exist among different species (Lawson, 2009; Lawson and Blatt, 2014). Similarly, plant stressed for seven days significantly ($P \leq 0.05$) reduced the stomata opening by 3 μ m as compared to daily irrigated crops (Figure 6). The result is in line with the result of (Jagmail et al., 1990) even if there were no variation in stomata width due to treatments but the variation comes from water deficit because it reduce leaf size and to temperature stress, by increasing stomata number (Reynolds-Henne et al., 2010).

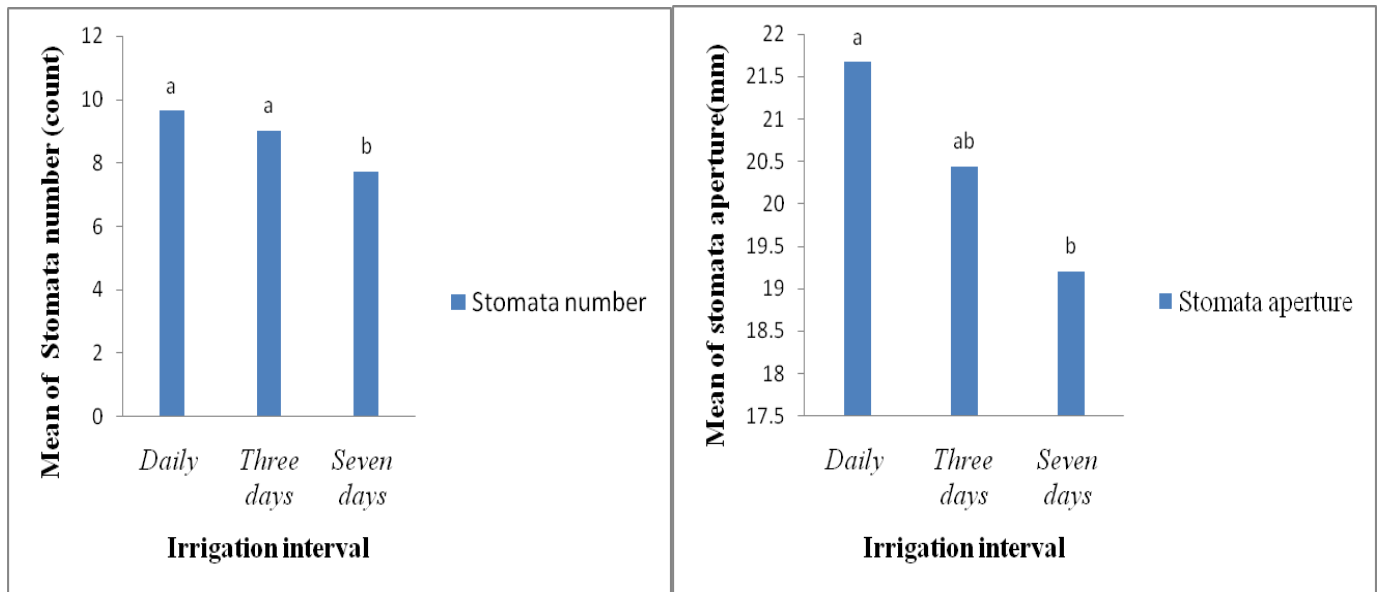


Fig 7. Stomata and aperture as affected by irrigation interval (Bar with the same letter are not statistically different)

UV-B irradiation and Moisture stress on tuber number and yield of sweet potato

At Field condition abiotic factors like soil moisture, soil and air temperature, nitrogen fertilizer and UV-B irradiation determined sweet potato yield (CHEN et al., 2020). It was observed that moisture stress combined with UV-B irradiation for 5hrs significantly influenced the number of tuber, tuber fresh weight, tuber dry weight of sweet potato varieties. Extension of moisture stress to seven days in both varieties resulted in significant reduction of tuber number by 50% as compared to daily irrigation in both crops. However, UV-B radiation had stronger reduction effect on the number of tubers per plant than the effect of irrigation and varieties. Maximum numbers of tuber were found on Awassa-83 (5.133) when irrigated daily without the involvement of UV-B radiation for 5hrs during the light period (Fig 8). The difference in number of tubers per

plant might be due to the effect of UV-B radiation that affect growth and yield through limiting the accumulation and translocation of assimilate. As previous report indicated that during the reproductive phase, leaves, stems, and other vegetative parts of the plant compete for assimilate and also influences the redistribution of assimilate within the plant organs. Moreover, it was indicated that plant exposed to UV-B decreased plant height, leaf area and dry weight, but increased axillary branching and leaf curling in spinach (Zegada-Lizarazu et al., 2012). The responses of plants to changes in UV-B also depend upon concomitant stresses, such as low and high levels of photosynthetic active radiation, temperature extremes, pollutants, metal toxicity, drought and nutrient limitation (Baud and Beck, 2005). Reduction in growth and yield due to UV-B radiation and other environmental stress on plants can be additive, synergistic or antagonistic effect (Bais et al., 2018). However, the effects of UV-B depend largely on the dose supplied and on other environmental variables encountered, such as the quality and quantity

of visible and UV light and availability of nutrients (Zhao et al., 2003). This is therefore such variation in our test plant might be due to capacity difference of varieties in response to stress factors. Therefore, result of the current study is in line with the finding of (Kakani et al., 2003) who reported that, the storage root number was significantly affected by UV-B but not the storage root weight.

Similarly, the reduction in tuber yield is directly related with the degradation of photosynthetic pigment and lower photosynthetic efficiency (Kataria et al., 2014). Moreover, stress due to moisture and sensitivity of genotypes to environmental stress attributed reduction the yield and total tuber produced per plant (Yooyongwech et al., 2013).

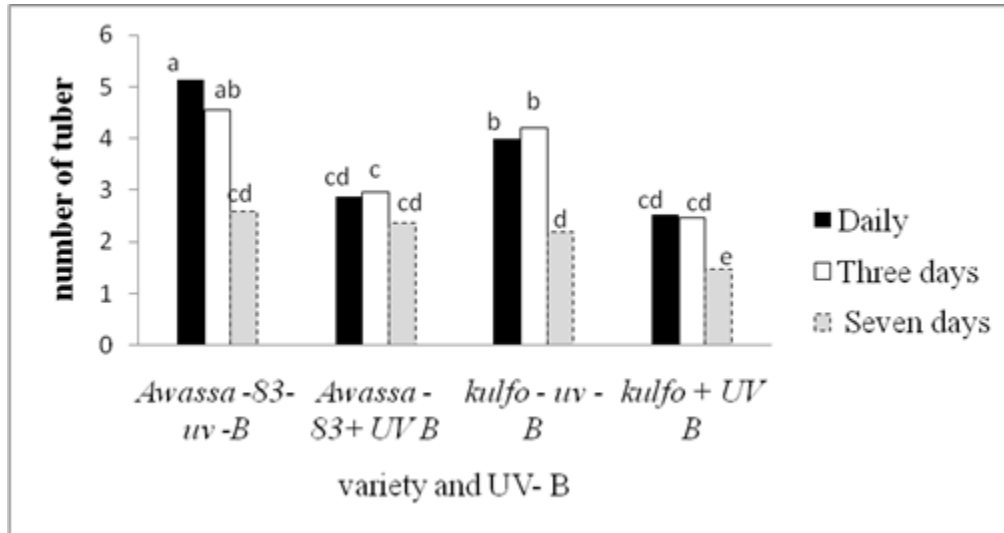


Fig. 8 Effect of UV-B and irrigation on number of tuber of sweet potato varieties (bars with the same lettering are not significantly different)

The analysis of variance indicated that UV-B radiation and variety had stronger effect on Fresh and dry weight of tuber (Table 8).

Irradiation of Awassa-83 and kulfo with $0.25 \text{ Wm}^{-2} \text{ S}^{-1}$ UV-B radiation for five hours during the light period (11:00-15:00hrs) significantly reduced tuber fresh weight dry weight of tuber, fresh weight and dry weight of total biomass under daily and three days of irrigation interval. Although an extension of moisture stress for seven days strongly reduced tuber fresh weight in both varieties as compared to control, there was no significant difference between UV-B treated and UV-B untreated varieties (Table 9). In both varieties it was observed that, moisture unstressed varieties were more sensitive to reduce tuber

fresh weight due to UV-B radiation and such reduction in tuber fresh weight reduced with increasing moisture stress.

In both varieties it was observed that, moisture stressed varieties were more sensitive to reduce tuber dry weight due to UV-B radiation and such reduction in tuber dry weight increased with increasing moisture stress (Table 9). The current result is supported by the result of (Kataria et al., 2014) who reported that direct effects of enhanced UV-B radiation on photosynthesis was the major cause for the reduction of dry weight per genotypes. Similarly report by (Feng et al., 2007) also indicated that, the economical yield was inhibited due to the effect of enhanced UV-B radiation and water stress.

Table 8 Impact of UV-B radiation applied during the light period (11:00-15:00), irrigation interval and variety on yield and yield related parameters, of sweet potato varieties grown in green house. (n=3)

<i>Irrigation interval</i>	<i>UV</i>	<i>Variety</i>	<i>Tuber fresh weight (gm)</i>	<i>Tuber dry weight (gm)</i>
Daily	+UV	Awassa -83	212.5c	60.26 ^c
	-UV	Awassa -83	292.4 a	105.04 ^a
	+UV	Kulfo	96.4 fg	27.61 ^g
	-UV	Kulfo	117.7e	37.03 ^{ef}
Three days	+UV	Awassa -83	203.7c	56.56 ^{cd}
	-UV	Awassa -83	270.9b	89.55 ^b
	+UV	Kulfo	85.5g	23.23 ^{gh}
	-UV	Kulfo	102.7f	30.64 ^{fg}
Seven days	+UV	Awassa -83	126.1de	42.42 ^e
	-UV	Awassa -83	137.4d	52.18 ^d
	+UV	Kulfo	53.9h	17.51 ^h
	-UV	Kulfo	63.2h	24.58 ^{gh}
P-Value		UV	<.001	<.001
		Var	<.001	<.001
		Irrign	<.001	<.001
		UV *Var	<.001	<.001
		UV* Irrign	<.001	<.001
		Var *Irrign	<.001	<.001
		var * Irrign * UV	<.001	<.001

Means in the same column followed by the same letters are not significantly different at 5% level of significance

Similarly, total biomass yield of the sweet potato varieties (Awassa-83 and kulfo) grown under daily irrigation interval increased by 61% and 73% due to exclusion of UV-B from the growth area. Further increase in irrigation interval to three days reduced total biomass yield by 37% (Awassa-83) and 23.65 % (kulfo) under the involvement of UV-B. Extended irrigation interval to seven days did not affect biomass yield of kulfo but 15%

reduction was observed for Awassa-83 grown with the involvement of UV-B (Figure 8).

The current result is in line with the work of (Feng et al., 2007) who reported that enhancing UV-B irradiation or drought stress could decrease the net photosynthetic capacity through different paths, and led to the reduction of root, stem and leaves biomass and yield, as well as changed biomass and the harvest index.

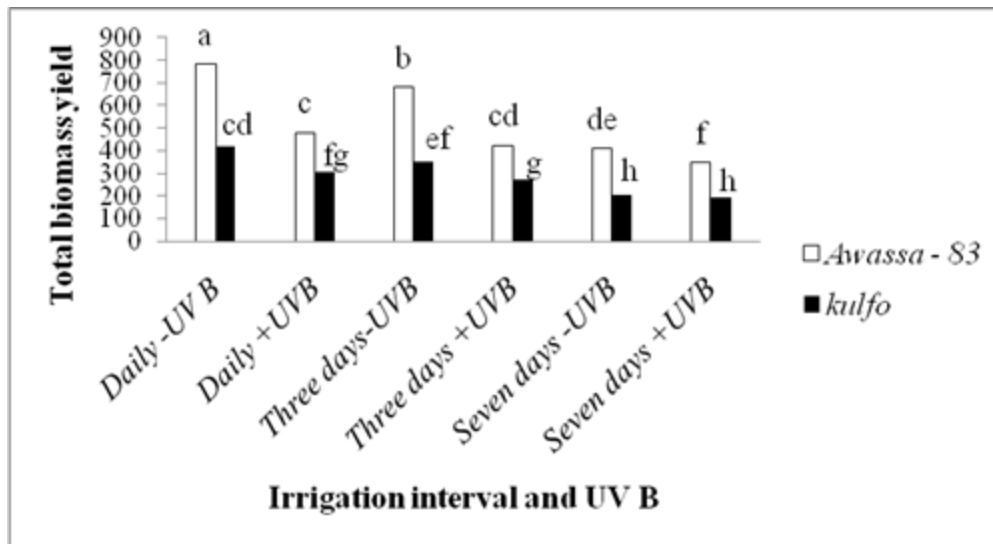


Fig 9. Total biomass yield as affected by the interaction effect of UV-B irradiance, Irrigation interval and varieties (Bars with the same letter are not significantly different)

Conclusions

This study was proposed to investigate the effect of UV-B radiation and irrigation frequency on growth performance and yield of sweet potato (*Ipomoea batatas* L.) Varieties, at Hawassa, SNNPR, Ethiopia under greenhouse condition. Extended irrigation interval in combination with UV-B irradiation slow down the rate of elongation in sweet potato vine length, but the reduction in rate of elongation was more stronger with daily irrigate variety than those irrigated every three or seven days. Exposure of sweet potato variety to UV-B radiation for five hours during the light period significantly reduces leaf area by limiting leaf emergency rate. Such reduction in leaf area and rate of leaf emergency was stronger under extended irrigation interval than daily irrigated variety.

The assessment of plant water status under drought conditions is essential for the understanding of the physiological adaptation mechanisms of plants, because water stress is one of the most common limitations of crop growth and yield. In this study it was observed that sweet potato variety subjected

to seven days of moisture stress and treated with UV-B radiation for five hours contain more leaf water content than plant regularly irrigated. From the result it was observed that Awassa-83 has higher leaf water content than Kulfo variety. The increase in leaf water content under UV-B radiation stress condition could be interpreted as an increased plant protection from UV damage and reduction of water loss in the continuing drought treatment. An increase in water use efficiency in kulfo might be due to an increase in intensity of moisture stress and reduction in stomata number and stomata aperture. Moreover, plant with more Leaf water content and intrinsic water use efficiency was due to reduction in transpiration rate, Stomata conductance and reduction in stomata aperture size under extended moisture stress and UV-B irradiation. Extension of moisture stress to seven days with involvement UV-B leads to 50% reduction in tuber number per plant as compared to daily irrigation in both sweet potatoes grown without the involvement of UV-B. However, UV-B radiation had stronger effect on reduction of tuber numbers than the effect of irrigation and cultivars. Finally, it

was observed that Awassa-83 and Kulfo variety significantly responded to environmental factors in terms of growth, physiology and yield. In conclusion, further studies including different sweet potato varieties, irrigation frequencies accompanied with economic analysis at field condition is suggested to give reliable recommendation and ascertain the result for sweet potato growers and other stakeholders.

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Optimizing Rates of Blended Fertilizer for High Yield and Agronomic Use Efficiency of Tef (*Eragrostis tef* (Zucc.) Trotter) at Central Ethiopia

¹Almaz Meseret Gezahegn*, ¹Gebrekidan Feleke,
¹Bizuwork Tafes, ¹Sisay Eshetu, ¹Solomon Chanyalew,
²Zerihun Tadele, and ³Dominik Klauser

¹Ethiopian Institute of Agricultural Research, Debre Zeit Agricultural Research Center, P.O. Box 32, Debre Zeit, Ethiopia; ²University of Bern, Institute of Plant Sciences, Altenbergrain 21, CH-3013 Bern, Switzerland; ³Syngenta Foundation for Sustainable Agriculture, Basel, Switzerland

Abstract

An experiment was conducted during two consecutive cropping seasons to optimize rates of blended fertilizer for high yield and N use efficiency of tef varieties at Chefe Donsa and Alem Tena. The treatments consisted of a factorial combination of two tef varieties (recently released for the areas) and five fertilizer rates (0, 100 kg ha⁻¹ Diammonium Phosphate (DAP), 50 kg ha⁻¹, 100 and 150 kg ha⁻¹ NPSB. Varieties, such as Dagim and Tesfa were used for Chefe Donsa, whereas Boset and Tsedey were used for Alem Tena. The treatments were arranged following randomized complete block design in triplicate. The result showed that phenology, growth and yield parameters were highly significantly ($P < 0.01$) influenced by the main effect of blended fertilizer rates. Higher grain yield was obtained from application of 150 kg NPSB ha⁻¹ fertilizer rate at both locations, but was not significantly different from the application of NPSB at rates of 100 kg ha⁻¹ at Chefe Donsa, and from 100 kg ha⁻¹ NPSB and 100 kg ha⁻¹ DAP at Alem Tena. Economic analysis showed that application of 100 kg ha⁻¹ NPSB gave the highest net benefit and acceptable marginal rate of return (MRR). Therefore, application of 100 kg NPSB ha⁻¹ fertilizer could be recommended for production of tef in the study areas and other areas with similar agro-ecological and soil conditions.

Keywords: Fertilizer, net benefit, tef, variety, yield

Introduction

Tef is one of the most significant and dominant staple grain crops in Ethiopia (*Eragrostis tef* (Zucc.) Trotter). Tef is gaining popularity around the world as a lifestyle crop since it has great nutritional benefits and is gluten-free (Spaenij-Dekking et al. 2005). Subsistence farmers exclusively grow the crop under rain fed condition. Tef ranks first in terms

of both production and consumption and second in terms of cultivated area next to maize with 17.22% of the production of cereal crops (CSA, 2021).

Tef production is growing year after year and the crop is important to the country's food, agriculture, and trade sectors. However, productivity is low compared to other cereals with a national average grain yield of 1.9 t ha⁻¹

¹ (CSA, 2022). Poor agronomic practices and low soil fertility are the most significant yield-limiting factors (Mihretie et al., 2021).. The main reason of the low soil fertility status in different parts of the country is the recurrent cultivation of the same crop on a particular targeted area of land and imbalance application of fertilizers. Nitrogen (N) and phosphorus (P) fertilizers are the common fertilizers applied by smallholder farmers growing tef in Central Ethiopia. Nevertheless, continuous application of N and P fertilizers without adequate consideration of other nutrients may have resulted in deficits of other macro and micronutrients and induced and soil deterioration (Stoorvogel et al. 1993; Bindraban et al. 2012). Studies showed that not only N and P fertilizers, but also sulfur (S) boron (B) and zinc (Zn) deficiencies are widespread in Ethiopian soils (EthioSIS, 2013) and also limiting nutrients for tef production (Habtegebrial and Singh, 2006; Bereket et al., 2011).

One way to alleviate such production constraints is to use blended fertilizers that contain both macro- and micronutrients. Even though tef farmers in Ethiopia, particularly in the study areas, have limited knowledge about the effects of blended fertilizers and their rates aside from just urea and di-ammonium phosphate (DAP), blended nutrient content of the fertilizer (NPSB) can supply the nutrients that the crop required,

consequently improve the productivity of the crops. In addition, there is limited information regarding the performance of different tef varieties at different rates of blended fertilizer (NPSB) in the study area as described in EthioSIS (2013). Thus, it is necessary to identify the source of nutrient and optimize blended fertilizer (NPSB) rates in order to boost tef production and productivity. The application of essential plant nutrients in optimum quantity and right proportion, through correct method and time of application, is the key to increased and sustained crop production. Therefore, the study was aimed at optimizing rates of blended fertilizer (NPSB) for high yield and agronomic use efficiency of tef varieties.

Materials and Methods

Site description

The field experiments were conducted during 2018 and 2019 cropping season at Alem Tena and Chefe Donsa, East Shewa Zone of the Oromia Region. Tef is the dominant crop in both locations. Alem Tena is located at a latitude of 8.30°N and longitude of 38.95°E with an elevation of 1,611 meters. The weather data regarding average min and max temperature (°C) and rainfall (mm) during 2018 and 2019 cropping season is presented in Figure 1. While, Chefe Donsa is located at a latitude of 08.85° N and longitude of 39.12° E and at 2040 meter a.s.l. The weather data regarding

average min and max temperature ($^{\circ}\text{C}$) and rainfall (mm) during 2018 and 2019 cropping season is presented in

Figure 2. The soil type is Andisol in Alem Tena, whereas, it is Vertisol in Chefe Donsa.

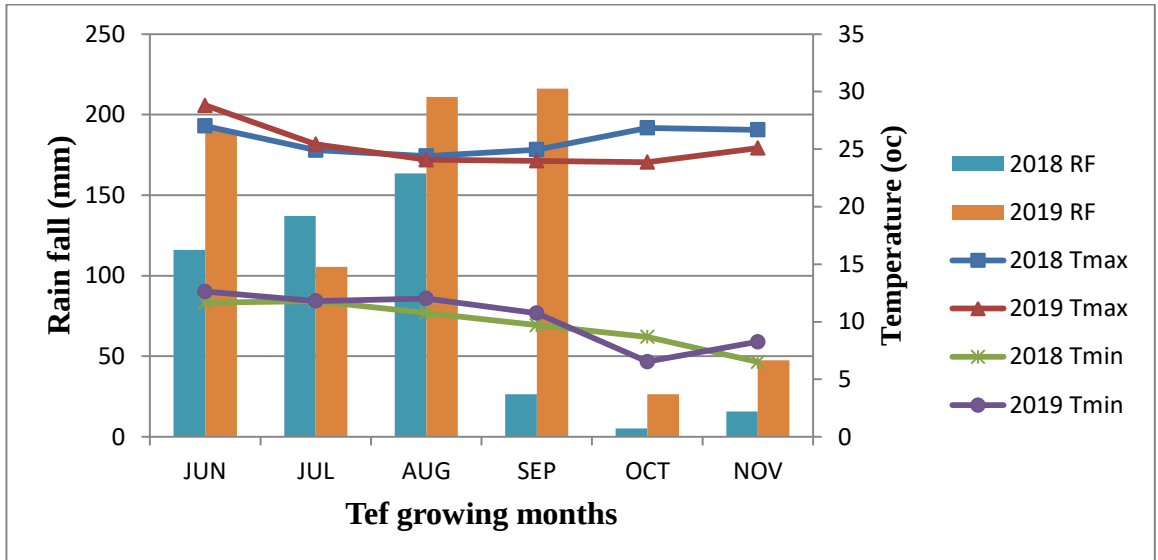


Fig. 2. Average min and max temperature ($^{\circ}\text{C}$) and total rainfall (mm) of Alem Tena during the cropping season of tef from June to November in 2018 and 2019

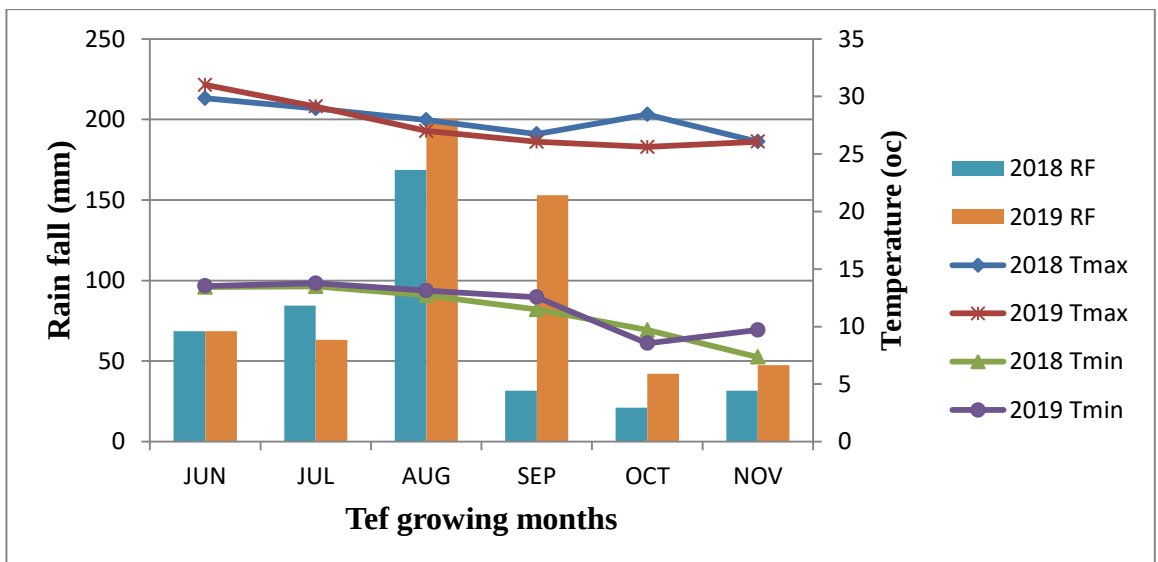


Fig. 2. Average min and max temperature ($^{\circ}\text{C}$) and total rainfall (mm) of Chefe Donsa during the cropping season of tef from June to November in 2018 and 2019

The soil samples from 0–30 cm depth from ten spots across the experimental field were collected, composited and analysed for determining selected soil physicochemical properties at Alem

Tena and Chefe Donsa following standard procedure. Values for the selected physicochemical properties of both locations are presented in Table 1.

Table 1: Soil physio-chemical properties analysis (0-30 cm depth) of the experimental site

Soil physio-chemical properties	Alem Tena		Chefe Donsa	
	2018	2019	2018	2019
pH	7.3	6.99	8.02	7.4
Total N (%)	0.1	0.07	0.08	0.05
Avalable P (cmol	8.09	12.57	13.57	14.0
Avalable K	0.89	0.87	0.88	0.89
CEC [Cmol(+) kg ⁻¹ soil]	19.92	19.54	50.88	49.0
OM%	1.34	1.65	0.94	1.08
Texture	Loam	Loam	Clay	Clay

Experimental design, treatments and crop management

The treatments consisted of a factorial combination of two tef varieties (recently released for the areas) and five fertilizer rates (0, 100 kg/ha Diammonium Phosphate (DAP) (18 % N and 46 % P₂O₅), 50 kg/ha, 100 and 150 kg ha⁻¹ NPSB (18.9% N+37.7% P₂O₅ + 6.95% S+0.1% B) (ATA, 2016)). Varieties, such as Dagim and Tesfa were used for Chefe Donsa, whereas Boset and Tsedey used for Alem Tena. The treatments were arranged following randomized complete block design (RCBD) in triplicate. Except for the control treatment, 50 kg/ha N in the form of Urea were applied to all treatments. Plot size of 4 m x 4 m was used. The spacing between replication and plots were 1 m and 0.5 m, respectively.

Tef grain was drilled into the row at the recommended rate of 15 kg per

hectare. Full doses of DAP and NPSB were applied at planting, while urea was applied at tillering via side dressing. No insect outbreaks or disease incidences occurred in this study. Other agronomic practices were maintained consistently across all treatments. At physiological maturity, when the vegetative parts became yellow, the crop was manually harvested.

Data Collection and measurements

When the plant reached maturity, the height was measured from the ground's surface to the tip of the panicle. The length of the panicle was measured from the node, where the first panicle branch began, to the tip. By counting the number of new plants growing from the main stem, the number of tillers per plant was determined. Ten randomly selected plants provided the samples for the aforementioned parameters. By

weighing the entire crop, including the grains, from each net plot area, above-ground biomass was calculated. By deducting the grain yield per net plot from the total above-ground biomass, straw yield was calculated. Grain yield (kg ha^{-1}) was measured after threshing and separating grains from straw from each net plot. Harvest index was calculated using the ratio of grain yield to above ground biomass.

Agronomic efficiency

Agronomic efficiency was calculated according to Ladha et al. (2005).

Agronomic efficiency of N (AE) = $(Y_F - Y_0)/F_N$

Where Y_F and Y_0 are the grain yields (kilograms dry matter per hectare) in the fertilized and unfertilized treatments, respectively, and F_N is the fertilizer N application rate (kilograms N per hectare).

Economic analysis

Partial budget analysis and marginal rate of return were used in accordance with CIMMYT (1988) guidelines to examine the economic viability of various fertilizer sources and rates. To account for the difference between the experimental output and the anticipated production of farmers from the same treatment, the average yield of grains and straw was reduced by 10%. Straw cost (8 Birr/kg) and the mean market price of tef grain (50 Birr/kg) were used. The costs of fertilizer (1786 ETB/qr) NPSZnB and DAP also were included to determine the variable costs.

Statistical Analysis

The data were subjected to combined analysis of variance (ANOVA) over years after confirmation of homogeneity of error variance using SAS software program Ver. 9.4. Separate analyses were conducted for each location because of heterogeneity of error variance. The means were compared using least significant difference (LSD) at 0.05 probability level.

Result and Discussion

Phenological Parameters

The results revealed that days of heading and days of maturity were significantly affected by source and rate of applied fertilizers at both locations. Similarly, varieties at Chefe Donsa and year at Alem Tena had a significant effect on days of heading and days of maturity. The interaction between variety and fertilizer application rate had no significant effect on the above parameters. The delayed days to heading and maturity of tef were observed in 2019 cropping season as compared to 2018. This might be due to the highest and better distribution of rain fall during 2019 as compared to 2018 cropping season (Fig 1.). When the distribution of rainfall tends to be poor, they may also be forced to head early before the needed time for vegetative growth.

Regarding varieties, the delayed days to heading and maturity of tef were recorded on variety Dagim whereas;

the earliest days to heading and maturity were recorded from variety Tesfa. This might be the result of genetic diversity among varieties, which eventually led to differences to mature.

The longest days to heading (70.83) and (133.83) days to maturity were obtained at the rate of 0 kg ha⁻¹ while the shortest days to heading (64.94) and physiological maturity (127.93) were verified at the rate of 100 kg ha⁻¹ NPSB at Chefe Donsa. Similarly, at Alem Tena, the longest days to heading (47.50) and (92.50) days to maturity were obtained at the rate of 0 kg ha⁻¹ while the shortest days to heading (46.16) and physiological maturity (91.16) were verified at the rate of 150 kg ha⁻¹ NPSB. Application of blended fertilize (NPSB) hastened

the time to reach heading and maturity as compared to DAP fertilizer (NP). This might be due to the fact that application of blended fertilizers with varying rates of N, P, S, and B may have aided in the early establishment, rapid growth, and development of crops, as a result shortening the time until heading, and maturity. This might be due to favorable conditions of soils for the crop nutrient requirement by application of deficient soil nutrients found in the blended fertilizer and the presence of Boron, which is necessary for stimulation of roots and shoots development and tassel and silk formation for maize. The result is in line with Diriba et al. (2019) who reported the difference in heading and maturity date of wheat in respect to application of different rats of blended fertilizer.

Table 2. Effect of variety and fertilizer on Phenology of tef at Chefe Donsa and Alem Tena during 2018 and 2019

Chefe Donsa			Alem Tena		
Year	Days of heading	Days of maturity	Year	Days of heading	Days of maturity
2018	67.70a	130.7a	2018	45.67b	90.67b
2019	67.70a	130.7a	2019	47.67a	92.67a
Variety			Variety		
Dagem	68.47a	131.47a	Boset	46.93a	91.93a
Tesfa	66.94b	129.94b	Tseday	46.40a	91.40a
Fertilizer sources and rate (kg/ha)			Fertilizer sources and rate (kg/ha)		
0	70.83a	133.83a	0	47.50a	92.50a
100 DAP	68.67b	131.67b	100 DAP	46.88ab	91.83ab
50 NPSB	67.33bc	130.33bc	50 NPSB	46.50b	91.50b
100 NPSB	64.93d	127.93d	100 NPSB	46.50ab	91.33ab
150 NPSB	66.75cd	129.75cd	150 NPSB	46.16ab	91.17ab
V x F	ns	ns	ns	V x F	Ns

Growth parameters

Plant height, panicle length and number of productive tillers were significantly ($P < 0.05$) affected by the main effect of year, and fertilizer application at both locations, but not by variety. The interaction effect of variety and fertilizer application was not significant (Table 3). The maximum plant height, panicle length and number of productive tillers were observed in 2019 cropping season as compared to 2018 cropping season at both locations. The variations in plant growth of tef were attributed to the variations in distribution and amount of rainfall registered during the cropping periods. Crops need water throughout the growing phase, so the availability of adequate water in the soil is essential to enable plants (crops) to grow rapidly.

The highest plant height (73.79 cm and 73.08 cm), panicle length (27.45 cm and 27.07 cm) and numbers of productive tillers (2.72 and 2.55) were recorded from the application of NPSB at the rate of 100 kg ha⁻¹ and 150 kg ha⁻¹, respectively. However, there was no significant difference with the application of DAP at the rate of 100 kg/ha DAP at Chefe Donsa. Similarly, at Alem Tena, the highest plant height (94.0 cm) was recorded on the application of NPSB at a rate of 150 kg ha⁻¹, but was not significantly different from other rates of NPSB and 100 kg ha⁻¹ DAP. Regarding panicle length (36.61 cm) and numbers of productive tillers (2.26) were recorded

from the application of NPSB at rate of 150 kg ha⁻¹, respectively, but were not significantly different from the applications of NPSB at the rate of 100 kg ha⁻¹ and DAP at the rate of 100 kg ha⁻¹. In contrast, the lowest panicle length and number of productive tillers were observed from the control. The increase in plant height with increasing NPSB and DAP fertilizer could be attributed due to sufficient supply of nutrient which in turn facilitates plants growth since nitrogen plays a crucial role in the structure of chlorophyll and P involved in the energy transfer for cellular metabolism. Moreover, the presence of Boron is necessary for stimulation of roots and shoots development and panicle formation for tef as a result increase growth of the crop. The result is in agreement with Tesfahun et al. (2018), who reported significantly higher number of total tillers in response to the application of 90 and 120 kg ha⁻¹ NPS. Similarly, Feyera et al., (2014) reported that the blended fertilization application and efficient utilization of nutrient leads to high photosynthetic productivity and accretion of dry matter, eventually increases plant height and panicle length.

The possible reason for increment in number of tiller or growth as a whole might be due to the availability of more N in 150 kg/ha NPSB which played a positive role in cytokinin synthesis and cell division, which is an important hormone for cell division and shoot growth.. Similarly Okubay

et al. (2014) reported a significant increase in number of total tillers with increase in levels of N from 0 to 69 kg ha⁻¹ in tef. Botella et al. (1993) also reported stimulation of tillers with optimal application of N. In contrary to this finding, Teshome and Sofya (2021) reported that number of tillers of tef was not significantly affected by

the rate and type of different blended fertilizers. In contrast, the lowest plant height, panicle length and number of tillers were observed from control at both locations, which might be due to the low level of those essential nutrients in the soil for crop requirements.

Table 3. Effect of variety and fertilizer on growth of tef at Chefe Donsa and Alem Tena during 2018 and 2019

Chefe Donsa				Alem Tena			
Year	Plant Height (cm)	Panicle Length (cm)	Productive tillers	Year	Plant Height (cm)	Panicle Length (cm)	Productive tillers
2018	65.38b	27.37a	2.36a	2018	74.43b	29.92b	1.87b
2019	70.48a	25.10b	2.52a	2019	106.59a	40.12a	2.18a
Variety				Variety			
Dagem	68.98a	26.72a	2.33a	Boset	88.99a	34.27a	1.99a
Tesfa	66.877a	25.76a	2.55a	Tseday	92.03a	35.77a	2.06a
Fertilizer sources and rate (kg/ha)				Fertilizer sources and rate (kg/ha)			
0	54.07b	23.51b	2.16c	0	87.17b	33.13c	1.83c
100 DAP	70.43a	26.67a	2.49abc	100 DAP	92.47ab	36.31ab	2.08ab
50 NPSB	58.27ab	24.48ab	2.28bc	50 NPSB	88.97ab	33.71bc	1.99bc
100 NPSB	73.79a	27.45a	2.72a	100 NPSB	89.94ab	35.36abc	2.16a
150 NPSB	73.08a	27.07a	2.55ab	150 NPSB	94.00a	36.61a	2.26a
V x F	ns	ns	ns	V x F	ns	ns	Ns

Yield and Yield components

Grain yield, biomass yield and harvest index of tef were significantly ($P<0.05$) affected by the main effect of fertilizer application at both locations. However, the main effect of variety and interaction effect of variety with fertilizer application at both locations were not significant ($P>0.05$) for all aforementioned yield components,

except a significant effect of variety on biomass yield of tef at Alem Tena (Table 4). Thus, Tseday variety gave a higher biomass yield of tef as compared to Boset variety. The difference in biological yield between the two tef varieties might be due to genetic variation and adaptability to soil and climatic conditions.

Table 4. Effect of variety and fertilizer on yield and yield component of tef at Chefe Donsa and Alem Tena during 2018 and 2019

Chefe Donsa				Alem Tena			
Year	Biological Yield (kg/ha)	Grain Yield (kg/ha)	Harvest Index	Year	Biological Yield (kg/ha)	Grain Yield (kg/ha)	Harvest Index
2018	7740.15a	1877.6a	0.24b	2018	6675.0b	1511.7b	0.25a
2019	5798.4b	1439.2b	0.25a	2019	7468.5a	1644.0a	0.20b
Variety (V)				Variety	0	0	
Dagem	7025.0a	1697.7a	0.24a	Boset	6814.5b	1582.8a	0.23a
Tesfa	6513.6a	1619.1a	0.25a	Tseday	7329.9a	1573.05a	0.21a
Fertilizer sources and rate (kg/ha) (F)				Fertilizer sources and rate (kg/ha) (F)			
0	3499.95c	1062.6d	0.27a	0	5629.2c	1322.7b	0.23a
100 DAP	7083.3ab	1688.85bc	0.26a	100 DAP	7462.8ab	1639.8a	0.21a
50 NPSB	6666.6b	1528.5c	0.23a	50 NPSB	6783.6b	1565.25a	0.23a
100 NPSB	8443.1a	1962.8ab	0.23a	100 NPSB	7847.85a	1668.15a	0.22a
150 NPSB	8153.6a	2049.3a	0.25a	150 NPSB	7637.55a	1693.5a	0.22a
V x F	ns	ns	ns	V x F	ns	ns	Ns

At Chefe Donsa, the highest grain yield and biomass yield of tef in 2018 cropping season as compared to 2019 cropping season, whereas, at Alem Tena, the highest grain and biomass yield of tef were obtained during 2019. A higher harvest index of tef was

The highest biomass yield (8443.10 and 8153.60 kg ha⁻¹) at Chefe Donsa and (7637.55 and 7847.85 kg ha⁻¹) at Alem Tena were recorded from the application of NPSB at rate of 150 kg ha⁻¹ and 100 kg ha⁻¹, respectively, but were not significantly different from the application of DAP at the rate of 100 kg ha⁻¹ DAP. At Chefe Donsa, the highest grain yield (2049.30 kg ha⁻¹) was recorded on the application of NPSB at the rate of 150 kg ha⁻¹, but was not significantly different from the application of NPSB at the rate of 100 kg ha⁻¹. On the other hand, the applications of NPSB at the rate of 100 kg ha⁻¹ gave statistically similar yield as of application of 100 kg ha⁻¹ DAP. At Alem Tena, the highest grain yield (1693.50 kg ha⁻¹) was recorded on the application of NPSB at the rate of 150 kg ha⁻¹, but was not significantly different from other rates of NPSB and 100 kg ha⁻¹ DAP. This may be because blended fertilizer application boosts the effectiveness of fertilizer use and increase crop yields by enhancing the physical, chemical, and biological conditions of the soil (Mahajan and Gupta, 2009). This could be attributed to the beneficial effect of yield contributing characters and positive interaction of nutrients in the blended fertilizer. In addition,

obtained during 2018 at Chefe Donsa and 2019 cropping season at Alem Tena. Variations in distribution and amount of rainfall record during the cropping periods (Fig. 1 and Fig. 2) prompted variations in yield and yield components of tef at both locations.

phosphorus found in NPSB responsible for improved root development at early growth stage and which in turn promotes N uptake and N assimilation by growth points triggering tillers which subsequently resulted to overall plant growth and yield, (Barker and Pilbeam, 2007), and sulfur facilitates the uptake of other nutrients by the crop (Samuel et al., 1993). Similarly, ample supply of boron facilitates photosynthetic activities and leaf expansion that leads into improved grain yield (Tahir et al., 2009). This result is in agreement with Brhan (2012), who reported that treatments using blended fertilizers for tef row planting produced 4155 kg ha⁻¹ and increased 30% and 378% above treatments using urea and DAP for row planting and control plots, respectively. Wakjira (2018) also reported the highest grain yield of tef at a rate of 120 kg ha⁻¹ NPS fertilizer.

The biomass and grain yield increment with the application of blended fertilizers which contained S and B as compared to DAP at Chefe Donsa indicated that there is a need to supplement these elements or the necessity of NPSB fertilizer for tef production for the area. However, at Alem Tena there is not a significant

yield increment with regard to application of NPSB blended fertilizers as compared to DAP (NP) fertilize. This finding is inconsistent with Mulugeta and Shiferaw (2017), who reported that the recommended rate of NP fertilizer (100 kg ha^{-1} DAP) for tef grain yield was not statistically different from the application of other types of blended fertilizer.

Agronomic fertilizer use efficiency of Tef

Agronomic Efficiency indicated the grain yield production potential of variety in response to the applied nutrients. The source and rate of fertilizer had a significant effect on agronomic use efficiency of tef. The

highest agronomic nutrient use efficiency was recorded at 50 kg ha^{-1} NPSB blended fertilizers, followed by 100 kg ha^{-1} NPSB at both locations (Fig 3). Agronomic Efficiency can be increased by increasing the amount, uptake and utilization of available nutrients, and by increasing the efficiency with which applied nutrients are taken up by the crop and utilized to produce grain (Cassman et al., 1996). This outcome was in line with those who found that different blended fertilizers and their rates had an impact on the yield and yield-related variables of barley, as well as impacts of blended fertilizers on nutrient use efficiency (Tesfahun, 2018).

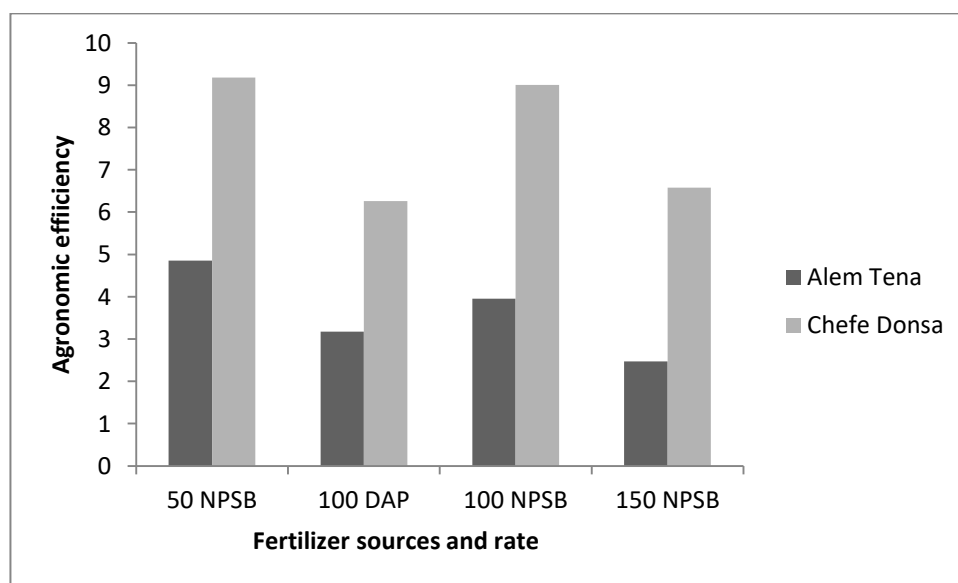


Fig.3 Agronomic use efficiency of tef at Chefe Donsa and Alem Tena

Partial Budget Analysis

The partial budget analysis showed that the application of 100 kg ha⁻¹ NPSB gave the highest net benefit of 74174.36 birr ha⁻¹ with marginal rate of return of 100 % at Chefe Donsa (Table 5) and the highest net benefit of 62771.41 birr ha⁻¹ with marginal rate of return of 100 % at Alem Tena (Table 6). While the lowest net benefit of 41122.62 birr ha⁻¹ and 51188.49 birr ha⁻¹ were obtained from no fertilizer application at Chefe Donsa and Alem Tena, respectively (Table 8). The highest economic benefit for 100 kg ha⁻¹ NPSB might be due to the highest grain yields produced. This implies that compared to growing tef without fertilizer application, the expected net benefit

for blended fertilizer is interesting. Similarly, Yared et al. (2020) reported that combined application of 150 kg NPS and 46 kg N had given the highest economic benefit of 61315.41 Birr ha⁻¹ with the marginal rate of return of 852.50%. Mathewos et al. (2022) also found the highest net benefit and MRR of wheat on application of blended fertilizer. Application of a unit fertilizer is economical, if the value of the increase in the crop yield due to the quantity of fertilizer added is greater than the cost of fertilizer used. If a unit of fertilizer does not increase the yield enough to pay for its cost, its application will not be economical and will not return profit even after a constant increase in the yield (Singh, 2004).

Table 5: Partial budget and marginal analysis for fertilizer sources and rate at Chefe Donsa

Fertilizer sources and rate (kg/ha) (F)	Grain Yield (kg/ha)	Adj. Grain Yield (kg/ha)	Total Cost Vary	Gross Benefit	Net Benefit	MRR (100%)
0	1062.6	956.34	0	41122.62	41122.62	
50 NPSB	1528.5	1375.65	893	59152.95	58259.95	95.05
100 DAP	1688.85	1519.965	1786	65358.5	63572.5	85.61
100 NPSB	1962.8	1766.52	1786	75960.36	74174.36	100.00
150 NPSB	2049.3	1844.37	2679	79307.91	76628.91	73.32

Table 6. Partial budget and marginal analysis for fertilizer sources and rate at Alem tena

Fertilizer sources and rate (kg/ha) (F)	Grain Yield (kg/ha)	Adj. Grain Yield (kg/ha)	Total Cost Vary	Gross Benefit	Net Benefit	MRR (100%)
0	1322.7	1190.43	0	51188.49	51188.49	
50 NPSB	1565.25	1408.725	893	60575.18	59682.18	90.49
100 DAP	1639.8	1475.82	1786	63460.26	61674.26	69.05
100 NPSB	1668.15	1501.335	1786	64557.41	62771.41	100.00
150 NPSB	1693.5	1524.15	2679	65538.45	62859.45	89.7

Conclusion

The study revealed that the fertilizer applications had a significant effect on grain yield and yield components of tef. However, varieties had not a significant effect on yield and yield components of tef at both locations. Higher grain yield was obtained from application of 150 kg ha⁻¹ NPSB at both locations, but was not significantly different from the application of 100 kg ha⁻¹ NPSB at Chefe Donsa, and from 100 kg ha⁻¹ NPSB and 100 kg ha⁻¹ DAP at Alem Tena. Economic analysis showed that application of 100 kg ha⁻¹ NPSB gave the highest net benefit and acceptable marginal rate of return (MRR). Therefore, application of 100 kg ha⁻¹ NPSB fertilizer could be recommended for production of tef in the study areas and other areas with similar agro-ecological and soil conditions.

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Editor in chief: Dagnachew Lule (PhD); E-mail: hawinok@gmail.com

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