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Contents

Preface

Agriculture is the backbone of Ethiopian economy contributing for food self-sufficiency, foreign currency earning, supplying raw materials for the emerging agro-processing industries while conserving the ecosystem for sustainable use. In alignment the government policy to transform the agriculture sector the research system has been playing the leading role in generating improved technologies, creating demand for the technologies and supplying start up technologies for targeted beneficiaries. The Ethiopian Institute of Agricultural Research has made the major contribution and has generated 60% of the improved crop varieties and are among the widely used technologies across regions. In the past two decades agricultural productivity has shown an increasing trend by 5.8% while the global average increment was 1.4%. The increasing uses of improved technologies specifically the use of improved varieties contributing for the increasing crop productivity and production. It is vital to extend the available technologies while generating new technologies addressing the development demand of the country.

The crop research directorate is being undertaking research to generate technologies resilient to the changing environments. In this regard, a fifteen years strategy has designed to increase the genetic gain through breeding by 1.5% per annum, and double productivity of the major food security and other economically important crops. In order to achieve these targets modernization of the breeding program is underway to increase efficiency and genetic gain through breeding. This proceeding is the result of the past three years research undertakings of the national programs. In the execution of the research activities the federal and regional research canters and some of the universities have been participated. In this proceeding the major results of the completed research activities of the 2020/21 crop season were published with the aim of sharing the major outputs of the research undertakings to beneficiaries and document the research experiences for future use.

The published papers have passed a two-stage review by assigned senior researchers in the respective disciplines and editors who have compiled the proceeding. The papers included in this proceeding were selected based on the contributions to generate appropriate technologies for users, scientific merits and contribution for advancement of scientific research in the country. This proceeding contained 39 articles on breeding of the field and pulse crops, horticultural crops, and crop husbandry. The papers organized into different sections as field crops, horticulture, root and tubers, spices and coffee and tea crops. The authors are recognized for the implementation of the research activities and their commitment in writing the papers as per the standard set initially and incorporation of the comments given by the reviewers for the betterment of the quality of the papers. The contribution of the senior researchers across canters in reviewing the papers was immense and I would like to thank those who have been

involved in the review and edition process. The final edition and formatting were done by Dr Fisseha and his team. I would like to extend my thanks for the support and efforts they made in shaping the proceeding to the standard. I believe that the papers included in this document will provide useful information for the scientific community and for other end users.

The Editors

Foreword

Agriculture plays a significant role in Ethiopian economy. The sector is a major source of food, feed, raw materials for industries and foreign exchange. Several biotic and abiotic factors constrain crop production and productivity in Ethiopia. Research in the crop subsector generally aiming at relieving these biotic and abiotic constraints. In the past decade agricultural productivity has shown an increasing trend. The productivity increment is related to the increasing use of improved technologies such as improved crop varieties and crop management practices. However, the growth has not been commensurate with the growing population and there is still considerable gap between food demand and supply. A number of factors are contributing to this demand and supply gap of which access to improved crops technologies can be mentioned.

The crop research directorate of the Ethiopian Institute of Agricultural Research is one of the directorates undertaking research activities aimed at generating appropriate technologies for the diverse agro-ecologies of the country on field and horticultural crops, and coffee and tea, root and tubers, and medicinal and aromatic plants. The sector focuses on the generation of technologies and information that are packaged and delivered to end users and also used for future research and development endeavors.

These proceedings contain the result of crop research activities implemented over the past three years implemented by the various research programs of the crop research sector. Compilation of such results of completed research activities enables the accessibility of the results to users. I would like to thank the authors and editors for their contribution in compiling the papers included in the document.

Diriba Geleti (Ph.D.)
Deputy Director General for Research, EIAR

Field Crop Research Results

Development of Brown Seeded Tef Genotypes for Yield and Yield Related Traits in the High Potential Growing Environments of Ethiopia

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Abstract

Over 50 improved varieties have been released for commercial production in the various tef growing environments since the inception of tef research in Ethiopia. Developing and releasing variety is a continuous process aiming at addressing the dynamic demands of our globe. In this study, 18 recombinant inbred lines along with a standard and local check were evaluated at Debre Zeit, Chefe Donsa, Ginchi, Holetta and Debre Markos in 2019 and 2020 cropping seasons to identify superior brown tef genotypes for verification and release. Each genotype was grown on a plot size of 2 m x 2 m using randomized complete block design with four replications. ANOVA and AMMI analyses showed that tef grain yield was highly significantly ($p< 0.001$) affected by environments (E), genotypes (G) and genotype × environment interaction (GEI) indicating the presence of genetic variation and possible selection for stable genotypes. Based on AMMI analysis, 52.6%, 11.8% and 35.7% of the total sum of squares were justified by environment, genotype and GEI, respectively. The GEI was further decomposed into eight principal component axes whereby PCA_1 and PCA_2 which were significant explained 42.65% and 23.22% of the GEI sum of squares, respectively. Three inbred lines viz., DZ-Cr-387 X DZ-01-99 (RIL-169)(2436.3) followed by DZ-Cr-387 X DZ-01-99 (RIL-106)(2379.9)and DZ-Cr-387 X DZ-01-99 (RIL-76)(2347.1) gave the highest mean grain yield based on combined data over environments. Among the three genotypes, DZ-Cr-387 X DZ-01-99 (RIL-106) was the most stable to be considered for verification and release in the high potential environments.

Keywords: Felagot, Brown seeded tef, Genotype, Genotype by environment interaction

Introduction

Tef [*Eragrostis tef* (Zucc.) Trotter] is an indigenous cereal crop adapting to various agro-ecological and climatic conditions in Ethiopia. However, the yield and quality of tef are significantly affected by its growing environments (Seyifu, 1993). As an indigenous crop, its improvement mainly depends on the variability existing in its germplasm resources and the efforts made by Ethiopian researchers. So far, over 50 varieties adapting to high potential high rainfall areas, low

moisture stress environments and highland water logging environments have been developed through hybridization and selection from existing landraces (MoA, 2020). Among these, 27 varieties were released by Debre Zeit Agricultural Research center while the remaining ones were released by seven other federal and regional research centers. In such varietal development and release efforts, the varieties developed through hybridization showed about 10 percent yield advantage over those developed and released through selection from landraces. The utilization of these improved varieties and agronomic practices have enabled to increase the national average productivity of tef by nearly two-folds from 0.9 t ha^{-1} to 1.85 ha^{-1} (CSA, 2020).

Tef provides enormous nutritional, health and agronomic merits to the farmers in Ethiopia and the consumers elsewhere in the world. Farmers prefer tef since it adapts to different agro-ecologies with reasonable resilience to both drought and waterlogging better than most other cereals (Kebebew *et al.*, 2011), fits to various cropping systems and crop rotation schemes; serves as a low-risk catch crop at times of failures of other long-season crops due to drought or pests; and little vulnerability to epidemics of pests and diseases (Solomon *et al.*, 2019). Consumers, on the other hand, prefer tef due to the dietary qualities of its grain which is gluten-free and contains all the eight essential amino acids as well as high contents of fiber, minerals, and vitamins (NRC, 1996). Furthermore, it is also preferred as a valuable forage crop due to its high feed quality, crude protein content, fast growth habit, and suitability for multiple harvests (Davidson, 2018).

Despite the fact that tef area coverage and productivity are increasing, its productivity compared to other major crops is still very low due to various factors (CSA, 2020). Therefore, it's essential to continue with developing and releasing varieties suitable for various tef growing corridors of Ethiopia by designing a specific release for various growing conditions, cropping patterns and consumer demands. The varietal development and release in each case, however, passes through several breeding steps, series of performance evaluation and variety verification trials. Hence, this study was designed to evaluate and identify superior brown seeded tef genotypes for variety verification and release in the high potential tef growing environments of Ethiopia.

Materials and Methods

Plant materials

Twenty genotypes including 18 recombinant inbred lines obtained from the cross between DZ-Cr-387 X DZ-01-99, a standard check *Felagot* and a local check were evaluated in the national variety trial late set brown seed group (Table 1).

Table 1. Description of the studied genotypes in NVT brown seeded late set in 2019 and 2020

Genotype Code	PEDIGREE Name
G_1	DZ- Cr -442/Felagot
G_2	DZ-Cr-387 X DZ-01-99 (RIL No. 23)
G_3	DZ-Cr-387 X DZ-01-99 (RIL No. 34)
G_4	DZ-Cr-387 X DZ-01-99 (RIL No. 35)
G_5	DZ-Cr-387 X DZ-01-99 (RIL No.138)
G_6	DZ-Cr-387 X DZ-01-99 (RIL No. 49)
G_7	DZ-Cr-387 X DZ-01-99 (RIL No. 70)
G_8	DZ-Cr-387 X DZ-01-99 (RIL No. 76)
G_9	DZ-Cr-387 X DZ-01-99 (RIL No. 101)
G_{10}	DZ-Cr-387 X DZ-01-99 (RIL No. 104)
G_{11}	DZ-Cr-387 X DZ-01-99 (RIL No. 106)
G_{12}	DZ-Cr-387 X DZ-01-99 (RIL No. 117)
G_{13}	DZ-Cr-387 X DZ-01-99 (RIL No. 145)
G_{14}	DZ-Cr-387 X DZ-01-99 (RIL No. 169)
G_{15}	DZ-Cr-387 X DZ-01-99 (RIL No. 137)
G_{16}	DZ-Cr-387 X DZ-01-99 (RIL No. 210)
G_{17}	DZ-Cr-387 X DZ-01-99 (RIL No. 246)
G_{18}	DZ-Cr-387 X DZ-01-99 (RIL No. 306)
G_{19}	DZ-Cr-387 X DZ-01-99 (RIL No. 340)
G_{20}	Local

Experimental environments, design and management

The field experiments were carried out during the main cropping season of 2019 at Debre Zeit black soil, Chefe Donsa, Ginchi, Holetta and Axum, while Holetta, Debre Markos, Debre Zeit, Chefe Donsa and Ambo were used as testing sites in 2020. A completely randomized block design with four replications was employed on 2 m x 2 m plot at a distance of 1 m and 1.5 m between plots and blocks, respectively. Planting was done by hand drilling of seeds within rows spaced at 0.2 m in each plot. The field trials management was done following the research recommendation and agronomic practices of the respective test locations.

Data Collection

Data on days to heading, days to maturity, lodging index, shoot biomass yield and grain yield were taken on plot basis. On the other hand, plant height and panicle length were taken on individual plant basis by making measurements on five random samples of plants from the central row of each plot where the mean of those five plants were considered for analysis.

Data Analysis

Hartley's (1950) F-max of homogeneity of variance test were deployed for individual environment for each trait. A combined analysis of variance was done upon getting positive results from tests of homogeneity of variances. For the analysis of variance, appropriate models suitable for the experimental design were employed (Gomez and Gomez, 1984) using SAS software version 9.00 (SAS Institute, 2002). Adaptability and stability analyses were done using the AMMI (Guach, 2013) and GGE-biplot methods (Yan *et al*., 2000; Yan, 2001 and Yan and Tinker, 2006) after confirming significant genotype by environment interaction. GGE biplot analysis was performed using the genotype by environment analysis in R (GEA-R) software v4.0 (Pacheco *et al*., 2016) and the first two principal components (PC_1 and PC_2) were used to graphically represent the GEI, to identify the rank of studied genotypes and environments (Yan *et al.*, 2000).

Results and Discussion

Analysis of variance

The mean square from the pooled analysis of variance over eight environments showed statistically significant ($P \leq 0.001$) genotype, environment and genotype by environment interaction effects (Table 2). The significant mean squares due to environments and genotypes suggests that the locations were diverse and the tested genotypes were variable. Similarly, the existence of significant genotype x environment interactions for yield of tef shows that the highest yielding genotype may not necessarily be the highest yielding in the other environments and vice versa (Table 2). This is in line with the previous reports of Habte *et al*. (2019).

Table 2. Analysis of variance for grain yield across eight environments

Source of Variation	Degree of freedom	Sum of squares	Mean squares	F-value	Pr
Genotype	19	8014834.5	421833.4	4.02	<.0001
Environment	7	35789600.2	5112800.0	48.75	<.0001
Rep	3	5600185.3	1866728.44	17.8	0.0001
Environment*Genotype	133	24294095.9	182662.4	1.74	0.0001

AMMI analysis of variance for grain yield

The AMMI analysis for grain yield at eight environments is presented in Table 3. Thus, the result revealed a highly significant ($P \leq 0.01$) differences for grain yield (t ha^{-1}) of 20 tef genotypes, eight environments and their interaction. This is in line with the previous works (Tiruneh *et al*., 2000, 2001; Habte *et al*. 2019). The AMMI analysis partitioned the G x E variance into principal component (PC) axes where the first and second principal component axis which were significant explained 65.87% (PCA1=42.65% and PCA2=23.22%) of the total variation. Contrary to this findings, PC_1 value of 66.1% (Lule, 2015), 93.1% (Crossa *et al*., 1990) were reported.

Table 3. ANOVA Table for AMMI model of grain yield (kg/ha)

Source	DF	SS	MS	F	PROBF
ENV	7	35789611.9	5112801.7	44.1	0.0
GEN	19	8014761.4	421829.5	3.6	0.0
ENV*GEN	133	24294185.7	182663.1	1.6	0.00029
PC1	25	10362393.2	414495.7	4.0	0.0
PC2	23	5640995.2	245260.7	2.3	0.00049
Residuals	480	55629518.3	115894.8	NA	NA

Genotype performance

The pooled mean performances over years and environments showed significant genotypic variation for all studied traits. There was a cross- over type of interaction in this study, since the best genotype at one location become inferior at the other locations (Table 3). The overall mean grain yield across 8 environments ranged from 1806.1 kg ha^{-1} at Debre Zeit 2019 to 2556.66 kg ha^{-1} at Debre Zeit 2020 followed by Ginchi 2019 and Debre Markos 2020 which were found to be the highest yielding environments, respectively (Table 3).

In this study, 13 genotypes were found to perform better than the standard check (*Felagot*) and the local. Among others, DZ-Cr-387 X DZ-01-99 (RIL No. 169) followed by DZ-Cr-387 X DZ-01-99 (RIL No. 106) gave 14.8 %, and 10.34 % over the best check, respectively (Table 3). DZ-Cr-387 X DZ-01-99 (RIL No. 169) gave the highest grain yield at Ginchi 2019, Holetta 2019, Ambo 2020 and Debre Markos 2020 while DZ-Cr-387 X DZ-01-99 (RIL No. 106) gave the maximum grain yield at Debre Zeit in both 2019 and 2020 cropping seasons. Especially, DZ-Cr-387 X DZ-01-99 (RIL No. 106) which had the second highest yield was the most stable and had higher yield than the grand mean in about 70% of the test environments (Fig. 1 &2; Table 3). The huge variability in the grain yield among the 20 tef genotypes at eight environments might be due to wide variability in climatic and soil conditions. Earlier works also reported similar inconsistencies in yield performance which complicated the selection and recommendation of stable genotype across environments (Fufa *et al*., 2000; Tiruneh *et al*. 2000, 2001; Habte *et al*., 2019).

Furthermore, DZ-Cr-387 X DZ-01-99 (RIL No. 106) had also very good mean biomass yield and panicle length and significantly lower value of lodging index. Thus, it had 24.6% and 15.6% shoot biomass yield advantage and 19.8% and 14.4 % panicle length advantage over the standard and local check, respectively (Table 4). This genotype has also found to have better crop stand and culm strength compared to the standard check *Felagot*. Hence, DZ-Cr-387 X DZ-01-99 (RIL No. 106) which is stable and have more than 10% grain yield advantage over the best check, should be verified for release in the high potential environments of Ethiopia.

Table 3. Mean grain yield performances of 20 tef genotypes evaluated over eight environments

No.	ENTRY	2019 cropping season				2020 cropping season			
		Chafe Donsa	Debre Zeit	Ginchi	Holeta	Chafe Donsa	Debre Zeit	Holetta	Debre Markos
1	DZ- Cr -442/Felagot	2123.1	1673.8	2342.4	1177.2	2378.1	2183.1	1680.5	2689.4
2	DZ-Cr-387 X DZ-01-99 (RIL No. 23)	1580.6	1718.8	2337.7	2050.0	2121.3	2553.1	2172.7	2067.5
3	DZ-Cr-387 X DZ-01-99 (RIL No. 34)	2127.5	1715.0	2529.8	2131.2	2476.3	2694.4	1929.5	2435.6
4	DZ-Cr-387 X DZ-01-99 (RIL No. 35)	1961.9	1857.5	2255.5	2152.0	2041.3	2353.1	1805.6	2147.5
5	DZ-Cr-387 X DZ-01-99 (RIL No.138)	2393.8	1721.3	2176.4	1788.5	2036.3	2297.5	1609.9	2426.9
6	DZ-Cr-387 X DZ-01-99 (RIL No. 49)	2046.9	1500.0	2158.4	1957.8	2067.5	2207.5	1626.8	2705.0
7	DZ-Cr-387 X DZ-01-99 (RIL No. 70)	2041.3	1837.5	2265.1	2503.1	2333.8	2422.5	2121.2	2355.0
8	DZ-Cr-387 X DZ-01-99 (RIL No. 76)	1766.3	1965.0	2630.0	1964.1	2334.4	2904.4	2236.5	2106.3
9	DZ-Cr-387 X DZ-01-99 (RIL No. 101)	1678.8	1572.5	2501.3	1986.2	2130.0	2670.6	1815.6	2377.5
10	DZ-Cr-387 X DZ-01-99 (RIL No. 104)	2042.5	1892.5	2247.9	2067.6	2043.1	2839.4	1986.4	2191.3
11	DZ-Cr-387 X DZ-01-99 (RIL No. 106)	2140.0	2181.3	2574.1	2567.1	2238.1	2763.1	1998.1	2253.8
12	DZ-Cr-387 X DZ-01-99 (RIL No. 117)	1763.1	1271.3	2091.5	1914.9	2203.8	2534.4	1931.9	2122.5
13	DZ-Cr-387 X DZ-01-99 (RIL No. 145)	1758.1	1851.3	2363.8	2323.2	2061.3	2719.4	2083.9	2253.1
14	DZ-Cr-387 X DZ-01-99 (RIL No. 169)	1962.5	2000.0	2687.2	2764.8	2365.0	2711.9	1926.0	2669.4
15	DZ-Cr-387 X DZ-01-99 (RIL No. 137)	1592.5	1963.8	2109.6	1922.2	2000.6	2730.6	2007.2	2028.1
16	DZ-Cr-387 X DZ-01-99 (RIL No. 210)	1478.8	1861.3	2361.1	2128.5	2195.6	2597.5	2006.8	2223.1
17	DZ-Cr-387 X DZ-01-99 (RIL No. 246)	1902.5	1951.3	2178.8	2241.1	1900.0	2611.3	2152.3	2340.6
18	DZ-Cr-387 X DZ-01-99 (RIL No. 306)	2005.6	1883.8	2170.4	2751.3	2454.4	2401.9	2022.3	2210.0
19	DZ-Cr-387 X DZ-01-99 (RIL No. 340)	1672.5	2095.0	2189.1	2026.1	1872.5	2833.8	1628.0	2437.5
20	Local	2021.9	1610.0	2144.1	1879.5	2098.1	2103.8	1802.9	2143.8
	Mean	1903.0	1806.1	2315.7	2114.8	2167.6	2556.7	1927.2	2309.2
	CV	15.33	15.63	11.38	4.91	11.86	13.33	15.46	19.88
	LSD (5%)	412.98	399.6	373.16	147.15	363.92	482.72	421.82	649.90

Table 4. Combined mean performances of eight traits of 20 tef genotypes evaluated over years and environments

No.	ENTRY	DTH	DTM	GFP	PH	PL	LI	SBM	GY
1	DZ- Cr -442/Felagot	58.9	125.8	66.9	90.0	33.9	69.5	7482.9	2054.9
2	DZ-Cr-387 X DZ-01-99 (RIL No. 23)	63.8	129.1	65.3	98.7	38.7	63.7	8919.0	2075.2
3	DZ-Cr-387 X DZ-01-99 (RIL No. 34)	64.8	129.1	64.3	99.3	39.5	62.6	8919.2	2252.6
4	DZ-Cr-387 X DZ-01-99 (RIL No. 35)	65.2	129.7	64.4	99.8	40.4	62.6	8801.7	2088.0
5	DZ-Cr-387 X DZ-01-99 (RIL No.138)	65.5	127.9	62.4	98.6	39.4	67.5	8016.9	2058.5
6	DZ-Cr-387 X DZ-01-99 (RIL No. 49)	65.4	130.3	64.9	99.5	39.7	58.7	8300.0	2037.0
7	DZ-Cr-387 X DZ-01-99 (RIL No. 70)	61.3	128.7	67.4	99.3	37.7	65.4	8665.3	2219.2
8	DZ-Cr-387 X DZ-01-99 (RIL No. 76)	61.7	126.5	64.7	90.8	33.9	69.4	8575.0	2245.5
9	DZ-Cr-387 X DZ-01-99 (RIL No. 101)	64.3	128.0	63.7	101.7	41.8	63.3	9421.5	2092.9
10	DZ-Cr-387 X DZ-01-99 (RIL No. 104)	65.8	129.2	63.3	100.5	38.8	67.4	8914.1	2163.8
11	DZ-Cr-387 X DZ-01-99 (RIL No. 106)	64.8	131.2	66.3	98.3	40.7	64.3	9255.2	2339.4
12	DZ-Cr-387 X DZ-01-99 (RIL No. 117)	65.3	129.9	64.6	99.1	40.1	61.3	8455.0	1985.7
13	DZ-Cr-387 X DZ-01-99 (RIL No. 145)	64.5	128.9	64.4	95.1	39.1	56.5	8573.3	2169.0
14	DZ-Cr-387 X DZ-01-99 (RIL No. 169)	62.1	127.7	65.5	95.4	36.9	68.0	8890.9	2374.4
15	DZ-Cr-387 X DZ-01-99 (RIL No. 137)	64.4	128.3	63.9	95.4	37.9	56.7	8326.6	2048.1
16	DZ-Cr-387 X DZ-01-99 (RIL No. 210)	65.9	129.3	63.4	104.3	41.5	61.1	8953.2	2109.5
17	DZ-Cr-387 X DZ-01-99 (RIL No. 246)	65.0	127.9	62.9	95.8	38.4	68.0	8391.9	2158.3
18	DZ-Cr-387 X DZ-01-99 (RIL No. 306)	67.4	128.1	60.7	95.8	39.5	66.1	8561.3	2219.4
19	DZ-Cr-387 X DZ-01-99 (RIL No. 340)	63.6	129.9	66.3	101.8	41.7	64.3	9100.0	2095.4
20	Local	62.2	128.5	66.3	93.2	35.9	71.2	8007.5	1969.1
	Mean	64.1	128.7	64.6	97.6	38.8	64.4	8629.6	2138.6
	LSD	1.1	1.8	2.1	4.3	1.5	4.4	650.1	159.1
	F test	***	***	***	***	***	***	***	***
	CV (%)	3.4	2.9	6.4	8.9	8.0	13.7	15.3	15.2

Analysis of GGE biplot and stability

The GGE biplot analysis was visualized on the basis of results explained for the first two principal components (Yan *et al*., 2001). In this study, the first and second PCs contributed for 42.25% and 21.73% of the total variation, respectively (Fig. 1). In GGE biplot graph, the various lines emanating from the origin appear perpendicular to the line connecting the vertex genotypes. The vertex genotypes are located at the greatest distance from the origin, the most responsive and high yielding genotype. In the present study, G1, G14 and G15 are among the vertex genotypes in the various sectors. These lines are very useful to divide the testing environments and genotypes into different sectors. In the present study, the test environments were grouped into three sectors while the genotypes were grouped

into four genotypic groups. The sector in which Holetta 1, Debre Zeit 1, Ginchi and Chefe 2 exist had two vertex genotypes (G14 followed by G11) which are the highest yielding and winning genotypes. This sector had five suitable genotypes unlike the sector in which DM and Chefe 1 existed and had no any suitable genotype. The sector in which Holetta 2 and DZ 2 existed had two suitable genotypes (G13 and G17). All the remaining genotypes in this study were not found to be good for any of the environmental sector (Fig. 1).

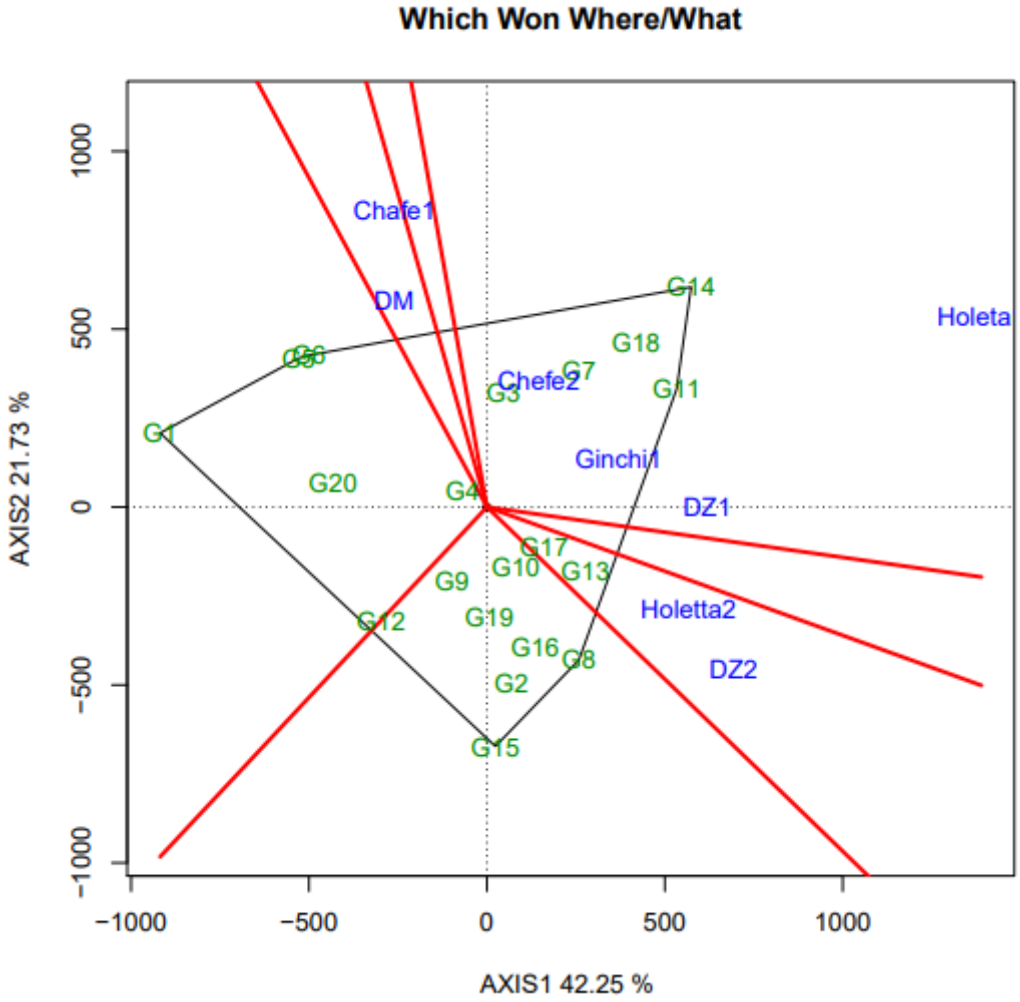

Figure 1. Which won where pattern of the GGE biplot of 20 tef genotypes evaluated at eight environments

Regarding mean yield and stability, genotypes like G11, G14, G18, G7, G17 and G13 had above average yield in all the test environments (Fig. 2). Among these, genotypes, G11 was the most stable and the second higher yielding genotypes identified to be suitable for all environments. On the other hand, all the remaining genotypes performed below the average in all environments.

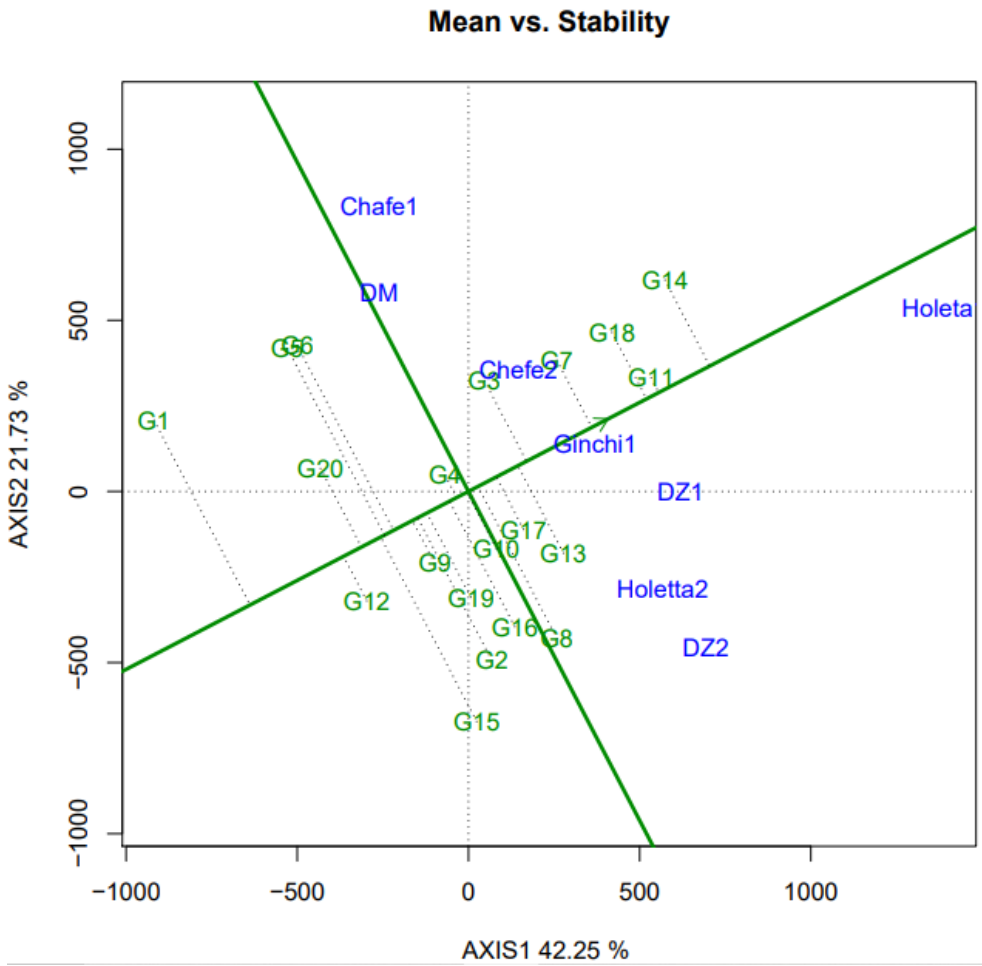

Figure 2. A graph showing the mean performances and stability of 20 genotypes studied at eight environments

The average environment coordination view of the GGE biplot shows the ranking of genotypes based on the performance of an ideal genotype (Fig. 3). The relative adaptation of the ideal genotype is evaluated by drawing a line passing through the biplot origin and the best genotype marker. This line is called a genotype axis and is connected to the best genotype (Yan *et al*., 2000). Such ranking of genotypes based on mean performance of ideal genotype revealed that G11 is closest to zero with respect to PC2 and is a more stable genotype with above average yield. Hence, it should be verified for commercial release in the high potential tef growing environments of Ethiopia.

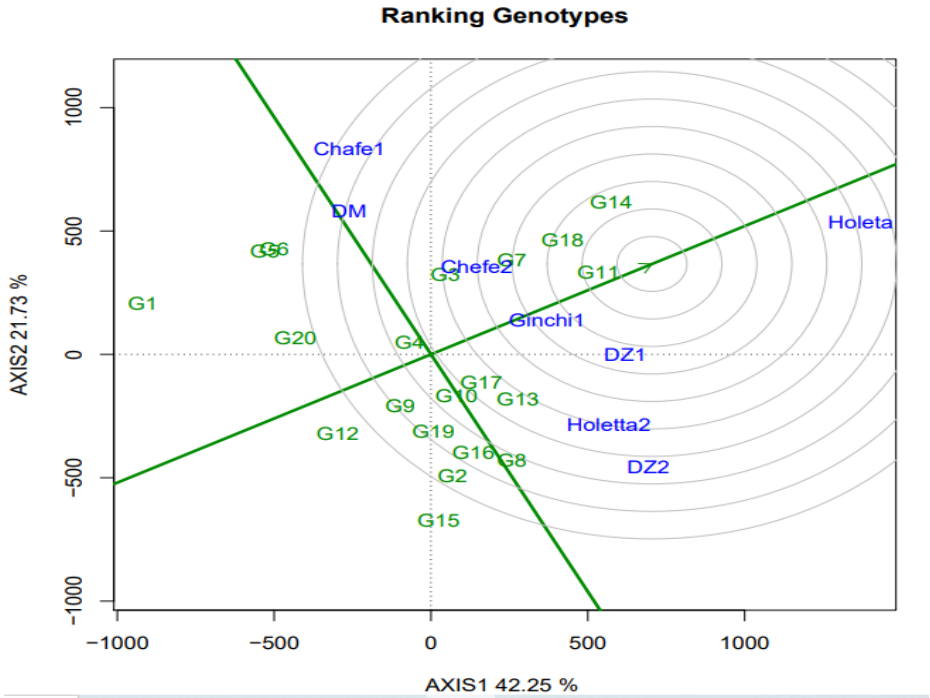

Figure 3. A graph showing the ranking of genotypes relative to the best genotype.

Conclusion and Recommendation

Germplasm enhancement efforts followed by subsequent selection and field testing of desirable genotypes is essential to develop suitable tef varieties for high potential environments. In line with this, 20 brown seeded tef genotypes were evaluated at eight environments under national variety trial late set group. Most of the tested tef genotypes performed better than the best check with DZ-Cr-387 X DZ-01-99 (169) and DZ-Cr-387 X DZ-01-99 (106) showing higher grain yield of 2436.3 kg/ha and 2379.9 kg/ha, respectively. The later was the most stable across environments and hence, proposed for verification and release in the high potential tef growing environments of Ethiopia.

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Evaluation of Selected Semi-dwarf tef (*Eragrostis tef (Zucc.) Trotter*) Genotypes for Yield and Yield Related Traits

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Abstract

Tef is the major staple food crop for Ethiopia which is cultivated by more than 6.7 million farmers' households. However, its productivity is very low mainly due to susceptibility to lodging. The objective of this study was to identify stable, high yielding and lodging tolerant tef genotype for moisture stress areas of Ethiopia. A total of twenty genotypes including standard and local checks were tested. The field experiment was conducted using 2m x 2m completely randomized block design at six locations during 2019 and 2020. Data were taken on plot and individual plant basis on eight pheno-agro-morphological characters including grain yield. The combined analysis of variance over six locations showed the mean squares due to genotypes, locations and genotype interactions were highly significant (P<0.01) for all the eight agronomical and morphological traits evaluated. Grain yield was highly significantly (P<0.01) affected by genotypes, location and year. In the same way, the genotype by environment (G×E) interaction effects showed significant difference (P<0.05) for grain yield indicating that the tested genotypes performed differently across the test environments. From the multi-environment trial, the genotype DZ-01-192 X GA-10-3 (RIL-185), DZ-01-192 X GA-10-3 (RIL-262) and DZ-01-192 X GA-10-3 (RIL-252) showed high grain yield performance among the tested genotypes. The standard check (Boset) performed well against lodging resistance followed by DZ-01-192 X GA-10-3 (RIL-137) and DZ-01-192 X GA-10-3 (RIL-185) with 76%, 80% and 82% respectively. It would be advisable to use DZ-01-192 X GA-10-3 (RIL-137) to further test in the breeding program especially for lodging tolerance.

Keywords: Genotypes, Inbred Lines, lodging, Semi-dwarf, Traits

Introduction

Tef, *Eragrostis tef* (Zucc.) Trotter, is an annual self-pollinated grass species of the family Poaceae, subfamily Chloridoideae. Tef is an allotetraploid, with $2n=4x=40$ chromosomes (Tavassoli, 1986) and Ethiopia is the place where tef is originated and diversified (Vavilov, 1951). Previous reports on morphological study of tef showed that five possible progenitors for this cereal were suggested, namely: *Eragrostis pilosa* (L.) (Hackel, 1890 and Rozhevits, 1928), *Eragrostis*

aethiopica or *Eragrostis pseudo-tef* (Trotter 1938), *Eragrostis macilenta* (Chevalier 1940) and *Eragrostis longifolia* (Porteres 1958). Of these, the first two look like tef morphologically more than the remaining three (Clayton, 1974). In the case of molecular study, thousands of SNPs were identified genome-wide from the germplasm panel. Genetic diversity, population structure, phylogenetic relationships and sequence similarity and/or divergence were assessed from those identified SNPs. Mapping individual reads to the tef reference genome revealed that of the 40 wild *Eragrostis* species included in this study, E. pilosa, E. aethiopica, E. obtusa, E. ferruginea, E. lugens, and E. lehmanniana had 92% of their sequences represented in the tef reference genome (Girma *et al*., 2018).

According to Ketema (1997) and Chanyalew *et al*. (2019), adaptation under varied climatic condition, tolerance to both drought and water-logging conditions, suitability for various cropping systems and crop rotation schemes, low-risk catch crop, and little vulnerability to epidemics of pests and diseases are the most important agronomic advantages of the crop. Over 6 million smallholder farmers in Ethiopia cultivate tef annually. While its health benefits and nutrition contents, tef is now growing in different countries as food and forage grass including United States, Israel, the Netherlands, Spain, South Africa, India, Australia, and Kenya (Ketema, 1997 and Assefa 2011). Despite its numerous relative advantages and economic importance, the productivity of tef in Ethiopia is low (CSA, 2020). The national average yield in Ethiopia for tef is 1.85 t ha $^{-1}$; while those of maize and wheat are 4.1 and 2.7 t ha^{-1} respectively (CSA 2020).

Lodging is one of the serious problems in tef production causing an estimated average yield loss of 15 to 45% (Ketema 1993 and Zhu *et al*. 2012). It has been challenging to develop resistant variety for lodging from the existing germplasm mainly because of the lack of variation for lodging resistance within the available germplasm (Assefa *et al*. 2010). Agronomic practices like application of increased amounts of nitrogen fertilizer to boost the yield results in severe lodging (Assefa *et al*. 2015). Different types of lodging were reported for tef, of which root lodging is dominant over stem lodging (Van Delden *et al*. 2010). The introduction of semi-dwarf varieties of rice and wheat during the green revolution greatly reduced culm bending-type lodging and increased productivity (Hedden 2003; Hirano *et al*. 2017). However, due to the high value of the tef straw as a livestock feed, breeding for a significant reduction in plant height might have little acceptance by farmers (Yami 2013). Both the grain yield and quality of tef can be affected by lodging, and also depending on the weather condition and inherent nature of the variety (Zhu *et al*. 2012). Therefore, lodging is a crucial problem to address as long as tef production and research is concerned. Although various attempts have been made by the research community to develop lodging-resistant tef cultivars (Assefa *et al*. 2011; Assefa and Tadele 2012) 'Kegne', which was developed using inhibitors of gibberellic acid biosynthesis especially paculobutrazol, is the only semi-dwarf tef cultivar resistant to lodging (Gebre *et al*. 2012; Plaza-Wüthrich *et al*. 2016).

According to Berhe *et al*. (2011), many efforts made in the past to implement different techniques and tools in order to improve tef. Some of these techniques included inter-specific crossing made between tef (*Eragrostis tef*) and *Eragrostis curvula* in an attempt to transfer the lodging tolerant trait of *Eragrostis curvula* to tef. However, no viable hybrid obtained from the crosses. Some efforts also made to develop double haploids using gynogenesis technique and some promising tef lines were obtained (Gugsa *et al*. 2006).

Through many struggles, about 51 improved tef varieties were released to the farming communities (MoARD 2020). However, development of high yielding and lodging tolerant tef varieties, adapting to the changing climate remains to be the primary focus of tef research (Chanyalew, 2009; Chanyalew *et al.* 2013). Therefore, the present study was designed to identify stable, lodging tolerant and high yielding tef genotype for moisture stress areas of the country.

Materials and Methods

Plant materials

The experimental plant materials comprised 20 semi-dwarf tef recombinant inbred lines including local and standard checks. These included 18 recombinant inbred lines (RIL) derived from the crosses of DZ-01-192X GA-10-3, the two parents (pure lines), and one standard and local check. The crossing combinations and names of recombinant inbred lines as well as control materials used in the study are shown in Table 2. The RILs are offspring of the intra-specific cross through continuous maintenance of progenies up to the seventh filial generation (F7) through selfing using F2-derived single-seed-decent breeding method. The tef cultivar DZ-01-192 is late maturing, thick culmed, tall, has loose panicle and white seed color. GA-10-3 is a mutant line developed through mutation breeding by using Ethyl methane sulphonate (EMS) assisted by Targeted Induced Local Lesions in Genomes (TILLING) method and introduced from university of Bern (Switzerland) which is a lodging tolerant to some extent.

Description of experimental sites

The field experiment was carried out at six locations (Debre Zeit, Minjar, Melkassa, Alemtena, Sirinka and Axum) during 2019 and 2020 cropping season. Geographical location and climatic condition of the testing sites were discussed in Table 1.

Table 1. Geographical location and climatic condition of the study areas

Site	Latitude ° N	Longitude ° E	Temperature (Min and Max / °C)	Ave. Rain fall (mm)	Altitude (m)
Debre Zeit	8° 44	38° 58	8.9 – 28.3	851	1900
Alemtena	8° 30	38° 95	12.3 – 28.8	706.3	1611
Melkassa	8° 24	39° 32	26 – 30	791	1550
Minjar	9° 09	39° 19	15.9 – 28.4	903.4	1040
Sirinka	11° 75	39° 61	18 – 27	1200	1861
Axum	14° 06	38° 36	12.2 – 26.8	613.92	2200

Table 2. Lists of semi-dwarfs tef lines used for the study

Genotype	Source
(RIL.No.137)	DZ-01-192 X GA-10-3
(RIL.No.158)	DZ-01-192 X GA-10-3
(RIL.No.185)	DZ-01-192 X GA-10-3
(RIL.No.198)	DZ-01-192 X GA-10-3
(RIL.No.208)	DZ-01-192 X GA-10-3
(RIL.No.218)	DZ-01-192 X GA-10-3
(RIL.No.223)	DZ-01-192 X GA-10-3
(RIL.No.238)	DZ-01-192 X GA-10-3
(RIL.No.252)	DZ-01-192 X GA-10-3
(RIL.No.259)	DZ-01-192 X GA-10-3
(RIL.No.260)	DZ-01-192 X GA-10-3
(RIL.No.264)	DZ-01-192 X GA-10-3
(RIL.No.210)	DZ-01-192 X GA-10-3
(RIL.No.235)	DZ-01-192 X GA-10-3
(RIL.No.262)	DZ-01-192 X GA-10-3
(RIL.No.91)	DZ-01-192 X GA-10-3
(RIL.No.68)	DZ-01-192 X GA-10-3
(RIL.No.63)	DZ-01-192 X GA-10-3
DZ-Cr-409 (Boset)	Parent (Standard check)
Local Check	Farmers' variety

Experimental design and management

A randomized complete block design (RCBD) with four replications was used in each testing site, with a plot size of 2m x 2m at spacing of 1m between plots. Sowing was done at the recommended period. 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. At the rate of 10 kg ha^{-1} from each genotype seeds were drilled along the 10 rows of each plot. The recommended amount of fertilizer was applied for each location (60 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} N at Debre Zeit and Minjar, and 60 kg ha^{-1} P_2O_5 and 40 kg ha^{-1} N at Alemtena, Melkassa, Sirinka and Axum. Nitrogen (N) was applied partly at planting and the remaining at tillering stage (after 30 -40 days of planting) and all

amount of P_2O_5 was applied at planting. Important agronomic practices were employed as per the recommendations of the respective test locations.

Data collection

Data for eight quantitative pheno-agro-morphological characters were recorded on plot and individual plant basis. Of these, the six characters taken on plot basis were days to panicle emergence, days to heading to maturity, grain filling period, above ground shoot biomass, grain yield and lodging index. The remaining two parameters i.e. plant height and panicle length data were taken on individual plant basis averages of data from the five random samples of plants per plot used for statistical analyses.

Data analysis

All data were subjected to analysis of variance (ANOVA) for RCBD, as described by Gomez and Gomez (1984), using SAS version 9 (SAS 2002). Combined analysis of variance was made, after testing for the homogeneity of variances for each trait using the F-max procedure, by dividing the largest variance to the smallest one (Hartley 1950). Mean performance was carried out in order to identify the best performing genotypes from the evaluated genotype and mean comparison for significant differences were made using Least Significant Difference (LSD).

Results and Discussion

Analysis of variance

The combined analysis of variance over six locations is presented in Table 3. Grain yield was highly significantly ($P<0.01$) affected by genotypes, location and year. In the same way, the genotype by environment (G×E) interaction effects showed significant difference ($P<0.05$) for grain yield indicating that the tested genotypes performed differently across the test environments. This implies that the genotypes tested exhibit differential adaptation to specific environments. The significant variability of genotypes observed in the present study for different traits of tef genotypes were in agreement with the previous report by different authors (Habte *et al*. 2017; Worku *et al*. 2020). Considerable difference was observed among the genotypes in grain yield performance pooled across all environments. The average grain yield of DZ-01-192 X GA-10-3 (RIL-185) was 2260 kg ha^{-1} (Table 4) which is maximum grain yield recorded among tested genotypes across pooled environments. The current result is in close agreement with that of Habte *et al*. (2017).

Table 3. Mean squares from the combined analysis of variance for grain yield traits of 20 tef genotypes evaluated in 2019 and 2020 main cropping seasons.

Source	DF	Sum Square	Mean Square	F Value	Pr> F
Loc	5	80805805.85	16161161.17	86.97	0.0001
Rep (Loc)	18	9116796.66	506488.70	2.73	0.0002
Year	1	12596391.01	12596391.01	67.79	0.0001
Loc*Year	5	26670506.07	13335253.03	71.76	0.0001
Genotype	19	12820082.12	674741.16	3.63	0.0001
Loc* Genotype	95	23105452.44	243215.29	1.31	0.0364
Year* Genotype	19	5441283.31	286383.33	1.54	0.0668
Year*Loc* Genotype	95	8655200.93	227768.45	1.23	0.1713
Error	522	96999444.5	185822.7		
Total	779	291481806.4			

The genotype DZ-01-192 X GA-10-3 (RIL-185) showed grain yield advantage of 15.82% and 28.44% over the standard (*Boset*) and local checks, respectively. The multi-location trial in the two consecutive years, the genotype DZ-01-192 X GA-10-3 (RIL-185), DZ-01-192 X GA-10-3 (RIL- 262) and DZ-01-192 X GA-10-3 (RIL-252) showed high grain yield performance among the tested genotypes. The standard check (*Boset*) performed well against lodging resistance followed by DZ-01-192 X GA-10-3 (RIL-137) and DZ-01-192 X GA-10-3 (RIL-185) with 76%, 80% and 82% respectively.

Mean genotype performances for various traits

The mean, minimum and maximum values for the eight traits of the tef genotypes were computed based on combined analyses over six locations of two main cropping seasons, and showed the existence of significant amount of variability among the test genotypes for all the studied traits (Table 4). DZ-01-192 X GA-10-3 (RIL-137) exhibited the longest days to maturity (92.67) and days to heading (49.39). Similarly, the longest plant height (114.81cm) and panicle length (45.57cm) as well as the highest above ground shoot biomass (10820.49 kg/ha) was scored by DZ-01-192 X GA-10-3 (RIL-137). However, DZ-01-192 X GA-10-3 (RIL-262) had the shortest plant height. On the other hand, RIL-158 gave the highest yield and shortest days to heading. Similarly, RIL-235 gave shortest days to maturity and panicle length. The shortest plant height (96.03cm) was scored by RIL-262. RIL-185 and RIL-68 showed highest above ground shoot biomass following to RIL-137. RIL-260 gave the longest grain filling period and RIL-63 and *Boset* showed shortest grain filling period. Furthermore, the lowest and highest lodging index was 76.30 and 95.23 respectively scored by the standard check (*Boset*) and RIL-260. Additionally, RIL-262 and RIL-252 were among the high yielding genotypes and RIL-264 scored the lowest grain yield (1788.55 kg ha^{-1}).

Table 4. Mean of eight agronomical traits of 20 tef genotypes evaluated at Debre Zeit, Minjar, Melkassa, Alemtena, Sirinka and Axum in the 2019 and 2020 main cropping seasons

No.	Genotypes	DTH	DTM	GFP	PH	PL	LI	SBM kg ha^{-1}	GY kg ha^{-1}
1	DZ-01-192 X GA-10-3 (RIL. 137)	49.39	92.67	43.94	114.81	45.57	80.94	10820.49	2180.02
2	DZ-01-192 X GA-10-3 (RIL. 158)	43.11	90.92	47.91	107.57	42.38	86.89	9128.57	2217.29
3	DZ-01-192 X GA-10-3 (RIL. 185)	46.31	92.36	44.25	105.15	38.74	82.71	10380.56	2260.31
4	DZ-01-192 X GA-10-3 (RIL. 198)	46.42	88.31	43.56	107.84	43.29	90.88	8992.01	2054.47
5	DZ-01-192 X GA-10-3 (RIL. 208)	49.17	90.33	42.53	111.09	43.24	88.49	9263.19	1817.45
6	DZ-01-192 X GA-10-3 (RIL. 210)	47.53	89.39	43.41	104.82	40.04	88.80	8991.67	1960.61
7	DZ-01-192 X GA-10-3 (RIL. 218)	45.28	92.28	46.25	109.88	43.12	84.59	9817.71	2138.77
8	DZ-01-192 X GA-10-3 (RIL. 223)	45.75	88.25	43.78	109.83	39.33	85.55	8310.76	2067.39
9	DZ-01-192 X GA-10-3 (RIL. 235)	44.58	87.72	43.97	101.02	37.57	91.98	8406.94	1960.21
10	DZ-01-192 X GA-10-3 (RIL. 238)	44.19	89.58	45.84	102.86	40.47	86.43	8606.35	2021.73
11	DZ-01-192 X GA-10-3 (RIL. 252)	46.06	90.31	45.94	105.42	39.03	90.68	8872.81	2241.88
12	DZ-01-192 X GA-10-3 (RIL. 259)	46.14	89.58	44.28	102.19	40.53	90.64	9151.04	2016.01
13	DZ-01-192 X GA-10-3 (RIL. 260)	45.36	91.81	47.97	103.00	41.34	95.23	8531.94	1968.74
14	DZ-01-192 X GA-10-3 (RIL. 262)	45.75	90.11	45.69	96.03	37.66	91.78	8206.25	2254.51
15	DZ-01-192 X GA-10-3 (RIL. 264)	47.44	89.42	43.88	106.72	39.71	90.01	8699.86	1788.55
16	DZ-01-192 X GA-10-3 (RIL. 63)	44.97	88.47	42.50	101.71	39.87	89.23	8524.60	1900.12
17	DZ-01-192 X GA-10-3 (RIL. 68)	43.61	90.11	47.31	104.07	39.90	92.15	8240.49	1942.68
18	DZ-01-192 X GA-10-3 (RIL. 91)	44.00	91.56	46.72	99.21	39.18	92.51	8944.79	2102.12
19	DZ-Cr-409 (Boset)	47.92	90.22	42.50	103.28	38.81	76.30	9128.13	2018.58
20	Local Check	48.64	92.64	43.56	106.64	40.02	85.60	9730.21	1902.14
	Grand mean	**46.08**	**90.30**	**44.79**	**105.16**	**40.49**	**88.07**	**9037.42**	**2040.68**
	R^2	**0.88**	**0.84**	**0.82**	**0.53**	**0.60**	**0.80**	**0.65**	**0.66**
	CV (%)	**3.73**	**3.49**	**6.95**	**8.69**	**8.46**	**8.25**	**19.22**	**21.12**
	LSD (0.05)	**	**	**	**	**	**	**	**

DTH= days to heading, DTM = days to maturity, GFP= grain filling period, PH= plant height, PL= panicle length, LI=lodging index, SBM = Shoot biomass (kg/ha), GY= grain yield (kg/ha)

From the study, 39% of the tested genotypes had higher yield over the standard check *Boset*. On the other hand, 44% of the genotypes were high yielder than the

local check. Evaluation of the mean performances of each trait at the six environments, also clearly showed that some locations were good enough for the accomplishment of some traits; while others were moderate or even the least for the performance of same traits (Tables 4 and 5).

Table 5. Mean grain yield performance of twenty semi-dwarf tef genotypes evaluated in the national variety trial over two years during main cropping season

Genotypes	2019						2020					Over all 2019 &2020
	Axum	D. Zeit	Melkassa	Minjar	Sirinka	2019 Total	Alemtena	D. Zeit	Minjar	Sirinka	2020 Total	
DZ-01-192 X GA-10-3 (RIL. 137)	1712.0	1326.6	1389.4	2625.0	2213.1	1853.2	1855.0	2477.5	2358.8	3662.9	2588.5	2180.0
DZ-01-192 X GA-10-3 (RIL. 158)	1773.7	1584.4	1716.9	3131.9	2015.6	2044.5	2359.4	1953.1	2259.4	3161.3	2433.3	2217.3
DZ-01-192 X GA-10-3 (RIL. 185)	1715.6	1303.9	1465.0	2937.5	2515.6	1987.5	2419.4	2270.6	2947.5	2767.6	2601.3	2260.3
DZ-01-192 X GA-10-3 (RIL. 198)	1704.5	1342.2	1630.0	2589.4	2240.6	1901.3	2043.8	2088.1	2190.0	2661.8	2245.9	2054.5
DZ-01-192 X GA-10-3 (RIL. 208)	1062.0	939.1	1611.9	2558.8	2077.5	1649.8	1683.8	1675.0	2125.6	2623.5	2027.0	1817.4
DZ-01-192 X GA-10-3 (RIL. 210)	2084.1	1255.5	1516.9	2200.6	1855.6	1782.5	1907.5	1964.4	2171.3	2689.8	2183.2	1960.6
DZ-01-192 X GA-10-3 (RIL. 218)	1948.2	1780.5	1635.0	2723.8	1840.0	1985.5	2281.3	1645.0	2462.5	2932.8	2330.4	2138.8
DZ-01-192 X GA-10-3 (RIL. 223)	2325.1	1444.5	1395.6	2197.5	2258.1	1924.2	2158.1	2171.3	2054.4	2601.9	2246.4	2067.4
DZ-01-192 X GA-10-3 (RIL. 235)	2117.6	1496.1	1470.0	2258.1	2050.6	1878.5	1721.9	2168.1	2003.8	2355.8	2062.4	1960.2
DZ-01-192 X GA-10-3 (RIL. 238)	1803.5	1317.2	1423.1	2879.4	2415.6	1967.8	1924.4	1901.3	2164.4	2366.8	2089.2	2021.7
DZ-01-192 X GA-10-3 (RIL. 252)	1588.3	1556.3	1863.8	3012.5	2000.6	2004.3	2316.3	2293.1	2576.3	2969.9	2538.9	2241.9
DZ-01-192 X GA-10-3 (RIL. 259)	2009.6	1335.2	1478.1	2670.6	1939.4	1886.6	1992.5	1934.4	2119.4	2665.0	2177.8	2016.0
DZ-01-192 X GA-10-3 (RIL. 260)	1492.2	1442.2	1458.8	2793.8	2016.3	1840.6	1863.8	2408.8	2030.6	2212.4	2128.9	1968.7
DZ-01-192 X GA-10-3 (RIL. 262)	2638.3	1707.8	1525.6	2598.8	2306.9	2155.5	1795.6	2380.0	2611.9	2725.8	2378.3	2254.5
DZ-01-192 X GA-10-3 (RIL.264)	1806.8	919.5	1325.6	2600.6	1865.0	1703.5	1656.9	1879.4	2045.6	1997.5	1894.8	1788.6
DZ-01-192 X GA-10-3 (RIL. 63)	1921.7	1189.8	1426.3	2509.4	1776.9	1764.8	1735.0	1844.4	1941.9	2755.8	2069.3	1900.1
DZ-01-192 X GA-10-3 (RIL. 68)	1751.7	1446.9	1455.6	2730.6	1801.9	1837.3	1930.0	1768.8	2340.0	2258.6	2074.3	1942.7
DZ-01-192 X GA-10-3 (RIL. 91)	1465.7	1656.3	1178.1	2792.5	2139.4	1846.4	2200.6	2003.8	2703.1	2779.6	2421.8	2102.1
DZ-Cr-409(Boset)	1340.9	1524.2	1445.6	2745.0	2016.3	1814.4	2080.0	1912.5	2475.6	2627.1	2273.8	2018.6
Local Check	1610.8	1024.2	1250.0	2061.9	1765.6	1542.5	1783.8	1953.8	2181.3	3488.0	2351.7	1902.1
Grand mean	**1793.6**	**1379.6**	**1483.1**	**2630.9**	**2055.5**	**1868.5**	**1985.4**	**2034.7**	**2288.2**	**2715.2**	**2255.9**	**2040.7**
R^2	**0.73**	**0.74**	**0.40**	**0.40**	**0.45**	**0.79**	**0.45**	**0.64**	**0.32**	**0.46**	**0.61**	**0.66**
CV(%)	**13.67**	**15.17**	**17.52**	**19.92**	**14.58**	**17.52**	**18.19**	**20.35**	**19.68**	**21.14**	**20.24**	**21.12**
LSD(0.05)	**	**	NS	NS	*	**	NS	NS	NS	*	**	**

Genotype performances at individual location and year

The tested tef genotypes showed inconsistence mean grain yield performance on the testing locations and over years. The average grain yield of DZ-01-192 X GA-10-3 (RIL- 262) was 2155.5 kg ha^{-1} which was the maximum grain yield recorded among tested genotypes across pooled environments during 2019 cropping season. Whereas, DZ-01-192 X GA-10-3 (RIL- 185) was high yielder (2601.3 kg $ha^{-1)}$ during 2020 cropping season (Table 5). During 2019 cropping season 2638.3 kg ha^{-1} grain yield was recorded by genotype DZ-01-192 X GA-10-3 (RIL- 262) from Axum testing site which was the second higher result next to Minjar 3131.9 kg ha^{-1}. In the next cropping season (2020) DZ-01-192 X GA-10-3 (RIL- 185) gave 2419.4 kg ha^{-1} grain yield at Alemtena followed by genotype DZ-01-192 X GA-10-3 (RIL- 137) 3662.9 kg ha^{-1} at Sirinka. This inconsistency may be due to the variation in the experimental locations and genotypes. The comparison of the RILs with the standard checks *Boset* variety showed the excelling grain yield performances of some RILs (Table 5). However, there was no single genotype exhibiting consistent superiority for grain yield across locations. On the contrary, the low yielding genotypes were DZ-01-192 X GA-10-3 (RIL-264) and DZ-01-192 X GA-10-3 (RIL-208) with the grain yield performance 919.5 kg ha^{-1} and 939.1 kg ha^{-1} at Debre zeit testing site during 2019 cropping season respectively.

Based on two years of multi-location trial, the genotype DZ-01-192 X GA-10-3 (RIL-185) was selected for its high grain yield performance of 2260.3 kg ha^{-1}. However, no single genotype performed best lodging tolerance than standard check (Boset). Therefore, there is no promising genotype for lodging tolerance that will be further tested in the variety verification trial.

Conclusion and Recommendation

The current experiment carried out on 20 semi-dwarf tef recombinant inbred lines that selected from DZ-01- 192 X GA-10-3 crosses of F7 single seed descent developed inbred lines. Results of evaluation of some promising lines of tef for lodging and yield improvement reveal that grain yield is significantly and positively associated with all traits. The genotype DZ-01-192 X GA-10-3 (RIL-185) gave the maximum of 2792.1 kg ha^{-1} pooled across two locations and years (Minjar and Sirinka) and at Axum and Alemtena the best performing lines were DZ-01-192 X GA-10-3 (RIL-262) and 192 X GA-10-3 DZ-01-192 X GA-10-3 (RIL-185). Therefore, it is recommended to use the selected genotypes for the experimental sites and related agro-ecologies. However, no genotypes tested were significantly superior in lodging tolerance characters to the standard check. Thus, none of the genotypes will be promoted for the further testing in the variety verification trial for release. Generally, evaluation of the mean performances of each trait at the six environments also clearly showed that some locations were

good enough for the accomplishment of some traits; while others were moderate or even the least for the performance of same traits.

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Evaluation of Tef (*Eragrostis tef*) Genotypes and Variety Development for Potential Growing Environments of Ethiopia

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Abstract

Fifty-one improved varieties of tef have been released until 2020 for production by the different Federal and Regional Agricultural Research Centers of Ethiopia. The productivity the crop is low though it has a potential yield that goes up to 6 t ha-1. These calls for further research and improvement. Hence, this experiment was initiated with the objective of evaluating the best performing lines selected from previous trials with respect to grain yield potential and stability in multi-location trial so as to eventually recommend the superior genotypes for further evaluation in the variety verification trials and possible release for the high potential tef growing areas. Twenty tef genotypes including a standard and local check were field evaluated using randomized complete block design with four replications of 4 m2 plots at fourteen environments during 2019/2020 (Year 1) and 2020/2021 (Year 2) cropping season. Pheno-agro-morphological data were collected and subjected to statistical analysis in order to identify the best genotypes. The difference in stability between genotypes was statistically significant ($P \leq 0.001$) showing genotype x environment interaction was the reason for the variation in yield and other traits of the genotypes across environments. The mean performance over environments exhibited that although some of the genotypes gave comparable grain yields, none of the tested genotypes showed a 10% yield advantage over the checks. Therefore, enhancing the germplasm base and extensive evaluation of genotypes from diverse source population would be compulsory.

Keywords: Negus, genotype, potential growing area, tef

Introduction

Plant breeding is a science and an art to develop new plant varieties. The varieties are being developed mainly through hybridization and/or selection. Debre Zeit Agricultural Research Center (DZARC) is the one that contributes a prominent role in the development agricultural technologies in the Ethiopia. DZARC has been taking the coordination of the National Tef Research Program since 1957. Over the years, 51 improved varieties have so far been released until 2020 for production by the different Federal and Regional Agricultural Research Centers

of the country, and DZARC provided 27 varieties of which 17 were obtained through hybridization. As the result of improved varieties, the national average grain yield which was about 0.7 t ha^{-1} (Habtegebrial *et al.*, 2007) was increased to 1.9 t ha^{-1} (CSA, 2021).

The long-sustained use of tef (*Eragrostis tef*) cultivation by the Ethiopian farmers, the current research needs and consumer-preference is due to its peculiar agronomic, dietary and forage virtues. The agronomic merit include it has versatile adaptation to different agro-ecologies with reasonable resilience to both drought and waterlogging better than most other cereals (Assefa *et al.*, 2010), aptness for various cropping systems and crop rotation schemes; usefulness as a consistent and low-risk catch crop at times of failures of other long-season crops such as maize and sorghum due to drought or pests; and little vulnerability to epidemics of pests and diseases in its major growing regions (Chanyalew *et al.*, 2019), and the dietary qualities contain that tef grain is gluten-free and contains all eight essential amino acids, as well as high contents of fiber, minerals, and vitamins (NRC, 1996), while the high feed quality, crude protein content, fast growth rate, and its suitability for multiple harvests gives the crop preference for forage (Davidson, 2018).

Owing to the aforementioned facts, the area coverage has been increasing from time to time and reported 3,101,177.38 ha, production volume of 5,735,710.187 ton that engaged 7,154,930 number private farmers with productivity mean of 1.9 t ha^{-1} (CSA, 2021). However, still the productivity is low as the crop has the potential yield that goes up to 6 t ha^{-1} (Ketema, 1993) and this calls for further research and improvement. Variety development is one effort, however, in tef it is prolix due to the painstaking task of crossing. Apart from hybridization, selection has also been used for tef improvement program. The genotypes developed using those techniques need to pass through several breeding steps until homozygosity achieved, and then these will be entered into series of performance tests and finally evaluated to multi-location variety/yield trials prior to getting into the variety verification trial for release. Therefore, this experiment was initiated with the objective of evaluating the best performing lines selected from previous trials with respect to grain yield potential and stability in multi-location trial so as to eventually recommend the superior genotypes for further evaluation in the variety verification trials and possible release for the high potential tef growing areas.

Materials and Methods

Plant materials

The twenty tef genotypes included in the study were sixteen recombinant inbred lines obtained from the cross between DZ-Cr-387 X DZ-01-99 and HO-TF-1486

X DZ-01-2787, a standard check variety DZ-Cr-429 (Neguse), a local check, and two selected landraces (Table 1). The activity was labeled as national variety trial late set, group two (NVT LS- GII).

Table 1 Description of genotypes used for the study

No.	Female (Ovule) parent	Male (Pollen) parent	Lines	Germplasm's collections
1	-	-	-	205321 from Minjar
2	-	-	-	205407 from Axum
3	DZ-Cr-387	DZ-01-99	RIL No. 38	
4	DZ-Cr-387	DZ-01-99	RIL No. 270	
5	DZ-Cr-387	DZ-01-99	RIL No. 279	
6	DZ-Cr-387	DZ-01-99	RIL No. 290	
7	DZ-Cr-387	DZ-01-99	RIL No. 346	
8	DZ-Cr-387	DZ-01-99	RIL No. 351	
9	DZ-Cr-387	DZ-01-99	RIL No. 357	
10	DZ-Cr-387	DZ-01-99	RIL No. 373	
11	HO-TFS-1486	DZ-01-2787	RIL No.112	
12	HO-TFS-1486	DZ-01-2787	RIL No.120	
13	HO-TFS-1486	DZ-01-2787	RIL No.18	
14	HO-TFS-1486	DZ-01-2787	RIL No.78	
15	HO-TFS-1486	DZ-01-2787	RIL No.96	
16	HO-TFS-1486	DZ-01-2787	RIL No.2	
17	HO-TFS-1486	DZ-01-2787	RIL No.23	
18	HO-TFS-1486	DZ-01-2787	RIL No.6	
19	Local check (farmers' variety) taken from the respective testing locations			
20	Standard check (Neguse / DZ-Cr-429 RIL 125)			

Experimental locations, seasons and design

The field experiment was carried out during the cropping season of 2019/2020 (Year 1) at five locations (Debre Zeit black soil, Minjar, Chefe Donsa, Ginchi and Axum) and 2020/2021(Year 2) at seven locations (Holetta, Ginchi, Worabe, Bichena, Minjar, Debre Zeit, Chefe Donsa). The data for some of the locations were excluded due to variance heterogeneity in the combined analysis. The field trial was carried out using randomized complete block design with four replications. The plot size was 2 m x 2 m ($4m^2$) with distances of 1 and 1.5 m between plots and blocks, respectively.

Experimental management and data collection

The materials were planted by hand drilling of seeds within rows spaced 0.2 m in each plot. The field trials were managed as per the research recommendation agronomic practices of the respective test locations. The following data were collected: days to heading was taken as the number of days from sowing up to the emergence of the tips of the panicles from the flag leaf sheath in 50% of the plot

stands, days to maturity was recorded as the number of days from sowing up to 50% of the plants in the plot reaching physiological maturity stage, grain filling period was recorded as the number of days from 50% heading to 50% maturity of the stands in each plot obtained by subtracting the former from the latter, shoot biomass yield *was taken as the* above ground total (shoot plus grain) biomass in gram for the entire plot, grain yield was taken as the weight of seeds harvested in gram from each plot, data on plant height was taken as the length from the base of the stem of the main tiller to the tip of the main shoot panicle at maturity recorded as the average of five plants per plot and measured in centimetre and panicle length is the length from the base of the main shoot panicle where the first branch emerges to the tip of the panicle at maturity recorded as the average of five plants per plot and measured in centimetre.

Data analyses

Hartley's (1950) F-max of homogeneity of variance test was deployed for individual location and year for each trait. A combined analysis of variance was done upon getting positive results from tests of homogeneity of variances. For the analysis of variance, appropriate models suitable for the experimental design were employed (Gomez and Gomez, 1984) using SAS software version 9.00 (SAS Institute, 2002).

Results and Discussion

Analysis of variance

The mean square from the pooled analysis of variance over eleven environments showed statistically significant genotype ($P \leq 0.001$) effects of grain yield implying that the genotypes tested were different. Likewise, environment indicates statistically ($P \leq 0.001$) significance difference suggesting the locations were diverse. The difference instability between genotypes is a wide occurrence of statistically significant ($P \leq 0.001$) genotype x environment interaction causes variation of yield and other traits (Table 2).

Table 2: Analysis of variance for grain yield across eleven environments

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-value	Pr F
Environment	10	87389621.38	8738962.14	49.44	<.0001
Genotype	19	11211881.17	590099.01	3.34	<.0001
Rep	3	6551629.15	2183876.38	12.36	<.0001
Genotype* Environment	190	55200266.93	290527.72	1.64	<.0001
Pooled error	657	116123658.3	176748.3		

Genotype performance

There was a cross- over type of interaction since the best genotype at one location become inferior at the other (Table 3 & 4). The overall mean grain yield performance of twenty tef genotypes for eleven environments ranged from 1263 kg ha^{-1} at Holetta (2020/21) to 3255 kg ha^{-1} at Minjar (2019/20). Minjar (Year 1 and Year 2) was the high yielding environment followed by Axum (Year 1), Ginchi (Year 2) and Worabe (Year 2). Whereas, Holetta (Year 2), Debre Zeit (Year 1), and Chefe Donsa (Year 2) were the low yielding environments. HO-TF-1486 X DZ-01-2787 RIL 18 gave the maximum grain yield of 3194 kg ha^{-1} and 3106 kg ha^{-1} at Minjar and Axum, respectively in Year 1 main season. Similarly, in the Year 2 HO-TF-1486 X DZ-01-2787 RIL 18 gave highest yield which is 3099 kg ha^{-1} at Minjar, then HO-TF-1486 X DZ-01-2787 RIL 23 resulted 3062 kg ha^{-1} and 2864 kg ha^{-1} at Minjar and Ginchi, respectively.

Table 3: Mean grain yield performance of 20 genotypes at five locations during 2019/20

No.	Genotype	2019/20 cropping season (Grain Yield kg ha^{-1})				
		Debre Zeit	Minjar	Chefe Donsa	Ginchi	Axum
1	205321	1734	1563	2056	2076	1323
2	205407	1804	2221	2079	2110	1990
3	DZ-Cr-387 X DZ-01-99 RIL 270	1664	2523	2070	1984	2574
4	DZ-Cr-387 X DZ-01-99 RIL 279	1871	1920	2029	2182	1806
5	DZ-Cr-387 X DZ-01-99 RIL 290	1403	2763	2119	2183	2524
6	DZ-Cr-387 X DZ-01-99 RIL 346	1879	2603	2045	1893	2346
7	DZ-Cr-387 X DZ-01-99 RIL 351	1738	2574	1936	2312	2327
8	DZ-Cr-387 X DZ-01-99 RIL 357	1918	1959	1641	2095	1890
9	DZ-Cr-387 X DZ-01-99 RIL 373	1729	2548	1773	1961	2071
10	DZ-Cr-387 X DZ-01-99 RIL 38	1619	2490	2041	1691	1814
11	HO-TF-1486 X DZ-01-2787 RIL 112	1761	2049	2036	1630	2677
12	HO-TF-1486 X DZ-01-2787 RIL 120	1296	2451	1828	1918	2812
13	HO-TF-1486 X DZ-01-2787 RIL 18	1684	3194	1947	2079	3106
14	HO-TF-1486 X DZ-01-2787 RIL 2	1597	1639	2014	2038	2305
15	HO-TF-1486 X DZ-01-2787 RIL 23	1665	2820	2169	2127	2515
16	HO-TF-1486 X DZ-01-2787 RIL 6	1599	2135	2079	1916	2547
17	HO-TF-1486 X DZ-01-2787 RIL 78	1373	2548	1636	2020	2638
18	HO-TF-1486 X DZ-01-2787 RIL 96	2203	2330	1846	2048	2349
19	Local Check	1983	2684	2181	2156	2785
20	Neguse	1547	3255	1813	1712	3016
Mean		1703	2413	1967	2006	2371
SE		50.33	69.72	32.23	37.94	57.93
CV (%)		26.12	18.84	14.33	16.79	13.04
LSD (0.05)		630.06	643.65	399.22	477.1	437.6

Table 4. Mean grain yield performance of 20 genotypes at six locations during 2020/21

No.	Genotype	2020/21 cropping season (Grain Yield kg ha^{-1})					
		Debre Zeit	Holetta	Ginichi	Worabe	Minjar	Chefe Donsa
1	205321	1864	1419	2563	2615	2251	1759
2	205407	1688	1846	2593	2367	2333	1822
3	DZ-Cr-387 X DZ-01-99 RIL 270	1962	1794	2006	2249	2617	2128
4	DZ-Cr-387 X DZ-01-99 RIL 279	2324	1978	2358	2439	2948	1616
5	DZ-Cr-387 X DZ-01-99 RIL 290	1730	1587	2731	1919	2226	1865
6	DZ-Cr-387 X DZ-01-99 RIL 346	2058	1660	2609	2187	2626	1858
7	DZ-Cr-387 X DZ-01-99 RIL 351	2138	1632	2293	2390	2588	2046
8	DZ-Cr-387 X DZ-01-99 RIL 357	2259	1702	2721	2383	2978	1357
9	DZ-Cr-387 X DZ-01-99 RIL 373	1970	1587	2536	2384	2278	1655
10	DZ-Cr-387 X DZ-01-99 RIL 38	1846	1639	2720	2169	2466	1734
11	HO-TF-1486 X DZ-01-2787 RIL 112	1478	1550	2178	1734	2455	1401
12	HO-TF-1486 X DZ-01-2787 RIL 120	2239	1659	2311	1616	2720	1714
13	HO-TF-1486 X DZ-01-2787 RIL 18	2258	1543	2504	2293	3099	1585
14	HO-TF-1486 X DZ-01-2787 RIL 2	2373	1263	2197	2001	2567	1792
15	HO-TF-1486 X DZ-01-2787 RIL 23	2223	1420	2864	2211	3062	1608
16	HO-TF-1486 X DZ-01-2787 RIL 6	1822	1497	2501	1854	2244	1414
17	HO-TF-1486 X DZ-01-2787 RIL 78	2018	1844	2475	2306	2722	1914
18	HO-TF-1486 X DZ-01-2787 RIL 96	2077	1726	2555	1986	2661	1583
19	Local Check	2099	1579	1875	2359	2451	1744
20	Neguse	2259	1749	1584	2180	2865	1507
Mean		2034	1634	2409	2182	2608	1705
SE		50.06	41.69	63.93	57.91	57.850	40.77
CV (%)		19.87	17.21	22.94	21.71	17.98	15.94
LSD (0.05)		572.44	398.12	782.29	704.8	663.99	385

The mean performance among the genotypes showed significant genotype effects on grain yield. Indeed, as grain yield has been the primary goal of the tef improvement program (Kebebew *et al.*, 2010), the tested genotypes HO-TF-1486 X DZ-01-2787 RIL18, HO-TF-1486 X DZ-01-2787 RIL 23, DZ-Cr-387 X DZ-01-99 RIL 270 and DZ-Cr-387 X DZ-01-99 RIL 351 in that diminishing order had good yield (Table 5). However, none of the tested genotypes showed a 10 percent yield advantage over the checks. In the study, HO-TF-1486 X DZ-01-2787 RIL 18 revealed the maximum yield advantages 7.68% and 5.84% over the standard and local checks, respectively. In this regard, it is to be noted that if any late maturing genotype is to be promoted to the variety verification trial for potential growing environments, it is expected to out-perform the standard check variety Neguse and the recently released variety " Bishoftu" at least with 10%

grain yield advantage while having comparable or better seed quality to these checks in terms of the whiteness of the color. Therefore, there is no promising genotype that will be further tested in the variety verification trial.

Table 5 Mean pheno-agro-morphological performance of 20 genotypes at eleven environments.

Genotype	Days to heading (days)	Days to maturity (days)	Grain filling period (days)	Plant height (cm)	Panicle length (cm)	Shoot biomass yield (kg ha^{-1})	Grain yield (kg ha^{-1})
DZ-Cr-387 X DZ-01-99 RIL 270	62	121	60	98	42	11151	2225
DZ-Cr-387 X DZ-01-99 RIL 279	61	141	80	93	41	9327	1988
DZ-Cr-387 X DZ-01-99 RIL 290	63	122	59	97	41	9735	2181
DZ-Cr-387 X DZ-01-99 RIL 346	58	120	62	95	41	9128	2168
DZ-Cr-387 X DZ-01-99 RIL 351	59	120	61	96	41	9520	2208
DZ-Cr-387 X DZ-01-99 RIL 357	61	121	60	92	40	8844	1992
DZ-Cr-387 X DZ-01-99 RIL 373	58	118	59	93	40	9253	2060
DZ-Cr-387 X DZ-01-99 RIL 38	61	123	62	95	41	9824	2037
HO-TF-1486 X DZ-012787 RIL 112	63	123	60	97	41	8994	1904
HO-TF-1486 X DZ-01-2787 RIL 120	60	119	58	94	41	9506	2051
HO-TF-1486 X DZ-01-2787 RIL18	63	123	60	96	41	10253	2299
HO-TF-1486 X DZ-01-2787 RIL 2	64	123	58	96	41	9196	1902
HO-TF-1486 XDZ-01-2787 RIL 23	61	123	61	95	42	9642	2234
HO-TF-1486 XDZ-01-2787 RIL. 6	63	123	60	96	42	9526	2079
HO-TF-1486 XDZ-01-2787 RIL 78	58	122	64	92	40	9392	2037
HO-TF-1486 XDZ-01-2787 RIL 96	59	121	62	97	41	9361	2197
205321	56	120	63	90	36	8935	1929
205407	57	122	65	93	40	9406	2078
Local Check	57	120	63	89	37	10247	2172
Niguse	55	118	63	87	37	9551	2135
Mean	60	122	62	94	40	9540	2094

SE	0.43	0.84	0.51	0.73	0.22	127.92	18.99
CV (%)	4.4	3.4	6.81	8.6	8	32.9	19.2
LSD (0.05)	1.104	14.32	12.41	3.41	1.34	1314.6	168.4

Conclusion and Recommendation

It can be concluded that under national variety trial late set Group II, genotypes showed statistically significant difference. However, none of the tested genotypes showed a 10 percent yield advantage compared to the standard check Neguse. Consequently, there was no any genotype that could be promoted for further testing in the variety verification trial for release. Therefore, enhancing the germplasm base and extensive evaluation of genotypes from diverse source population would be compulsory for tef breeding targeting high potential environments in the future.

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Genotype by Environment Interaction and Grain Yield Stability Analysis of Advanced Tef Genotypes for High Potential Tef Growing Areas of Ethiopia

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Abstract

Tef [Eragrostistef (Zucc.)Trotter]) is one of the most important cereal crops grown in Ethiopia. It's the first crop in terms of acreage, however, its production has been partly constrained by low yield and less stability of the genotypes under cultivation. This study was conducted to estimate genotype by environment (GE) interactions and stability analysis in tef genotypes in the highlands of Ethiopia. Eighteen promising recombinant inbred lines plus one standard and one check varieties were evaluated in six environments under rain fed conditions using the randomized complete block design with four replications. AMMI analysis showed that tef grain yield was highly significantly ($p < 0.001$) affected by environments (E), genotypes (G) and genotype × environment interaction (GEI) indicating the presence of genetic variation and possible selection of stable entries. 50.57% of the total sum of squares was justified by environmental fluctuations exhibiting that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield. GEI was further partitioned by principal component analysis. The first two multiplicative axis terms (PCA1, and PCA2) explained 45.51% and20.69% (66.2%) of GEI sum of squares, respectively. The mean grain yield value of tested genotypes averaged over environments indicated that G4 (HO-TF-1486 x DZ-01-2787(RIL No. 173) had the highest grain yield (2827 kgha-1) compared to the standard check variety Negus (2565 kgha-1). In addition, this variety proved stable across environments for grain yield during the variety evaluation experiment. The genotype will be promoted to variety verification trial to be evaluated by the national variety released committee for possible release as a new variety in the year 2021/22.

Keywords: AMMI analysis, Stability, Genotype by environment interaction, Tef Genotypes

Introduction

Tef is the most important staple cereal crop in Ethiopia that adapts to extreme environmental conditions and present in diverse socio-economic conditions. It is the first staple crop in terms of area coverage and consumers preference in Ethiopia, however the average grain yield is still low which is 1.85 tha^{-1} (CSA. 2020) Genetic improvement of crop varieties play a pivotal role in the development of tef research industries in almost all tef growing regions. Crop

performance is a function of genotype, environment, and genotype by environment interactions (GEI). Effects of genotype, environment and genotype × environment interaction determine the phenotypic performance and its general and specific adaptation to different environments [Falconer, and Mackey, 1960]. This information is required for planning better selection strategies and to identify the best environment to select genotypes for grain yield (Gauch 2013; Kang, 1998)

Yield is a complex character which is dependent on a number of other characters and is highly influenced by many genetic factors as well as environmental fluctuations. One of the most exigent issues in plant breeding progress is to perfectly dissect genotype x environment (G x E) interaction, because it is based on figures from multi-environment experiments (Alemayhu, 2020). In most trails, the G x E interaction is witnessed and then modeled statistically and elucidated. Genotype x environment interaction adjusts the reasonable grain yield of genotypes in diverse environments and makes it. Thus, the understanding of G x E interaction enables breeders to determine optimum breeding strategy to make informed choices of the locations and input systems to be used in the breeding efforts and to develop and release crop varieties suitable for various agro-ecologies. As there are very limited studies on G x E in tef crop, the importance of conducting more studies across major tef growing environments have been suggested (Habte *et al.,* 2019; Yazachew *et al.,* 2020). Therefore, breeders will be able to identify adaptable, stable and high yielding genotypes.

Additive main effects and multiplicative interaction (AMMI) and the genotype and genotype by environment (GGE) are some of the most widely used stability models to estimate the magnitude of GE interactions (Giridhar *et al*., 2016; Munawar *et al.,* 2013). To identify high yielding and better adapted genotypes (Oliveira *et al*., 2010). GGE biplot, especially, is useful, to graphically represent the GE interaction, and to rank the studied genotypes and environments (Yan *et al.,* 2006). The AMMI model is a hybrid model involving both additive and multiplicative components of two-way data structure which enabled a breeder to get precise prediction on genotypic potentiality and environmental influences on it. It has been intensively used recently, since it incorporates both the classical additive main effects for GEI and the multiplicative components into an integrated least square analysis and thus become more effective in selection of stable genotypes (Dewi *et al.,* 2014; Frutos *et al*., 2015). AMMI uses ordinary ANOVA to analyze the main effects (additive part) and principal component analysis (PCA) to analyze the non-additive residual left over by the ANOVA (Yan *et al*., 2000). The effectiveness of AMMI procedure has been clearly demonstrated by various authors using multi-location data in tef (Alemayh, 2020; Habte *et al*., 2019; Yazachew *et al.,* 2020). G x E interaction analysis or testing genotypes for wide and specific adaptation to a micro environment is a paramount for yield stability of tef varieties. Therefore, the present study was undertaken to analyze

the magnitude of GEI and evaluate the adaptability and stability of recombinant tef genotypes for grain yield, using Additive Main Effects and Multiplicative Interaction (AMMI) model.

Materials and Methods

Plant materials

Eighteen recombinant inbred lines from two crossing parental lines plus a standard check and local check were evaluated in multi-environments; however, for the sake of homogeneity of variance, data analyses of only seven environments were used. The 18 promising recombinant inbred lines were obtained through single seed descent (SSD) method from two different crosses (Table 1). From the two crosses Ho-TF-1486 and Quncho (DZ-Cr 387 RIL355) were used as the ovule parent while cultivar DZ-01-2787 and DZ-01-99 were used as pollen parent. Cultivar Ho-TF-1486 is characterized by high number of florets per spikelet and hence used to pyramid yield traits into the cultivar DZ-01-2787 which is very white seed. Likewise, the variety DZ-01-99 was the paternal parent for nine of the 18 RILs, and the cross of variety Quncho with DZ-01-99 aimed at introgressing higher panicle length for yield. The standard check variety was the variety Nigus released in 2017 (Yazachew *et al.,* 2020) for agro-ecologies similar to the particular set of test locations and classified as high potential tef growing areas. On the other hand, the local check is a farmers' variety commonly grown around each of the respective test locations

Table 1. Detailed descriptions of the genotypes used for the study

Designation no.	Genotypes	Maturity type
G1	Variety Nigus /standard check/	Late set
G2	HO-TF-1486 x DZ-01-2787(RIL No. 146)	,,
G3	HO-TF-1486 x DZ-01-2787(RIL No. 167)	,,
G4	HO-TF-1486 x DZ-01-2787(RIL No. 173)	,,
G5	HO-TF-1486 x DZ-01-2787(RIL No. 190)	,,
G6	HO-TF-1486 x DZ-01-2787(RIL No. 201)	,,
G7	HO-TF-1486 x DZ-01-2787(RIL No. 239)	,,
G8	HO-TF-1486 x DZ-01-2787(RIL No. 242)	,,
G9	HO-TF-1486 x DZ-01-2787(RIL No. 257)	,,
G10	HO-TF-1486 x DZ-01-2787(RIL No. 297)	,,
G11	DZ-Cr-387 x DZ-01-99(RIL No. 41)	,,
G12	DZ-Cr-387 x DZ-01-99(RIL No. 67)	,,
G13	DZ-Cr-387 x DZ-01-99(RIL No. 97)	,,
G14	DZ-Cr-387 x DZ-01-99(RIL No. 114)	,,
G15	DZ-Cr-387 x DZ-01-99(RIL No. 160)	,,
G16	DZ-Cr-387 x DZ-01-99(RIL No. 185)	,,
G17	DZ-Cr-387 x DZ-01-99(RIL No. 209)	,,
G18	DZ-Cr-387 x DZ-01-99(RIL No. 242)	,,
G19	DZ-Cr-387 x DZ-01-99(RIL No. 244)	,,
G20	Local cultivar	,,

G1- G20= genotype code

Experimental Design and Management

The field experiment was conducted using a randomized complete block design with four replications of 2 m x 2 m ($4m^2$) plot size during the two main cropping seasons of 2019 and 2020. The field experiment was managed as per the research recommendation of agronomic practices of the respective test locations.

Data Collection

Grain yield (g) of each plot was measured on clean, sun-dried seed and the measured grain yield value (g) was converted to kilogram per hectare for data analysis.

Statistical analysis

First analysis of variance was made for each of the environments to know the existence of genetic variability among experimental genotypes and to verify homogeneity of the error variances. The combined analysis of variance of the environment (location) and genotypes was performed, to identify the possible interactions of genotypes with environments. For the analysis of variance, Proc GLM (general linear model) suitable for the experimental design were employed using SAS software version 9.00 (SAS 2002). Adaptability and stability analyses were done using the multivariate AMMI and GGE-biplot methods after the significance of the GxE interaction was determined.

AMMI and GGE biplot analysis

The AMMI and GGE biplot package in R software, GEA-R (2015) version 2.0 was used for the analyses. The AMMI method combines ANOVA and PCA into a single analysis with both additive and multiplicative parameters (Gauch, 2013). The first part of AMMI uses the normal ANOVA procedures to estimate the genotype and environment main effects. The second part involves the PCA of the interaction residuals (residuals after the main effects are removed). The interaction G × E was analyzed in an AMMI model (Gauch, 2013) with a view to identify tef genotypes better adapted to different environments. AMMI's stability value (ASV) was calculated. Stability per se might not be the only selection parameter because the most stable genotypes do not necessarily have the best yield performance (Lotan *et al.,* 2014; Mohammadi *et al.,* 2007)**.** Both yield and stability were incorporated in a single index to classify stable genotypes. The genotype stability index (GSI) considered the ranks of the genotype yields across environments and AMMI stability values. This index incorporates the yield mean and stability index in single criteria and is calculated as: GSI = RASV+RY where RASV is the rank of ASV and RY the rank of mean genotype yield of all environments.

The GGE-biplot methodology, which is composed of two concepts, the biplot concept (Gabriel, 1971) and the GGE concept (Yan *et al*., 2000) was used to

visually analyze the multi-environment yield trial (MEYTs) data. This methodology uses a biplot to show the factors (G and GE) that are important in genotype evaluation and that are also sources of variation in GEI analysis of MEYTs data (Yan, 2001; Yan *et al*., 2000). The data were graphically analyzed to interpret the GxE interaction to identify stable and adaptive genotypes by the GGE biplot, as described by (Yan & Tinker, 2006). The lines that connect the test environment to the biplot origin are called environment vectors and the cosine of the angle between the vectors of two environments approximates the correlation between them (Yan *et al*., 2007).

Results and Discussion

Additive Main Effect and Multiplicative Interaction (AMMI) analysis of variance

AMMI variance analysis for grain yield of 20 tef genotypes tested in seven environments is presented in Table 2. AMMI analysis indicated variation among E, G and G×E showed highly significant different at level ($P< 0.001$), indicating the presence of genetic variation and possible selection of stable entries. The partitioning of sum squares (SS) indicated that environment effect was a predominant source of variation followed by GE and genotype effect. In genotype variation, E explains most of the variation, when variations of G and G×E are usually smaller (Yan, 2001).

The application of AMMI model for partitioning of GEI (Table 2) also revealed the first two principal component axis (IPCAs) of AMMI were highly significant ($P< 0.001$) and ($P< 0.05$), respectively using an approximate F-statistic (Gollob, 1968). The AMMI with IPCA1 and IPCA2 is the best predictive model for cross validation of the yield variation explained by the GEI (Habte *et al*. 2019; Tsion *et al.,* 2020; Yazachew *et al.,* 2020) Components of variation of ANOVA from additive main effect and multiplicative interaction (AMMI) for grain yield showed highly significant ($p \leq 0.001$) for genotypes and environments and genotype by environment interaction (GEI) effects. The effect of environment, genotypes and genotype by environment interaction accounted for 50.57%, 14.72% and 34.71% of the total sum squares (Table 2), respectively. A large sum of squares for environments indicated that the test environments were diverse with large differences among environmental means which causing most of the variation in grain yield. Therefore, this result designated the reliability of the multi-environment experiments. The variation in temperature, rainfall, soil type, soil fertility, and moisture availability might be the main reasons for the presence of variation. The AMMI analysis also showed that the first interaction principal component (PC1) and second interaction principal component (PC2) explained 45.51% and 20.69% of the interaction sum squares, respectively. Thus, the mean squares for the IPCA1 and IPCA2 cumulatively contributed to 66.2% of the total GEI. The model was adequate enough to explain the total genotype × environment

interaction component (Yan, 2001). The mean squares for PC1 were highly significant ($p< 0.01$) effect GEI for grain yield. The significant interaction indicated that the genotypes respond differently across different environments. The significant variability of genotypes traits showed in the present study for different traits of tef genotypes are in agreement with the previous report by different authors for genotype variability (Habte *et al*., 2019; Tsion *et al*., 2020; Yazachew *et al*., 2020)

Table 2. ANOVA table for AMMI model

Source	D.F.	S.S.	M.S.	V.r.	F pr	Explained GEI SS %
Treatments	119	72639632	610417	4.19	<0.001	
Genotypes (G)	19	10688999	562579	3.87	<0.001	14.72
Environments (E)	5	36735794	7347159	8.73	<0.001	50.57
Block	18	15156138	842008	5.79	<0.001	
Interactions (G*E)	95	25214840	265419	1.82	<0.001	34.71
IPCA 1	23	11474923	498910	3.43	<0.001	45.51
IPCA 2	21	5218037	248478	1.71	0.0280	20.69
Residuals	51	8521879	167096	1.15	0.2378	
Pooled Error	342	49771093	145530			

DF = degree of freedom, S.S = Sum squares, V.r= F calculated value, Fpr = F probability Value

Grain yield mean performance and stability of genotypes

The mean yield performance and stability of genotypes was evaluated by an average environment coordination (AEC) method (Yan, 2001). The average grain yield of each environment and genotype are given in Table 3. The mean grain yield performances of the 20 advanced tef genotypes at each of the six environments are presented in Table 3. The overall mean grain yield of the 20 tef genotypes for the six environments ranged the lowest from 2241 kg ha^{-1}(G8) at Chefe-2020 to the highest 3093 $kgha^{-1}$ (G4) at Minjar-2020. Among the tested genotypes G4 was the top yielder at four environments (Minjar 2019 and 2020, Ginchi 2019). Overall, the genotype code G4 (candidate variety), performed better than others, at least it is high yielder at four environments. The huge variability in the grain yield among the 20 tef genotypes at the six environments might be due to wide variability in climatic and soil conditions. This finding is in accordance with previous studies (Habte *et al.*, 2019; Tsion *et al.*, 2020; Yazachew *et al*.2020) that reported similar situations in which it confirmed complications of selection and recommendations of stable genotype across environment.

Table 3. Grain yield performance and superior stability coefficient ranks across six environments

No.	Minjar -2019	Minjar -2020	Chefe -2020	Ginchi -2019	DebreZeit -2020	Axum -2019	Mean	Stability Coefficient rank
G1	2591	2861	2166	2487	2340	2960	2567±120	105263 (7)
G2	2491	3047	2444	2440	2661	2479	2594±88	88973 (5)
G3	2279	3179	1791	2136	2159	2512	2343±104	196335 (17)
G4	3163	3622	2564	2470	2358	2787	2827±106	12047 (1)
G5	2754	3196	1664	2185	2356	2369	2421±123	15917 (12)
G6	2598	3577	2584	2350	2417	2778	2717±142	38494 (3)
G7	2970	3438	1596	2525	2477	2561	2594±140	116383 (8)
G8	1628	3133	1529	2422	2064	2280	2176±123	393203 (20)
G9	2722	3352	2307	2537	2091	2736	2624±108	65232 (4)
G10	2754	2917	2386	2487	2622	2240	2568±88	105143 (6)
G11	3137	3229	2455	2509	2472	2616	2736±110	29759 (2)
G12	2509	3242	2121	2477	2300	1849	2416±121	186542 (16)
G13	2394	2703	2284	2441	2398	2043	2377±81	208460 (18)
G14	2564	3188	2238	2488	2051	2191	2453±119	142246 (9)
G15	2644	3045	2501	2310	2406	1796	2450±99	175458 (14)
G16	2186	3252	2387	2530	2469	2117	2490±121	159725 (13)
G17	2465	2886	2586	2533	2677	2137	2547± 93	142539 (10)
G18	2429	2694	2441	2448	2398	2124	2422+81	185912 (15)
G19	2608	2747	2657	2415	2565	2162	2525+73	144878 (11)
G20	2230	2546	2114	2293	2454	2452	2348+66	224246 (19)
Mean	2556	3093	2241	2424	2387	2359	2510+24	
CV (%)	17	15	17	12	25	15	16	
LSD (0.05)	630	673	552	428	553	519	239	

CV= Coefficient of variation, LSD = least significant difference

The significant GEI in the present study indicates unstable performance of the tef genotypes across the testing environments (Figure 1, 2 & 3). Thus, it implied that the genotypes respond differently across the different environments. In genotype x environment interaction (GEI) the result exhibited the genotypes gave statistically higher grain yield (10.13%) than the standard check variety. In addition to this, considering the current tef grain price, 46 Birr kg^{-1}, there was an economically meaningful difference among tested genotypes. Therefore, one promising candidate variety, Genotype Code G4, gave grain yield 2827 kg ha^{-1} compared to the standard check variety Negus depicting grain yield of 2567 kg ha^{-1}. Therefore, genotype Code G4 has been recommended for variety verification trial to be evaluated by the National Variety Release Technical Committee (NVRTC) for possible release as new commercial Variety.

Stability analysis

The visualization of a 'which-won-where' pattern in multi-environment trials is essential to study adaptability of genotypes in the specific or across all test environments Yan & Tinker, 2006). The vertex genotypes were the most responsive for being located at the greatest distance from the biplot origin. The genotypes with either the best or poorest performance in one or all environments were considered responsive Yan & Tinker) falling within the sectors. The GGE biplots of graph results was used to show the relative performance of all genotypes at a specific environment (Figure 3) falling within the sectors. The GGE biplots of graph result was used to show the relative performance of all genotypes at a specific environment (Figure 3)

In the average environmental coordinate (AEC) system, AEC X axis (PC1) passes through the biplot origin with an arrow indicating the positive end of the axis and indicates the mean performance axis of genotypes. The ATC Y-axis passes through the biplot origin and is perpendicular to the ATC X-axis. This axis indicates the stability axis (PC2) (Figure 1). Based on these, statistically, the stable genotypes located near the AEC X axis (PC1) with PC2 scores of almost zero. According figure 1 and 2, genotype code G11, G6 and G4 were the most stable genotypes. The genotype code G8, G20, G13, G3 and others were less stable because of the high PC2 values and they were adapted for specific environments. In respect to total environment, the stability and high yield should be considered together when making the selection. Because G11, G6, and G4 genotypes were closest to zero in respect to PC2, these genotypes were more stable with above average yield. Therefore, the genotype with stable and high yield can be considered as commercial for the high potential tef growing region in Ethiopia. In addition to GGE biplot graph, genotype superiority with the small measured coefficient value indicates the more stable genotypes (Table 3). Therefore, from the present study, genotype code G4 /RIL No. 173/ was the most stable and high yielder and genotype code G4/ RIL No. 242/was the most unstable and low yielder genotypes, respectively. This result is in accordance with the previous studies (Chekol *et al.*, 2020; Yazaachew *et al.*,2020).

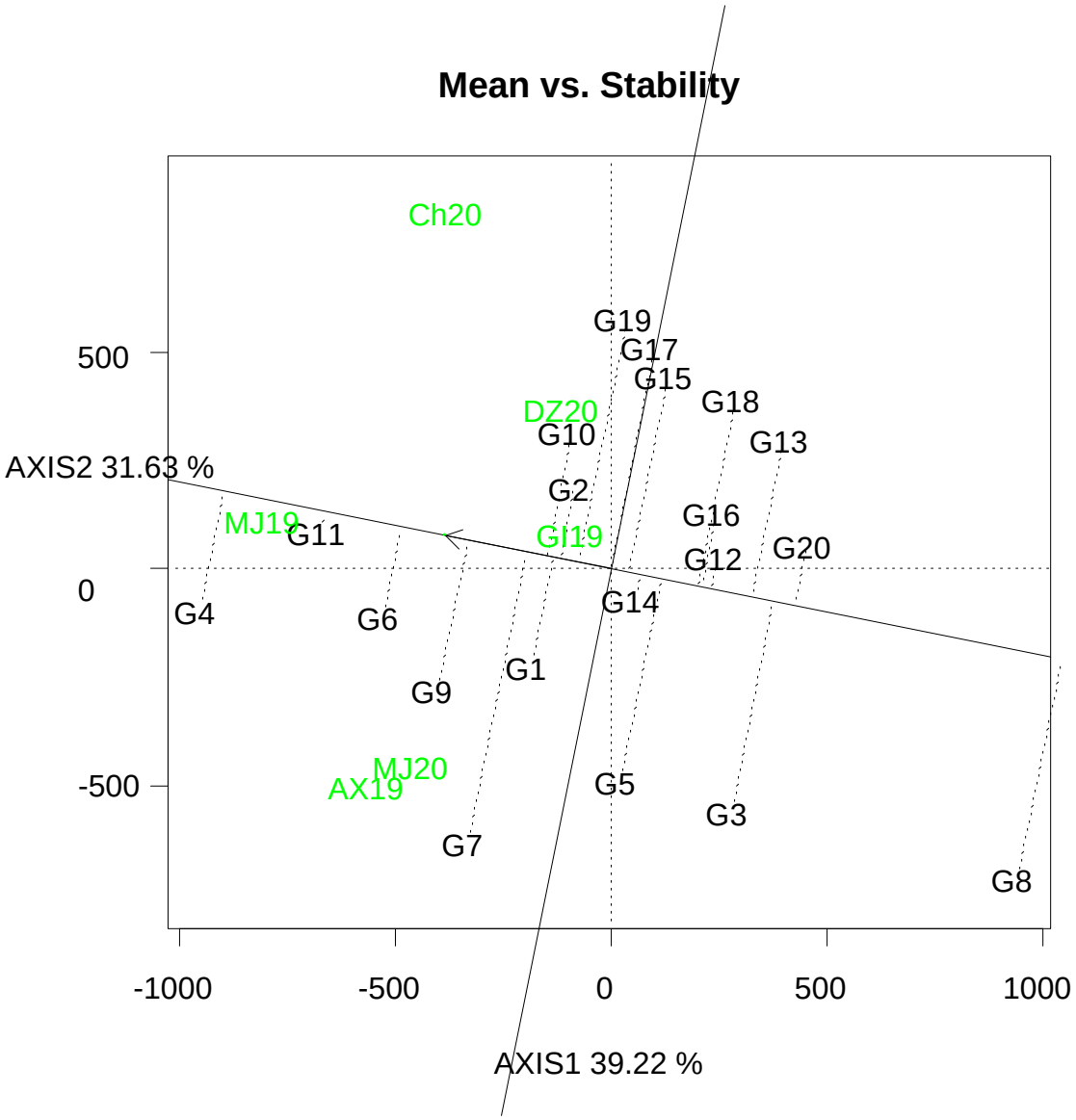

Figure 1: Stability and mean performance of genotypes to show ranking genotype based on both mean and stability

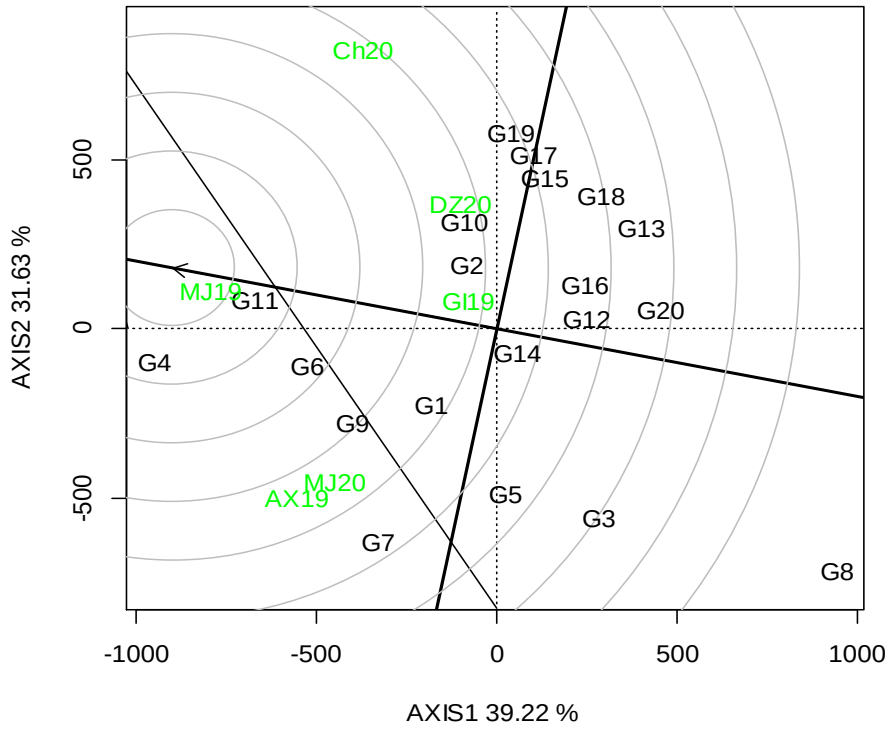

Figure 2: The average-environment coordination (AEC) view to rank genotypes relative to an ideal genotype (the center of the concentric circles)

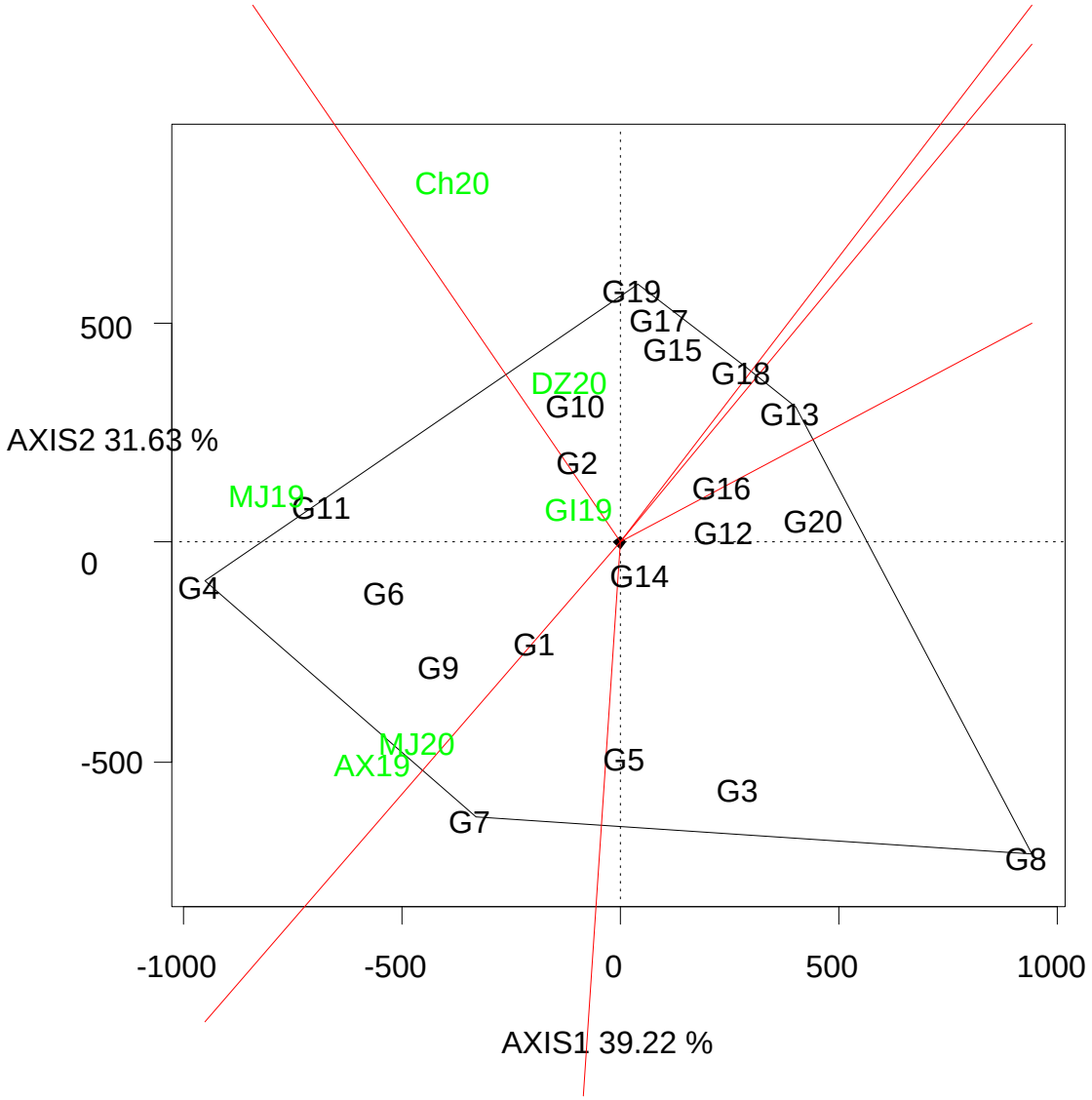

Figure 3: which-won-where view of the GGE biplot to show which genotypes performed bets in which environments.

Conclusion and Recommendation

The results of AMMI analyses indicated that tef grain yield performances were highly affected by environmental factors followed by the magnitude of GEI and genotype contributed the least effect. The AMMI and GGE biplot analysis permitted estimation of interaction effect of a genotype in each environment and it helped to identify genotypes best suited for specific environments. GGE biplot analysis showed that the polygon view of a biplot is the best way to visualize the interaction models between genotypes and environments. According to the

AMMI and GGE biplot, considering simultaneous average yield and stability, G4 and G11 genotypes were the best genotype across all tested environment. Therefore, Genotype code G4 (HO-TF-1486 x DZ-01-2787(RIL No. 173) should be used as a commercial variety for potential tef growing areas to increase tef productivity and production in the country after the NVRC approves it in the variety verification trial.

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Development of Bread Wheat (Triticum aestivum L.) Genotypes for Low Moisture Stress Areas of Ethiopia

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Abstract

Multi-environment trials were carried out for 47 advanced bread wheat genotypes and 3 standard checks in low moisture stress environments of Ethiopia from 2019 to 2020 rainy seasons to evaluate the genotypes and identify high yielding and stable genotypes. The genotypes were arranged in Row-Column Design and replicated three times across all environments. Data were collected for days to 50% heading (DTH), days to 90% maturity (DTM), plant height (PHT), thousand kernel weight (TKW), hectoliter weight (HLW) and grain yield (GY) and subjected to analysis of variance using R software. The results indicated that environment (E), genotype (G), and E x G interaction were highly significant at (P<0.01) for grain yield. The Environment sum of square was higher (63.54%) than the Genotype (8.65%) and GEI (17.87%) component sum of squares indicating the environment has significant impact on performance of the genotypes for grain yield. The genotypes, viz., ETBW17-365 (5.18 t ha-1), BW172071 (5.20 t ha-1), ETBW9581 (5.24 t ha-1), ETBW9578 (5.30 t ha-1), ETBW9065 (5.36 t ha-1), ETBW9136 (5.42 t ha-1), and BW173528 (5.61 t ha-1) showed superior performances over the best standard check, DEKA (4.81 t ha-1). AMMI stability analysis identified z. ETBW173528 and ETBW17-365as high yield and stable genotypes and could be recommended for variety verification trial in the coming seasons.

Keywords: Bread wheat, Genotypes, Yield, Moisture Stress, Stability.

Introduction

Wheat is one of the most important cereal crops widely cultivated in Ethiopia. Among the wheat species bread wheat (*Triticum aestivum* L.) and durum wheat (*Triticum turgidum var. durum* L.) are the two species that are mainly cultivated by large and small-scale farmers in Ethiopia. The average national wheat productivity is about 3.00 tons/ha (CSA, 2020; FAO, 2020); and is very low as compared to the research station (6-7 tha^{-1}). In contrast, the potential yield is about 5 t ha^{-1} in high elevated wheat agro-ecolgies of the country (Fisseha *et al*., 2020). The yield gap observed could be attributed to different factors viz. lack of high yielding and unstable varieties with poor production packages in low moisture growing environments.

Multi-environment trials are important in variety development for evaluating genotypes for stability and adaptability. Estimating the magnitude of genotype by environment (GE) interaction is important at final stage of selection based on grain yield (Yan and Hunt, 1998). Significant G × E interaction is a consequence of variations in the extent of differences among genotypes in diverse environments called qualitative or rank changes or variations in the comparative ranking of the genotypes called a quantitative or absolute difference between genotypes (Falconer, 1952; Fernandez, 1991).

Evaluation of different genotypes in a multi-environment (locations and years) is not only important to determine high-yielding cultivars but also to identify sites that best represent the target environment (Yan, 2001). A high-yielding cultivar should have a stable performance and broad adaptation over a wide range of environments. A genotype or cultivar is considered stable if it has adaptability for a trait of economic importance across diverse environments. The genotypes and GEI are relevant and meaningful in analysis of variance to evaluate the performance of cultivars and considered simultaneously for making selection decisions (Yan & Kang, 2003). In multi-environment trials, it is important to compare cultivars based on grain yield performances with other agronomic traits. In Ethiopia, the moisture stresses wheat growing environments are characterized by high GEI. Evaluation of the genotypes for adaptability and stability for grain yield are usually practiced before registration as commercial variety. Hence, the objectives of the study were to evaluate the genotypes across moisture stress environment and identify high yielding and stable genotypes.

Materials and Methods

Forty-seven advanced genotypes and three standard check bread wheat varieties were tested at four locations from 2019 to 2020 in moisture stress areas of Ethiopia. The genotypes were arranged in row-column design in three replications. All other agronomic recommendations are applied uniformly to all treatments. Finally, data was recorded for days to 50% heading (DTH), days to 90% maturity (DTM), plant height (PHT), thousand kernel weight (TKW), hectoliter weight (HLW) and grain yield (GY). The data was subjected to different statistical analysis.

Data analysis

Analysis of variance was carried out using AMMI model to partition the different sources of variation into environment, genotype and environment x genotype interaction sum of square (Yan, 2011). Different stability models (ASV and YSI) were used to identify the most stable and high yielder genotypes (Purchase, 1997). All data analyses were run by R software. In addition, diseases data were used to supplement the identification of varieties.

Results and Discussion

Analysis of variance

Analysis of variance indicated that environment, genotype and genotype x environment were significant ($P<0.01$) on grain yield (Table 1). The environmental component of variance was higher than the genotype and genotype x environment sum of square, and the environment sum of square contributed about 63.54% while the genotype and the genotype x environment sum of square contributed about 8.65 % and 17.87 %, respectively. This indicated that the environmental variations were higher and affecting the performance of the advanced genotypes. Terminal drought in most of the testing sites probably the reason to obtain low grain yield at Asasa, Melkassa, Dhera and Alemtena. Different researchers also reported similar results (Alemu *et al*., 2021; Gadissa *et al*., 2020) for grain yield of bread wheat genotypes evaluated in low moisture stress areas of Ethiopia.

Mean performance of the genotypes for grain yield

The grain yield performance of the advanced genotypes is presented in Table 2. The mean grain yield of the genotypes ranged from 3.42 t/ha (ETBW9119) to 5.61 t/ha (BW173528) with average value 4.61 t/ha. About 56 % of the genotypes produced higher yield than the average value. The top yielder genotypes include; ETBW17-365 (5.18 t/ha), BW172071 (5.20 t/ha), ETBW9581 (5.24 t/ha), ETBW9578 (5.30 t/ha), ETBW9065 (5.36 t/ha), ETBW9136 (5.42 t/ha), and BW173528 (5.61 t/ha). The best standard check DEKA gave 4.81 t/ha. The environmental variations were displayed on the performance of the overall genotypes and the environmental mean yield ranged from 2.17 (Kulumsa 2020) to 6.65 t/ha (Kulumsa 2019) indicating the year variations was also larger. Kulumsa 2020 was the worst environment due to terminal moisture stress and low soil fertility problem due to high floods in the wheat fields; while the Kulumsa 2019 was the highest yielding environment. The grand mean for the environment was 4.61 t/ha and the following environments: Asasa 2019, Kulumsa 2019, Melkasa 2019, Asasa 2020 and Dhera 2020 were the top yielding environments. On the other hand, Dhera 2019, Alemtena 2020, Kulumsa 2020 and Melkasa 2020 were the low yielder environments. Similar results were reported for the Melkasa and Dhera environments by Alemu *et al*. (2021) with low yielding potential due to moisture stresses. Though Kulumsa site is not categorized under moisture stress environment, in 2020 cropping season due to intensive rainfall at beginning of the season which aggravated soil erosion and terminal stress at the crop maturity, it tremendously reduced the yield.

Table 1. AMMI Analysis of variance for grain yield of advanced bread wheat genotypes grown in 9 environments of low moisture stress areas of Ethiopia

Sources of variation	DF	sum sq	Mean sq	F value	Pr(>F)	Percent variance (%)	Cumulative variance (%)
ENV	8	2808.98	351.12	396.53	0		
Rep (ENV)	8	7.08	0.89	2.03	0		
GEN	49	382.64	7.81	17.88	0		
ENV*GEN	384	790.3	2.06	4.71	0		
PC1	56	242.79	4.33	9.93	0	48.6	48.6
PC2	54	110.75	2.05	4.7	0	22.2	70.7
PC3	52	57.62	1.11	2.54	0	11.5	82.2
PC4	50	29.60	0.59	1.36	0.05	5.9	88.2
Residuals	990	432.45	0.44				

DF- Degrees of Freedom; Sum Sq- Sum of square; Mean Sq= Mean sum of square.

Table 2. Mean grain yield (t ha^{-1}) performance of 50 bread wheat genotypes tested in 2019 and 2020

S/No	Genotype	AA19	DR19	KU19	MK19	AT20	AA20	DR20	KU20	MK20	MEAN
1	BW172056	7.61	3.56	6.57	5.29	3.78	4.00	6.57	1.96	4.37	4.86
2	BW172060	5.52	4.15	6.95	5.28	3.71	6.21	6.46	2.13	3.57	4.89
3	BW172070	4.43	3.73	6.03	4.91	3.44	5.69	6.30	2.03	3.81	4.48
4	BW172071	6.96	4.18	7.35	5.17	3.73	6.69	6.49	2.39	3.85	5.20
5	BW172105	6.82	4.01	7.31	4.39	3.19	7.24	5.96	2.57	3.07	4.95
6	BW172139	5.88	3.97	6.84	4.65	3.42	5.96	6.21	2.25	3.52	4.75
7	BW172142	6.89	4.20	6.48	5.09	3.69	5.50	6.48	1.93	3.78	4.89
8	BW172144	6.91	4.44	7.79	4.93	3.36	6.89	6.06	2.41	3.12	5.10
9	BW172145	6.38	4.17	7.44	4.83	3.49	6.62	6.24	2.39	3.71	5.03
10	BW173457	6.73	3.57	7.48	5.20	3.39	5.22	6.12	2.16	3.60	4.83
11	BW173472	6.53	4.24	6.99	5.47	3.82	4.35	6.55	1.94	4.17	4.90
12	BW173528	7.77	4.81	7.78	4.86	3.79	8.04	6.53	2.80	4.11	5.61
13	BW173546	7.19	4.10	6.89	4.89	3.57	6.58	6.39	2.42	3.10	5.01
14	BW174080	6.05	3.35	6.20	4.93	3.25	2.86	6.07	1.76	3.48	4.22
15	BW174102	3.65	3.80	5.61	4.05	3.28	5.01	6.16	2.11	3.24	4.10
16	BW174116	6.12	4.13	6.48	4.86	3.81	6.68	6.67	2.33	4.66	5.08
17	BW174458	6.05	4.77	6.77	5.45	3.87	1.45	6.60	1.73	3.78	4.50
18	Deka	5.97	4.14	6.78	4.49	3.36	7.17	6.16	2.32	2.91	4.81
19	ETBW 9065	8.06	4.57	7.20	4.24	3.51	8.03	6.34	3.02	3.31	5.36
20	ETBW 9077	5.38	3.83	6.77	4.69	3.35	7.80	6.14	2.27	3.61	4.87
21	ETBW 9078	7.61	4.38	6.96	4.83	3.54	6.63	6.36	2.53	3.63	5.16
22	ETBW 9116	4.90	3.67	6.29	3.80	3.02	5.80	5.84	2.18	2.98	4.28
23	ETBW 9119	3.23	3.12	5.10	4.14	2.75	3.23	5.61	1.46	2.14	3.42

S/No	Genotype	AA19	DR19	KU19	MK19	AT20	AA20	DR20	KU20	MK20	MEAN
24	ETBW 9128	5.99	3.69	7.25	4.38	3.01	4.26	5.73	2.07	2.87	4.36
25	ETBW 9136	6.90	4.84	7.70	5.20	3.73	7.53	6.48	2.60	3.83	5.42
26	ETBW 9139	6.19	3.71	7.24	5.61	3.60	4.38	6.33	2.08	3.31	4.72
27	ETBW 9149	4.97	3.54	6.67	4.72	3.03	2.92	5.82	1.88	3.09	4.07
28	ETBW9578	7.44	4.47	7.09	4.72	3.92	6.49	6.71	2.74	4.14	5.30
29	ETBW9581	6.81	4.21	7.55	5.41	3.78	6.20	6.52	2.31	4.38	5.24
30	ETW17-271	3.50	3.14	5.79	4.19	2.93	2.01	5.73	1.54	3.08	3.55
31	ETW17-293	3.41	3.12	5.35	4.13	3.00	2.11	5.82	1.48	2.95	3.48
32	ETW17-294	3.16	2.97	5.41	3.98	3.03	3.90	5.93	1.92	3.17	3.72
33	ETW17-296	5.28	3.28	5.09	4.76	3.61	3.02	6.48	1.57	3.65	4.08
34	ETW17-328	5.33	3.08	6.01	4.84	3.21	2.62	6.00	1.51	3.37	4.00
35	ETW17-365	7.39	4.75	7.55	4.99	3.65	5.90	6.40	2.60	3.39	5.18
36	ETW17-366	6.92	3.95	5.68	4.14	3.69	4.79	6.56	1.99	4.55	4.70
37	ETW17-389	3.12	3.20	6.37	3.82	2.57	6.44	5.40	2.18	2.45	3.95
38	ETW17-407	6.07	4.52	6.41	4.16	3.35	7.05	6.23	2.55	3.40	4.86
39	ETW17-416	5.02	4.01	7.11	4.79	3.38	5.87	6.12	2.20	3.22	4.63
40	ETW17-417	5.97	3.93	6.95	5.18	3.70	4.00	6.42	1.88	4.08	4.68
41	ETW17-438	5.28	3.46	6.26	4.36	3.29	4.65	6.07	2.01	3.21	4.29
42	ETW17-447	3.79	4.15	6.67	4.81	3.18	5.16	5.97	2.14	2.71	4.29
43	ETW17-470	5.45	3.76	6.87	4.81	3.56	4.02	6.32	2.26	3.40	4.49
44	ETW17-471	4.76	3.80	6.28	4.88	3.25	2.54	6.04	1.81	2.83	4.02
45	ETW17-475	7.49	4.65	7.73	4.18	3.28	7.29	6.05	2.99	2.69	5.15
46	ETW17-476	5.87	4.15	6.95	3.86	2.87	4.53	5.67	2.56	2.51	4.33
47	ETW17-477	3.88	4.40	6.67	4.42	3.33	5.72	6.12	2.40	3.25	4.46

S/No	Genotype	AA19	DR19	KU19	MK19	AT20	AA20	DR20	KU20	MK20	MEAN
48	ETW17-484	5.94	4.32	6.76	4.34	3.47	7.10	6.30	2.56	3.41	4.91
49	Kakaba	6.63	4.04	5.49	4.98	3.52	3.36	6.42	1.87	3.48	4.42
50	Kingbird	5.41	3.26	5.54	4.07	3.10	4.72	5.95	1.81	2.92	4.09
	MEAN	**5.81**	**3.95**	**6.65**	**4.68**	**3.40**	**5.24**	**6.20**	**2.17**	**3.42**	**4.61**
	SE±	**0.261**	**0.253**	**0.310**	**0.252**	**0.179**	**0.267**	**0.186**	**0.187**	**0.220**	**0.235**

Where, AA19= Asasa 2019; DR19= Dherea 2019; KU-17 = Kulumsa 2019; MK = Melkasa2019; AT = Alemtena2020; DH20 = Dhera 2020; Ku20=Kulumsa 2020; and MK20= Melkasa2020.

Genotype x environment interaction and stability of the genotypes for grain yield

The results showed that there was significant genotype x environment interaction, indicating there was a cross over interaction by the genotypes' performance in the different environments (Table 3). This means a genotype performed in one environment may not be the best in the other environment hence analysis of the stability parameters was done. The yield stability (YSV) and Yield stability index (YSI) indicated that genotypes: BW173528, ETBW9136, ETBW9065, ETBW17-365, and ETBW9581 had high value in YSV and YSI and their grain yield were above average. The GGE biplot analysis showed that the environments viz., Asasa 2019 and Asasa 2020 highly discriminated the genotypes for yield potential and these environments were separated from other environments (Figures 1). These two environments were high yielding potential and the high yielding genotypes expressed their potential in these environments. Some advanced genotypes (ETBW173528 and ETBW9065) aligned with Asasa 2019 and Asasa 2020 indicating they are best performing in these environments. Kulumsa 2020 was the least yielding environment and none of the advanced genotypes performed well in this environment.

Table 3: AMMI and Yield stability parameters for grain yield of bread wheat genotypes (early set, 2019-2020)

S/No	Genotypes	ASV	YSI	rASV	rYSI	GY (t/ha)
1	BW172056	1.1947	52	35	17	4.86
2	BW172060	0.4843	25	11	14	4.89
3	BW172070	0.5431	48	16	32	4.48
4	BW172071	0.5357	22	15	7	5.2
5	BW172105	1.5466	66	45	21	4.95
6	BW172139	0.5186	35	13	22	4.75
7	BW172142	0.215	15	2	13	4.89
8	BW172144	0.9492	35	25	10	5.1
9	BW172145	0.8399	35	23	12	5.03
10	BW173457	0.4462	27	9	18	4.83

S/No	Genotypes	ASV	YSI	rASV	rYSI	GY (t/ha)
11	BW173472	1.0243	44	28	16	4.9
12	BW173528	1.3673	39	38	1	5.61
13	BW173546	0.9431	44	24	20	5.01
14	BW174080	1.2783	77	37	40	4.22
15	BW174102	0.6626	58	19	39	4.1
16	BW174116	0.5125	20	12	8	5.08
17	BW174458	2.5764	79	50	29	4.5
18	Deka	1.2757	61	36	25	4.81
19	ETBW 9065	1.9389	52	49	3	5.36
20	ETBW 9077	1.4013	54	39	15	4.87
21	ETBW 9078	1.0594	40	29	11	5.16
22	ETBW 9116	0.6325	52	17	35	4.28
23	ETBW 9119	1.0211	77	27	50	3.42
24	ETBW 9128	0.4113	43	7	36	4.36
25	ETBW 9136	1.1469	35	33	2	5.42
26	ETBW 9139	0.6437	44	18	26	4.72
27	ETBW 9149	1.4033	82	40	42	4.07
28	ETBW9578	0.4334	14	8	6	5.3
29	ETBW9581	0.3767	10	5	5	5.24
30	ETW17-271	1.6764	95	47	48	3.55
31	ETW17-293	1.8841	97	48	49	3.48
32	ETW17-294	1.0188	73	26	47	3.72
33	ETW17-296	1.482	87	42	45	4.08
34	ETW17-328	1.4995	86	43	43	4
35	ETW17-365	0.4686	14	10	4	5.18
36	ETW17-366	0.5355	42	14	28	4.7
37	ETW17-389	1.4765	87	41	46	3.95
38	ETW17-407	1.1612	57	34	23	4.86
39	ETW17-416	0.3971	30	6	24	4.63
40	ETW17-417	0.8307	49	22	27	4.68
41	ETW17-438	0.2299	41	3	38	4.29
42	ETW17-447	0.7496	54	20	34	4.29
43	ETW17-470	0.8038	51	21	30	4.49
44	ETW17-471	1.6709	87	46	41	4.02

S/No	Genotypes	ASV	YSI	rASV	rYSI	GY (t/ha)
45	ETW17-475	1.5035	53	44	9	5.15
46	ETW17-476	0.288	41	4	37	4.33
47	ETW17-477	1.0668	61	30	31	4.46
48	ETW17-484	1.1248	51	32	19	4.91
49	Kakaba	1.0814	64	31	33	4.42
50	Kingbird	0.2043	45	1	44	4.09

Note: ASV- Ammi stability value; YSI- Yield Stability Index; rASV- Rank of Ammi Stability Value; rYSI-Rank of Yield Stability Index; GY – Grain Yield (tons per hectare).

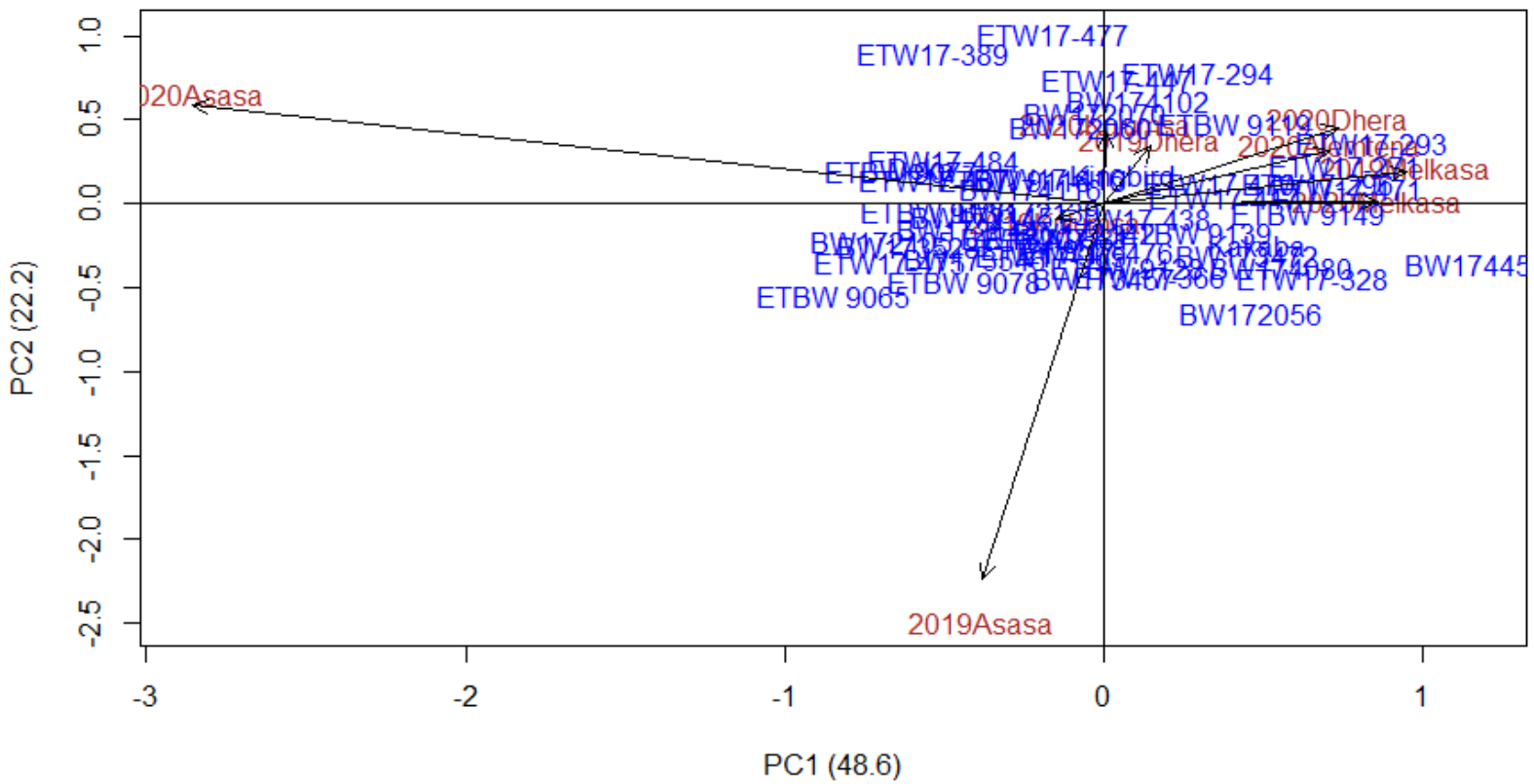

Figure 1: GGE biplot analysis for the first two IPCA scores of the genotype x environment interaction for mean grain yield of 50 bread wheat genotypes evalauted on 9 enevoments (2019 and 2020).

Other desirable agronomic and disease traits

Mean of other agronomic traits *viz*., DTH, DTM, PHT, TKW and HLW for the advanced bread wheat genotypes including the standard checks varied significantly (data not presented). The mean plant height ranged from 81 cm (ETBW9128) to 93.04 cm (ETBW9065) and the grand mean was 87.74 cm. The mean DTH ranged from 54.16 (BW172056) to 66.30 (ETBW17-476) and the grand mean was 59.67 days. The mean TKW ranged from 26.57 g (ETBW17-271) to 38.67 g (BW173546) and the grand mean was 31.54 g. Similarly, the mean HLW was ranged from 64.52 kg/hl (BW174458) to 70.60 kg/hl (BW173528) and the grand mean was 67.62 kg/hl. Generally, genotypes with superior TKW with mean above 35 g include BW172056, BW173528, BW172105, ETBW17-417, ETBW17-365 and BW173546. Similarly genotypes with mean above 70 kg/hl include ETBW9136, BW172145 and BW173528. The two high yielding stable varieties had low yellow rust (YR) and stem rust (SR) score indicating that they are resistant to the pathogens (Table 4).

Table 4. Disease scores for selected candidate bread wheat varieties with the standard checks

Disease	BW173528	BW17-365	Kingbird (Standard Cheek)	Kakaba (Local Check)
Stem rust-SR (%+ reaction)	5MS	10MSS	40S	40S
Yellow rust-YR (%+reaction)	15MRMS	10MSS	30S	70S
Leaf rust-LR (%+ reaction)	0	0	0	0
Septoria (00-99)	21	32	12	56

Conclusion and Recommendation

Based on yield and other desirable agronomic traits, genotypes which performed best and good stability across the environments were selected. These include ETBW173528 and ETBW17-365. The two genotypes had yield advantage of 16.63 % and 7.70% respectively over the best standard check DEKA. With regard to TKW and HLW the two genotypes were superior by 10% and 21% respectively to the st. check DEKA (recent check). Based on the YSI, ETBW173528 and ETBW17-365 had the rank of 1 and 4 respectively. Hence, the two advanced genotypes topes were selected and proposed for variety verification trial during 2021 season and verified on the farmers filed.

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Evaluation of Elite Durum Wheat (Triticum Durum L.) Genotypes Across Multiple Environments and Release of The New Variety - 'Etcross21' for the Mid and Highland Areas of Ethiopia

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Abstract

Durum wheat is a tetraploid wheat species and traditionally grown on heavy black soils (vertisols) of the central and northern highlands of Ethiopia between 1800-2800 meters above sea levels. The objective of this paper was to determine 1) the effect of genotype by environment interaction (GEI) on grain yield and grain yield stability using Additive Main Effect and Multiplicative Interaction (AMMI) and GGE biplot models, and 2) to report the the agronomic and quality performance of a newly released vareity ETCross21 analysed from on-farm trials. Hence, twenty-five elite durum wheat lines including three standard checks were evaluated in 13 environments during the 2018 and 2019 cropping season. The expriment was conducted using row-column design in three replications. Analysis of variance, AMMI, stability and GGE biplot analysis was conducted using appropriate packages of R-statitical software. AMMI analysis indicated highly significant effects of environments, genotypes and their interactions on grain yield. The highest proportion of the total sum of squares was accounted for by the environment (42.3%) followed by the GEI (26.7%). The highest magnitude of sum of squares due to the environment suggested test environments were diverse that may affect expression of the grain yield trait. The first two PCs of the biplot explained 65.5% of the total variation due to GEI. Genotype 5 and 15 were the highest in mean yield and highly stable among all genotypes. Accordingly, genotypes 5 and 15 were verified at three on-farm and six on stations in 2020/21 and genotype 5 was released in 2021 with the name ETCross21. ETCross21 had 15.9% and 32.3% yield advantage over the standard check, good physical and chemical quality traits, semi-dwarf and good level of resistance to stem and yellow rust.

Keywords: Durum wheat, elite lines, GEI, AMMI, Stability

Introduction

Durum wheat (*Triticum durum* Desf.) is an important tetraploid wheat specices produced for industrial purpose and to prepare traditional recipies consumed in different countries. This crop is produced under rainfed condition and has been produced in Ethiopia since ancient times (Tesfaye and Getachew, 1991, Semane *et al*.,1995). Ethiopia is endwoed with diverse landraces adapted mainly to the

highland vertisol areas (Tesema, 1987). Ethiopia is also known as the center of diversity for tetraploid wheat and a current study indicated that the country is the secondary center of origin for durum wheat (Hodson *et al*., 2020; Kabbaj *et al*., 2017). However, these landraces are not well characterized and under utilized for breeding purpose. Tessema (1987) reported that Durum wheat occupied 60% to 70% of the total wheat area around the mid 1980s. At this time, the landraces were dominant over the imporoved vareites that were estemated to account below 10% of the durum wheat area. The current proportion of durum wheat area has decreased dramatically due to the introduction of semi-dwarf fertilizer responsive bread wheat varities and the largerst area share among the two species was shifted to bread wheat (Hodson *et al*., 2020). However, the durum wheat area is expected to increase due to the urbanization related demand for pasta products (Letta *et al*., 2013). Hence, continous effort by the federal and regional durum wheat research institutes is paramount to replace the landraces which are low yielders with imporoved varities to increase productivity of durum wheat.

The durum wheat research program is mainly working on advanced lines from elite by elite crosses to combine high yield, acceptible industrial quality and disease resistance. The majority of the parental lines and elite lines are introductions from international institutes mainly the International Maize and Wheat Improvement Center (CIMMYT) and The International Center for Agricultural Research in the Dry Areas (ICARDA). Hence, the major breeding activites were using elite lines which may perform differently at varying environments. Multi-environment trials should be conducted at the advanced stage of performance trials (Yan & Tinker, 2006). In such cases, the the relative performance of genotypes planted in diverse environments may differ due to the prescnece of genotype by environment interaction (GEI) (Lule *et al*., 2014). In the durum wheat breeding program, multi-environmental trial were undertaking to evaluate and select stable and high yielding genotypes that can be potential candidates for release. A stable genotype is a genotype which is high yielding with minimum variation in performaces when grown in diverse enviroments (Zerihun *et al*., 2016). In identifying a stable and high yielding vareity, genotype by environment interaction casues difficulity for breeders to take selection decision. Therefore, proper analysis of multi-environmental trial data and exploitation of gentoypes that performed differently in diverse enviroments is crucial to make progress from breeding (Gauch, 2006).

For the analysis of multi-environment data, traditional ANOVA is not sufficient to model and exploite GEI. Appropriate methods of analysis of GEI helps to identify adaptive and stable genotypes. Among those, the additive main effects and multiplicative interaction (AMMI) model and the genotype main effect and genotype by environemnt interaction (GGE) biplot are the most extensively used statitical methods to model GEI and increase the efficiency of selection in yield trials. Therefore, the objectives of this study were 1) to determine the effect of

genotype by environment interaction using AMMI and GGE biplot analyses and yield stability of elite durum wheat lines at the national vareity trial stage 2) to report the the agronomic and quality performance of a newly released vareity ETCross21from on-farm verification trials.

Materials and Methods

Test environments, planting materials and exprimental design

Twenty-five durum wheat genotypes including three standard checks (Boohai, Utuba and Tesfaye) were evaluated in 13 environments (Location by year) during the 2018 and 2019 cropping season. The description of the testing environments was presented in Table 1 and they were AD-18, AD-19, CD-18, CD-19, DZ-18, DZ-19, GN-18, GN-19, HL-18, HL-19, MJ-18, MJ-19 and KU-19 (Table 2). These environments represent the potential durum wheat production environments.

The genotypes were arranged using row-column design in three replications. The plot size was 6 rows of 2.5 m length and 0.2 m between row spacing. The seed rate was 125 kg/ha and fertilizer rates of 200 kg/ha urea with two split application (1/2 at planting and 1/2 at the stage of tillering) and 100 kg/ha DAP applied at planting. Data was recorded on days to heading, days to maturity, plant height, grain yield, thousand kernel weight and hectoliter weight and grain yield (kg/ha) was considered for GEI analysis.

Table 1. Lists of durum wheat genotypes evaluated in thirteen environments in 2018/2019 in Ethiopia

Geno No.	Designation	Pedigree
1	DW173204	C F4 20 S/4/YAZI-1/AKAKI-4//SOMAT-3/3/AUK/GUIL//GREEN/5/CANELO-9.1//SHAKE-3/
2	DW173209	C F4 20 S/4/YAZI-1/AKAKI-4//SOMAT-3/3/AUK/GUIL//GREEN/5/CANELO-9.1//SHAKE-3/
3	DW173210	AG 1-22/2*ACO89//2*UC1113/3/5*KOFA/5/KOFA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/
4	DW173211	AG 1-22/2*ACO89//2*UC1113/3/5*KOFA/5/KOFA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/
5	DW171226	Yerer/UC11132.25Yellow/DZ2013mehF1 P#6/DZ2014meh F2 P#6-1
6	DW171227	Yerer/UC11132.25Yellow/DZ2013mehF1 P#6/DZ2014meh F2 P#6-6
7	DW171231	Yerer/UC 1113GPC Lr 1908001/59/ DZ 2013mehF1P#7/DZ 2014 mehF2 P#7-2
8	DW171244	Kilnto/UC 1113 GPC Lr 1908001/59/DZ 2013 meh DW F1 #18/DZ 201 meh DW F2 P#17-1
9	DW171247	Mangudo/Mekuye/DZ 2013 meh DW F1 P#20/DZ 2014 meh DW F2 P#19-1
10	DW171250	Mangudo/Mekuye/DZ 2013 meh DW F1 P#20/DZ 2014 meh DW F2 P#19-8
11	DW184183	TDICOCCUN1/CH1//ICAMORTAO469/3/ICAMORTAO459//CANDOCROSSH25/BIK204144/4/4MRF1/STJ2//BCRCH1/5/F413/3/ARTHUR7 1/LAHN//BIK2/LAHN/4/QUAMAN
12	DW173268	ALAM0:DR/4/ARMENT//SRN-3/NIGRIS-4/3/CANEL0-9.1/5/PLATA-6/GREEN-17//SNITAN/4/
13	DW173269	JUPARE C 2001*2/IM/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/ALAS/
14	DW173270	NASSIRA/10/PLATA-10/6/MQUE/4/USDA573//QFN/AA-7/3/ALBA-D/5/AV0/HUI/7/PLATA-13/8/
15	DW173274	AG 1-22/2*AC089//2*UC1113/3/5*K0FA/5/K0FA/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/
16	DW173275	BHA/15/MOHAWK/4/DUKEM-1//PATKA-7/YAZI-1/3/PATKA-7/YAZI-1/6/CF4 20S/4/YAZI-1/
17	DW173183	CMH83.2578/4/D88059//WARD/YAV 79/3/ACO89/5/2*SOOTY.9/RASCON-37/6/1A.1D 5+1-6/
18	DW173186	JUPARE C 2001* 2/RBC/5/MOHAWK/3/GUANAY//TILD-1LDTUS-4/4/ARMENT //SRN- 3/
19	DW173188	YAVA 79/9/ USDA 595/3/D67.3/RABI//CRA/4/ALO/5/HUI/YAV-1/6/ARDENTE /7/HUI/YAV 79/8/
20	DW173191	ALTAR 84/STINT//SILVER-45/3/GUANAY/4/GREEN-14//YAV-10/AUK/10/CMH79.959/CHEN//
21	DW164214	Icasyr-1/3/Gcn//Sti/Mrb3
22	DW164216	ALAM0:DR/4/ARMENT//SRN-3/NIGRIS-4/3/CANEL0-9.1/5/PLATA-6/GREEN-17//SNITAN/4/
23	Utuba	(=Icajihan42) Omruf1/Stojocri2/3/1718/BeadWheat24//Karim ICD01-0251-0T-14AP-0AP-3AP-0AP-4AP-0AP-1AP-0AP
24	Tesfaye	ARMENT//SRN-NIGRIS-4/3/CANED-9.1/4/TOSKA-26RASCON-37//SNITSN/5/PLAYERO
25	Boohai	Coo's Cndeal II, CD 3862

Table 2. Description of testing environments for durum wheat national variety trial in 2019 and 2020

Environment	Environment code	Altitude (m.a.s.l)
Adet,2018	AD-18	2240
Adet, 2019	AD-19	
Chefe Donsa, 2018	CD-18	2460
Chefe Donsa, 2019	CD-19	
Debre Zeit, 2018	DZ-18	1920
Debre Zeit, 2019	DZ-19	
Gonder, 2018	GN-18	2133
Gonder, 2019	GN-19	
Holeta, 2018	HO-18	2400
Holeta, 2019	HO-19	
Minjar, 2018	MN-18	1804
Minjar, 2019	MN-19	
Kulumsa, 2019	KU-19	2200

Statistical analysis

The data was analysed using the R statitical software version 4.1.2 (R Core Team, 2021). The multi-environment data was first subjected to anlysis of variance (ANOVA) using the *aov()* function of the R package *car* (Fox and Weisberg, 2019) to observe the presence of genotype by environment interaction. The GGEModel() function of R statitical package GGEBiplots was applied to the genotype by environment data matrix (Sam, 2022). The *DiscRep*() and *MeanStability*() function of the same packge were used to plot the discrimination ability and representativeness view and stability plots, respectively. AMMI analysis was done using the *AMMI* () function of the *agricolae* package (Mendiburu, 2017). Stability of genotypes was further evaluated using AMMI Stability Value (ASV) as described in Purchase *et al*. (2000).

$$ASV = \sqrt{[\text{SS\_IPCA1} \div \text{SS\_IPCA2}(\text{IPCA1Score})]^2 + [\text{IPCA2Score}]^2}$$

Where: ASV = AMMI stability value, SS_IPCA1 = sum of squares of IPCA1, SS_IPCA2 = sum of squares of IPCA2 and IPCA1Score and IPCA2Score are scores of principal component one and two, respectively.

Variety verification of candiate varieties

Candidate genotype 5 and genotype 15 were verified with Mangudo (Standard check) and Boohai (local check). The vareity verification trial (VVT) was undertaken at two on-farm and one on station at each of the trhee test locations in the 2020/21 cropping season. The locations were Chefe Donsa, Minjar and Enewarei. Additionaly the VVT was planted at the main station (Debre Zeit). The trial was non-replicated with a plot size of 10m by 10 m area each and 1.5 m between plots. The seed rate was 150 kg/ha and fertilizer was applied as per the recommendation for each site. Weeds were managed with the traditional hand

weeding after crop establishment. Then, trials were evaluated by national vareity release committee towards maturity. After yield per plot was measured and converted to tones per hectare. Then seed samples were taken to measure physical and chemical quality triats. The physical quality traits measured were Thousand kernel weight (TKW), hectoliter weight (HLW), hardness index, and seed diameter while the chemical quality paramerters were protien content (%), starch content(%), Zeleny (ml), starch content (%), Wet gluten (%), Dry gluten (%) and gluten index (%). Then averages over the test locations was reported.

Results and Discussion

Yield performance

Figure 1 presents the distribution of grain yield of the twenty-five genotypes across the thirteen environments. Among the testing environments the mean grain yield of genotypes at Chefe Donsa in 2019 was the highest (4716.6 kg ha^{-1}) whereas at Kulumsa in 2019 (2297.5 kg ha^{-1}) was the lowest (Table 1). The highest grain yield harvested at Chefe Donsa could be due to the longer growth period giving a extended time for assimilate production during the grain filling period. In agreement with this explanation Richards (2000) indicated that extended photosynthesis period increases both biomass and grain yield. Moreover, Chefe Donsa is free from rust and Septoria tritici blotch occurs rarely in the lower leaf with little or no effect on the crop yield. Across environments the top performing genotypes were differerent. The yield varied from 1345.8 kg ha^{-1} for genotype-24 at AD-19 to 6335 kg ha^{-1} for genotype-10 at CD-19 (Table 3). The difference in the performance of genotypes across the testing environments is explained by the pesence of genotype by environment interaction and the presence of large variation in grain yield.

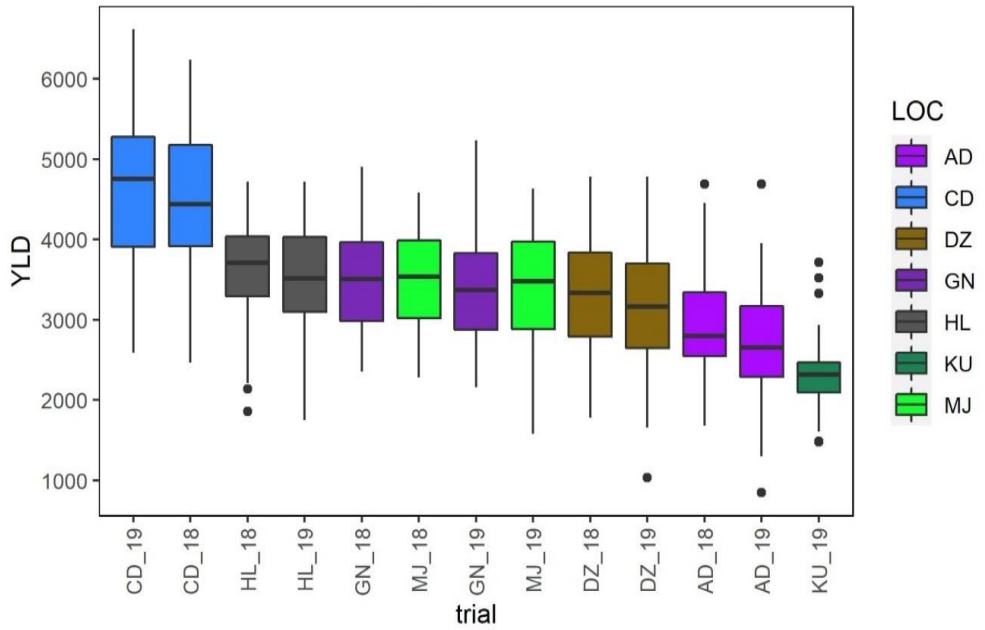

Figure 1. Box plot indicating distribution of durum wheat grain yield in kg ha^{-1} across thirteen environments (year by location).

Additive Main Effects and Multiplicative Interaction (AMMI)

AMMI analysis revealed highly significant effects of environments, genotypes and their interactions on grain yield ($P < 0.001$). Considering the multiplicative component of AMMI, the sum of squares due to the GEI was further divided in to five significant Interaction Principal Components (PC-1 to PC-5) (Table 4). The highest proportion of the total sum of squares was accounted by the environment (42.3%) followed by the genotype by environment interaction (26.7%) (Table 4). This agrees with the result expected in GEI analysis described in Gauch (2006). The highest magnitude of sum of squares due to the environment suggests that the test environments are diverse and affect the expression of the grain yield trait. In agreement with this result the highest proportion of variation in environment followed by GEI was reported on barley grain yield (Pour-Aboughadareh *et al*., 2022) and durum wheat grain yield (Mohammadi *et al*., 2015).

Table 3. Mean grain yield performance (kg h^{-1}) of durum wheat genotypes evaluated across thirteen environments in Ethiopia.

Ge	Environment													
no.	AD	AD	CD	CD	DZ	DZ	GN	GN	HL	HL	KU	MJ	MJ	Me
No.	_18	_19	_18	_19	_18	_19	_18	_19	_18	_19	_19	_18	_19	an
1	181	153	493	486	340	329	303	304	329	338	211	234	217	301
	2.7	7.2	8.0	3.3	0.7	8.3	5.3	3.7	3.0	3.8	1.0	5.0	0.0	7.8
2	304	304	407	407	272	272	363	363	399	399	239	372	372	344
	9.7	9.7	5.0	5.0	1.7	1.7	2.7	2.7	5.0	5.0	5.3	3.3	3.3	5.4
3	234	156	443	464	241	227	248	232	218	210	162	321	328	268
	8.0	1.2	7.3	8.3	4.3	1.7	5.7	2.8	1.0	1.7	0.7	8.3	6.7	4.4
4	234	213	426	422	315	316	285	272	243	247	186	338	344	295
	1.0	9.2	1.7	6.7	0.0	8.3	4.7	0.2	6.7	5.8	9.0	0.7	8.3	9.4
5	403	365	572	552	450	349	435	345	421	387	198	388	368	402
	5.0	7.0	3.7	3.3	0.0	3.3	4.2	6.0	5.8	5.3	6.0	0.0	0.0	9.2
6	323	278	484	561	434	418	278	258	375	340	203	404	389	365
	1.5	1.8	3.3	0.0	8.3	1.7	4.3	7.3	7.7	2.2	6.7	0.0	0.0	3.4
7	282	202	495	492	314	267	302	266	389	375	224	304	264	321
	7.3	4.8	6.7	3.3	1.3	3.3	8.0	2.7	0.0	8.8	5.0	5.0	5.0	7.0
8	285	285	509	509	427	427	323	323	361	361	238	315	315	360
	6.3	4.2	1.7	1.7	0.0	0.0	5.0	5.2	7.7	7.7	7.7	1.7	1.7	2.4
9	317	284	400	416	377	369	373	326	376	349	247	347	311	346
	9.7	6.5	1.7	8.3	6.0	6.7	5.0	8.7	3.7	7.0	3.7	8.3	1.7	1.3
10	276	292	607	633	392	387	379	366	307	287	240	341	324	372
	1.7	0.2	1.5	5.0	7.3	1.7	4.0	5.7	7.0	9.7	4.0	2.0	3.3	0.2
11	289	257	399	430	416	394	289	252	310	293	232	327	283	321
	4.7	7.5	4.3	1.7	5.7	5.0	3.3	1.7	6.0	2.3	8.7	3.3	1.7	2.8
12	286	286	534	553	357	349	332	330	390	386	242	348	336	364
	9.0	8.0	7.3	1.7	8.0	8.3	6.0	7.8	3.3	6.0	7.3	9.7	0.0	4.0
13	310	243	421	438	324	311	368	368	405	407	270	405	386	358
	6.3	4.5	4.3	5.0	5.3	3.3	3.3	7.0	0.3	3.3	4.0	1.0	8.3	5.8
14	349	331	432	449	395	382	359	347	348	338	227	399	389	365
	9.7	9.0	2.3	0.0	7.0	0.0	1.3	0.7	6.7	7.3	2.3	5.0	5.0	4.3
15	404	390	559	562	387	320	441	393	374	304	352	387	320	399
	4.3	1.7	7.0	7.5	4.7	8.3	3.3	8.7	3.0	4.7	2.7	3.3	4.5	9.5

16	385	385	435	451	286	286	416	417	400	400	159	342	342	362
	4.3	5.8	0.3	6.3	5.3	6.7	9.7	3.2	2.3	4.1	8.0	9.0	9.0	4.2
17	315	309	279	306	253	214	446	459	380	376	231	394	403	336
	5.7	9.7	0.7	0.0	3.0	8.3	7.3	2.0	7.7	5.8	3.7	0.0	0.0	1.8
18	258	239	395	450	308	288	367	372	339	335	248	403	397	338
	8.7	8.3	6.0	0.0	8.3	0.0	8.0	9.0	9.3	0.0	6.7	2.3	6.7	9.5
19	260	200	464	461	250	284	313	310	344	346	237	362	358	322
	3.7	8.3	9.7	6.7	4.0	1.7	1.0	5.8	6.0	8.8	0.7	7.0	8.3	7.8
20	317	320	488	526	336	335	336	337	433	440	230	336	346	368
	7.7	3.7	2.7	2.5	3.0	3.3	8.3	6.0	8.7	2.5	2.0	5.3	5.0	1.6
21	239	233	437	488	206	223	419	449	450	449	223	287	264	336
	3.0	3.8	7.3	5.0	9.3	6.7	9.0	9.3	8.7	0.3	4.7	6.3	1.7	5.0
22	276	263	462	484	300	289	385	385	350	348	227	336	315	340
	5.0	0.0	0.0	8.3	1.0	8.3	4.5	6.5	3.3	0.5	7.0	1.7	6.7	4.1
23	306	289	493	539	358	362	296	280	338	342	221	357	330	347
	0.0	3.8	1.7	5.0	3.3	6.7	9.0	0.7	9.0	2.5	1.7	3.3	3.3	3.8
24	212	134	343	343	277	224	324	372	383	386	258	360	335	304
	3.3	5.8	8.3	8.3	9.0	6.7	8.7	0.8	8.7	5.7	4.3	9.0	0.0	5.3
25	350	350	349	359	342	374	376	376	374	374	227	343	343	349
	1.2	1.2	8.0	1.7	6.3	6.7	0.7	0.7	7.3	7.3	5.3	0.0	0.0	3.6
Me	296	270	453	471	334	320	350	340	361	353	229	350	335	343
an	3.2	9.7	4.8	6.6	7.3	3.1	7.7	5.4	9.9	1.5	7.5	4.0	5.2	8.2
Min	181	134	279	306	206	214	248	232	218	210	159	234	217	268
	2.7	5.8	0.7	0.0	9.3	8.3	5.7	2.8	1.0	1.7	8.0	5.0	0.0	4.4
Ma	404	390	607	633	450	427	446	459	450	449	352	405	403	402
x	4.3	1.7	1.5	5.0	0.0	0.0	7.3	2.0	8.7	0.3	2.7	1.0	0.0	9.2

Table 4. Analysis of variance table of grain yield of durum wheat genotypes using Additive Main Effects and Multiplicative Interaction Model

Source of Variation	DF	SS	MSS	F-value	Pr > F	Sum of square explained (%)		
						Total Variation	GXE explained	GXE Cumulative
ENV	12	3.76E+08	31354741	27.92	8.48E-12	43.4		
REP(ENV)	26	29195324	1122897	4.98	5.08E-14	3.4		
GEN	24	90246396	3760267	16.68	1.93E-52	10.4		
ENV: GEN	288	2.31E+08	801147	3.55	4.12E-40	26.6		
Residuals	624	1.41E+08	225354.1			16.2		
PC1	35	1.06E+08	3018951	13.4	0		45.8	45.8
PC2	33	44947522	1362046	6.04	0		19.5	65.3
PC3	31	27284980	880160.6	3.91	0		11.8	77.1
PC4	29	23701341	817287.6	3.63	0		10.3	87.4
PC5	27	14237308	527307.7	2.34	2.00E-04		6.2	93.5

Discriminating ability and representativeness of testing environments for seed yield

A testing environment should discriminate the genotypes to be evaluated and represent the target region of evaluation. The discriminating ability and representativeness view of the GGE biplot is presented in Figure 2 (left). The environment vectors (the line from the center of the biplot to the environment) for CD-18, CD-19, DZ-18, DZ-19, AD-19, AD-18, GN-19, and GN-18 were long indicating that these eight environments are the most discriminating (informative) environments. The positive relationship between the length of environment vector and discriminating ability is reported previously by Yan & Tinker (2006). The smallest circle in the biplot was for KU-19 suggesting that KU-19 was the average environment (Fig.2, left). The arrow on the straight line passing through the origin of the GGE biplot was aligned with this environment. Moreover, KU-19 had the smallest angle with the average environment axis (AEA), the line that passes through the origin of the biplot (Fig. 2, left). Hence, KU-19 was the most representative suggesting that genotypes selected in this environment were likely perform well in the other environments in the same group, environments with an acute angle vector from KU-19 (Nai-yin *et al*., 2014; Yan & Tinker, 2006). CD-18, CD-19 and GN-19 were the least representative (larger angle with the AEA) but discriminating environments indicating that these environments are convenient to select specifically adapted genotypes. AD-18, AD-19 and DZ-18 were long vectored among others and small angle with the AEA suggesting that these environments are both discriminating (informative) and representative that are useful to select widely adapted genotypes (Fig. 2, left) (Yan & Tinker, 2006).

Yield stability of durum wheat genotypes

Figure 2 (right) presents the mean performance and stability of durum wheat genotypes across the thirteen test environments. The arrow points to a genotype with higher mean yield across environments and genotype 5 (named ETCross21after release) was close to this arrow indicating that this genotype had

the highest mean yield (4020.2 kg/ha) followed by genotype 15 (3999.5 kg/ha). Both genotype 5 and 15 were highly stable (Fig. 2, right). Genotype 2 had mean grain yield similar to the grand mean and was highly stable while genotype-17 was highly unstable. Genotype 19 and 20 were the most stable genotypes but both had yield below the overall mean. Genotype 15 and 5 combine higher stability with higher mean yield (Fig 3, right, Table 5). Genotype-3 had the lowest mean yield among all genotypes (Fig. 4, left). Hence, genotype 5 and 15 are suggested candidates for release and can also be used as parents in a crossing program.

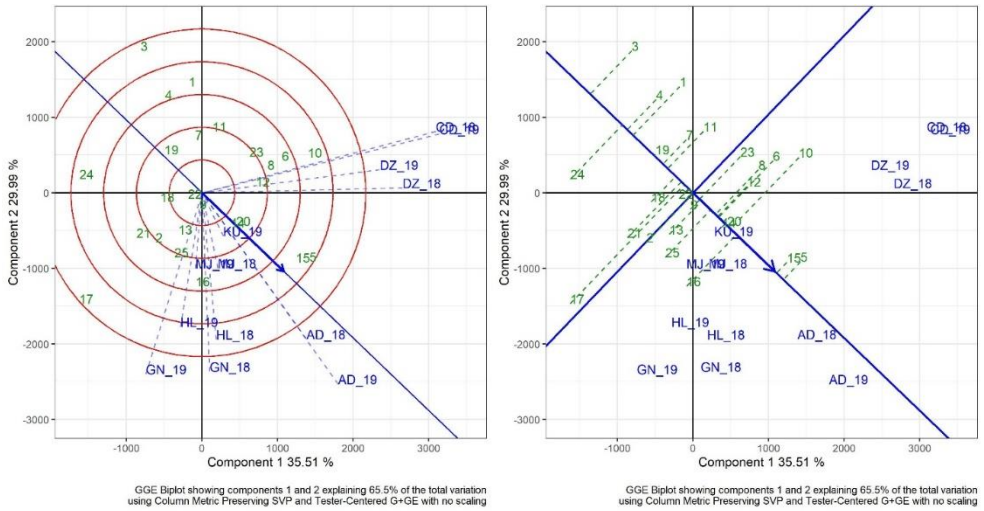

Figure 2. Discriminating ability versus representativeness of environments (left) and mean performance stability of durum wheat genotypes across thirteen environments (right).

Stability of genotypes was further evaluated and confirmed using AMMI stability values (ASV). Accordingly, genotypes 19 and 20 were the most stable but lower mean yield (Table 5). The genotypes with the highest mean yield, genotype 5 and 15, were the 6th and 5th lowest ASV, respectively and had higher stability compared to the rest of the genotypes.

Table 5. Mean yield, the first two principal component scores and AMMI stability value (ASV) of durum wheat genotypes

Geno. No	Mean yield (kg ha^{-1})	PC1	PC2	ASV
1	3017.8	-14.6208	17.79527	37.6
2	3445.4	16.7425	-0.47881	37.9
3	2684.4	-11.5063	-0.93539	26.1
4	2959.4	-8.21076	-12.0323	22.2
5	4029.2	-9.37302	-1.10002	21.3
6	3653.4	-20.1313	-13.7309	47.6
7	3217.0	-7.33903	14.69991	22.2
8	3602.3	-16.0386	-3.34192	36.5
9	3461.3	2.973237	-11.4198	13.3
10	3720.2	-25.6161	10.34641	59.0
11	3212.8	-12.1491	-19.3209	33.6
12	3644.0	-10.9593	9.149494	26.5
13	3585.9	11.60107	-1.08944	26.3
14	3654.3	-0.0334	-19.1902	19.2
15	3999.5	-6.58349	2.397625	15.1
16	3624.2	15.64548	0.606242	35.5
17	3361.8	40.94629	-10.4687	93.4
18	3389.5	9.640072	-3.97502	22.2
19	3227.8	1.205589	6.754893	7.3
20	3681.6	-1.14689	8.183054	8.6
21	3365.0	19.68192	34.67227	56.5
22	3404.1	3.538154	9.024068	12.1
23	3473.8	-14.8561	-2.73776	33.8
24	3045.3	21.36694	5.276268	48.7
25	3493.6	15.22295	-19.0844	39.4

Performance of the newly released variety ETCross21

Research on durum wheat began in 1960 and since then about 41improved varieties (MoARL 2020) were developed with their management practices. However, the adoption of these technologies was not as expected due to market insecurity by farmers. The current government policy to stop wheat subsidy and import ban is likely to motivate producers for a better adoption of improved technologies. Variety ETCross21 was developed through local hybridization between the pure lines of Yerer and UC11132.25Yellow**.** After subsequent evaluation at preliminary stages, the genotype was included and tested in multi-location yield trial in 2018 and 2019/20. In national variety trial and variety verification trial, ETCross21 performed better in medium to highland environments of Ethiopia. As indicated in the multi-environment trial result, this variety showed high yield and stable performance. The yield advantage over the recently released commercial cultivars Utuba and Tesfaye was 15.9 and 32.3%, respectively (Table 5). Morphologically, ETCross21 has medium height (Semi-

dwarf), amber seed color, good tillering capacity, lodging tolerant, erect growth habit, deep green vegetative growth. It also showed partial resistance to stem and yellow rusts (Table 8) and met the major quality standard required by the industries.

Table 6. Yield and physical quality parameters of ETCross21 as compared to checks at the stage of Variety Verification trial in 2020

Variety name	TKW (g)	YLD (t)	HLW (kg/hl)	Moisture (%)	Impurity (%)	Hardness Index	Diameter
ETCross21	42.1	5.62	82	9.4	4	91.6	2.91
DW 173274	38.3	5.4	78.47	9.7	6	81.2	3.0
Mangudo	42.4	5.12	76.4	9.8	4	69.95	2.9
Boohai	44	4.2	80	10.1	5	56.29	3.12

Note: TKW: thousand kernel weights (gm), HLW: test weight (kg/hl), YLD: grain yield (t/ha)

Table 7. Durum wheat cultivars chemical quality parameters of the candidate verified at multi-location (2020)

Variety name	Grain Protein	Zeleny (ml)	Starch Content (%)	Wet Gluten Content (WGC) %	Dry gluten Content (DGC) %	Gluten Index (%)
ETCROSS21	13.6	30.1	67.6	48.7	18.6	73
DW 173274	12.8	26.3	67.2	40.2	14.8	74
Mangudo	11.7	26.7	69.5	42.8	15.5	78
Boohai	8.2	20	71.7	34	14	70

Table 8. Phenological traits and disease response of ETCross21 (DW171226) compared to test genotypes under NVT in 2018/19 and 2019/20

NO.	Genotype name	DTH	DTM	PHT	Stem Rust	Yellow Rust
1	DW173204	69.15	118.31	77.62	40MS	20MSS
2	DW173209	67.82	119.18	80.42	40SMS	30S
3	DW173210	60.62	149.51	81.07	5MS	TMS
4	DW173211	60.85	116.90	82.36	TMS	TMS
5	DW171226	63.56	117.82	82.64	15MS	20MS
6	DW171227	62.51	117.64	81.22	40SMS	40S
7	DW171231	70.74	120.59	77.02	10MS	10MS
8	DW171244	63.00	118.62	82.29	40SMS	40S
9	DW171247	65.59	119.87	86.94	40SMS	60S
10	DW171250	60.64	116.21	81.98	30MS	30S
11	DW184183	58.67	116.36	83.29	50SMS	40S
12	DW173268	67.08	119.18	75.59	50SMS	50S
13	DW173269	65.28	118.64	76.92	50MS	70S
14	DW173270	61.18	116.03	85.31	5MS	60S
15	DW173274	62.41	116.82	84.70	5MR	0

NO.	Genotype name	DTH	DTM	PHT	Stem Rust	Yellow Rust
16	DW173275	62.23	117.56	84.53	5MS	0
17	DW173183	65.64	116.92	74.63	60S	60S
18	DW173186	66.33	119.03	79.78	60S	60S
19	DW173188	63.82	116.00	70.10	40S	50S
20	DW173191	64.49	142.41	76.75	50S	60S
21	DW164214	68.82	119.10	89.87	40SMS	40S
22	DW184216	69.00	120.38	79.18	40SMS	40S
23	Utuba	62.67	118.49	82.98	40SMS	30S
24	Tesfaye	65.74	118.85	74.88	40SMS	30S
25	Boohia	64.41	119.13	115.30	30MSMR	25S
	Heritability	72.00	85.00	84.00		
	Grand Mean	64.49	120.38	81.90		
	LSD @5%	4.62	2.69	1.80		
	CV (%)	4.45	2.36	2.98		
	Gen x Year significance	NS	NS	NS		

Note: ** =highly significant, NS =non-significant, DTH=days to heading, DTM=days to maturity, PHT=plant height, the mean values in the table are averages over test environments.

Conclusion and Recommendation

This paper evaluated the effect of genotype by environment interaction on grain yield using AMMI and GGE biplot analyses and yield stability of elite durum wheat genotypes. AMMI and GGE biplot analysis revealed significant GEI. The genotype by environment interaction in this analysis is a crossover type where ranks of genotypes changed with changing environment. Genotypes 5 (DW171226) and 15 (DW173274) are the most stable and high yielding candidates for vareity verification and parents in the breeding program. The two were under vareity verification trial in 2021 and genotype DW171226 was released and named 'ETCross21'. The variety has a yield advantage over the recent standard check, fulfills the quality standard demanded by industries. It is, therefore, recommended for pre-extension demonstration, scaling up and then linkage with industries to secure market and encourage producers.

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The Agronomic and Quality Descriptions of a Newly Released Bread Wheat (Triticum aestivum L.) Variety 'Boru'

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Abstract

*Developing and diffusing improved varieties to growers has been at the core of agricultural development for decades in Ethiopia. Continuous replacement of old varieties by new ones is paramount important due to the fast evolution of new rust pathogens which the improved resistant varieties break their resistances within a short period time. The paper gives an over view for the new bread wheat variety called 'Boru', adapted to optimum moisture areas of Ethiopia. Boru is a commercial name given for a newly released bread wheat variety with the pedigree: SAUAL/MUTUS/6/CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7/7/CNO79// PF70354/ MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7 originated from CIMMYT. Boru is adapted within an altitudinal range of 1900 m.a.s.l. to 2780 m.a.s.l. with annual rainfall amount reaching 640 mm to 1290 mm. Boru produced a 11% and 15% grain yield advantage over the checks, viz., Wane and Hidasse, respectively. Boru was the highest yielding and stable variety and adapted to all the tested envionments. The new variety had a bolder seed size than Wane and Hidasse. Boru showed relative resistance to stem (Puccinia graminis f. sp. tritici.), yellow (Puccinia striiformis f. sp. tritici), and leaf rust (Puccinia triticinaas) compared to other old bread wheat varieties under medium to highland wheat-growing agro-ecologies. Boru offers new hope for resource-poor farmers in rust-prone areas of Ethiopia. Boru is known for its higher protein content* (14.37 %) than standard check Wane (12.14%) and local check Hidasse (12.3%).

Keywords: Commercial variety; Disease's resistance; High yielding; Optimum growing areas.

Introduction

According to Kiss (2011) wheat (*Triticum spp*.) is one among the globally produced and marketed cereal crops which covers 15% of the total sowing areas of cereal crops in the world. Wheat is a crucial industrial and grain that ranks second among the foremost important cereal crops in the world after rice and is traded internationally (Falola *et al.*, 2017). In sub-Saharan African

countries, wheat is also a strategic commodity which generates farmer income and improves food security (Amentae*et al.*, 2017). It is an important staple food crop in Ethiopia and the country is the largest producer (5.0 million tones) of wheat grain in sub-Saharan Africa (FAOSTAT, 2018); it is grown on 1.6–1.8 million hectares annually and is produced by an estimated 5 million farming households (CSA, 2020). However, Ethiopia remains a net importer of wheat, meeting just over 70% of demand from domestic production (Shiferaw*et al.*, 2011). In Ethiopia, the two major wheat species grown are bread wheat (*Triticumaestivum* L.) and durum wheat (*Triticumdurum* L.). Wheat is cultivated from 1500 to 2700 masl in rainfed areas of Ethiopia; though irrigated wheat is becoming important recently. In Ethiopia, the demand for wheat consumption surpasses the production though productivity has increased nationally in the the last five years from 2.5 ton/ha to 3.0 tons/ha and total production was reached close to 6.7 million tons per anum while the total consumption is about 7.9 million tones, hence there is a shortage of about 1.2 million tons per annum and increasing production and productivity to meet the national demand is paramount important (Tadesse *et al*., 2022).

The productivity of wheat in Ethiopia is low owing to various biotic and abiotic stresses; viz. septoria leaf blotch; fusarium head blight, leaf rust, yellow rust; stem rust, and grass weeds. Environmental stresses include erratic rainfall pattern, low soil fertility, high temperature is some of the abiotic yield-limiting factors in wheat (Aktaş*et al.*, 2010; Kılıç*et al.*, 2010). In addition, Ethiopia is characterized by diverse climatic factors; lowland, midland, and highland wheat growing areas (Tolessa *et al*., 2019). Developing bread wheat varieties suitably adapted to each of the main growing agro-ecologies is the priority area of breeding in the country. Therefore, breeding for high grain yield, stability/ adaptability, and resistance to diseases has become the first areas of interest for breeders within the country. To develop and release improved varieties for commercial cultivations, screening, and testing at different environments to identify for specific and broad adaptations of potential genotypes is important (Aktaş, 2016; Sajid and Mohammed, 2018). A number of bread wheat varieties with rust resistance and high yield were so far released in Ethiopia and contributed to increased productivity to some extent though the potential target is not yet met (MOANR, 2019). Therefore, the objective of the present paper is to give an overview for the agronomic and quality performance of the recently developed and released bread wheat variety ‘Boru’.

Materials and Methods

Twenty-eight advanced bread wheat genotypes and two standard checks were tested under national variety trial at Kulumsa, Asasa, Robe Arsi, Bekoji, Areka, Enawari, Awelgera from 2017 to 2018; while at Shambu, Holeta, Adet, and Debra Zeit in 2018 cropping season. The advanced genotypes were selected from observation nurseries and preliminary variety trials in the preceding years. A plot size of six rows of 2.5 m by 1.2m (3m2) long and 0.2m inter-row spacing. The genotypes were arranged in alpha lattice design with three replications. A seed rate of 150 kg/ ha was used as per the recommendation across locations. Fertilizer was applied at the recommended rate for the specific location. Agronomic management practices were applied uniformly to each plot. Data were collected for days to heading, days to maturity, plant height, thousand seed weight, hectolitre weight, and grain yield; and diseases data (stem rust, leaf rust, yellow rust, and septoria). In addition, some quality parameters (percent protein and gluten index) were analyzed in the laboratory. Multi environments analysis were carried out; while for quality parameters samples were analyzed from each genotype. Based on the agronomic performance; disease resistance, and quality parameters, two candidate genotypes viz. ETBW9553 and ETBW9554 were selected and verified on farmers' field along with the standard check varieties, Wane and Hidasse in 2019. Boru (ETBW9554) official released in 2020 as a commercial variety.

Varietal evaluation

Boru variety is high-yielding and resistant to diseases which allows it to thrive in a range of environments. This new variety developmenthad passed several stages of evaluation, before it was officially released, registered, and commercialized under the common name "Boru" with the pedigree name SAUAL/MUTUS/6/CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7/7/CNO79//PF70354/MUS/3/PASTOR/4/BAV92*2/5/FH6-1-7. It's Targeted for optimum moisture areas of midland to high land areas. It has good agronomic characteristics and late-maturing type as compared to the present varieties. As Boru outshined many bread wheat lines obtained from ICARDA, CIMMYT, and local crossing in observation and preliminary yield trials, it had been advanced to a national variety trial to be tested across wide locations over years. The bread wheat national variety trial consisting of 28 advanced bread wheat genotypes andthe standard checksviz. Wane, and Hidase was conducted at major bread wheat-growing regions in Ethiopia. Boru consistently out-yielded other tested bread wheat genotypes over two years. Combined years over locations analysis revealed that it had produced a mean yield of 5.23t/ha (Table 1). The candidate ETBW 9554 (Boru) produced 11% and 15% yield advantage over the standard check (Wane) and local check (Hidasse), respectively. Thus, ETBW 9554 (Boru) was verified at ten locations (at on-stations and on-farms) in 2019 for official

release. Consequently, ETBW 9554 (Boru) showed superior overall agronomic performances over the standard check Wane and therefore the local check Hidase under verification trial. Likewise, it proved to be more resistant to stem, yellow and leaf rust as compared to all or any currently produced varieties within the medium to high land part of wheat growing agro-ecologies. Boru offers new hope for resource-poor farmers in stem rust-prone and yellow rust-prone areas of Ethiopia. It's expected to replace the varieties 'Ogolcho' in medium altitude areas, and 'Hidasse' in high land areas.

Agronomic and morphological descriptions

Boru was adapted to mid to high land-agro-ecologies of Ethiopia, within the range of altitude 1900 m.a.s.l. to 2780 m.a.s.l. It gives a high yield under the rain fall range of 640 mm to 1290 mm annually. In an attempt to develop Boru, higher yield, and resistance to major bread wheat diseases were important traits of consideration. Boru was taken 70 days for heading and 128 days for maturing (Table 1). Concerning day to heading, the number of days to heading was later than the standard check wane and local check Hidase by four days. The "Boru" variety is comparatively taller than the standard check varieties Wane and local check Hidase. However, Boru has better thousand kernel weights (42.70g) than standard check Wane (38.3g), and local check Hidase (38.10g) and it had good hectlitre weight (71.4 hl/kg) (Table 1). Seed size is directly associated with grain yied; and Boru is resitant to lodging though it is taller in height.

Table 1. Mean performance for some important agronomic traits of 28 genotypes and 2 checks tested in 2017 and 2018 cropping season

Entry	Genotype	DH (days)	DM (days)	PHT (cm)	TKW (g)	HLW (hg hl^{-1})	GYLD (t ha^{-1})
1	Wane	66.00	123.00	89.00	38.30	71.20	4.61
2	ETBW 8751	65.00	123.00	89.00	39.60	73.20	5.12
3	ETBW 8858	67.00	124.00	91.00	39.30	73.10	4.77
4	ETBW 8870	67.00	126.00	94.00	37.90	72.80	4.87
5	ETBW 8802	68.00	129.00	90.00	33.00	71.80	4.36
6	ETBW 8991	65.00	123.00	85.00	37.40	72.70	5.04
7	ETBW 8862	69.00	127.00	100.00	40.20	73.80	4.88
8	ETBW 8804	65.00	123.00	80.00	34.00	72.10	3.67
9	ETBW 8996	64.00	124.00	93.00	39.80	73.40	4.99
10	ETBW 8583	68.00	127.00	89.00	38.70	73.40	4.77
11	ETBW 8668	65.00	125.00	95.00	43.30	74.80	5.00
12	ETBW 8595	65.00	126.00	95.00	42.80	74.30	4.88
13	ETBW 8684	64.00	125.00	90.00	40.50	74.10	4.60
14	ETBW 9486	66.00	123.00	87.00	41.10	73.80	4.37
15	ETBW 9547	72.00	128.00	87.00	43.40	73.40	4.91
16	ETBW 9548	72.00	128.00	87.00	40.00	73.40	4.49
17	ETBW 9549	70.00	129.00	88.00	39.20	73.10	4.31

Entry	Genotype	DH (days)	DM (days)	PHT (cm)	TKW (g)	HLW (hg hl^{-1})	GYLD (t ha^{-1})
18	ETBW 9550	68.00	126.00	85.00	36.50	73.90	4.17
19	ETBW 9551	67.00	127.00	87.00	38.70	71.50	4.24
20	ETBW 9552	69.00	128.00	89.00	42.70	72.70	3.91
21	ETBW 9553	74.00	131.00	92.00	40.40	72.30	4.90
22	ETBW 9554 (Boru)	70.00	128.00	94.00	42.70	71.40	5.10
23	ETBW 9555	67.00	127.00	88.00	36.90	71.60	4.14
24	ETBW 9556	68.00	125.00	91.00	39.80	73.50	4.63
25	ETBW 9557	68.00	126.00	90.00	37.30	69.70	4.87
26	ETBW 9558	67.00	126.00	91.00	40.50	73.90	4.79
27	ETBW 9559	69.00	126.00	92.00	40.20	72.60	4.49
28	ETBW 9560	66.00	125.00	89.00	37.80	72.00	4.75
29	ETBW 9561	72.00	130.00	90.00	39.80	74.40	4.59
30	Hidasse	66.00	124.00	92.00	38.10	70.80	4.42
Grand mean		68.00	126.00	90.00	39.30	72.80	4.62

Note: DH: - Days to 50% hrading; DM: - Days to 90% maturity; PHT (cm): Plant height; TKW (g):- Thousand grain weight; HLW (hl/hg):- Hectolitre weight; GYLD (t/ha): Grain yield.

Stability analysis

The significant GE interaction sum of squares is further partitioned into 18 interaction principal component axes (IPCAs), of which the first six are significant (Table 2). These six IPCAs showed 80% of variation of the total sum of squares due to the interaction. The first four IPCAs explained 25.26%, 18.07%, 14.57% and 8.26%, of the GE interaction variation, respectively. The extracted IPCAs are capable of providing adequate information on the interaction effects but their degree decreases from the first to the last IPCAs. Thus, the first two best explain the interaction sums of square (Zobel *et al*., 1988; Gauch, 2006). Hence, data set obtained by evaluating 30 bread wheat genotypes across 18 environments was best predicted by using the first two IPCAs. The closer the IPCA scores approximate to zero the stable the genotype across all environments (Purchase, 1997). The greater the values, either positive or negative, the unstable the genotype is. In the biplot display system, either main effects and IPCA-1, or IPCA-1 and IPCA-2 are commonly used as abscissa and ordinates (Zobel *et al*., 1988).

Table 2. AMMI analysis of variance for grain yield (kg/ha) of 30 bread wheat genotypes evaluated across 18 environments in Ethiopia in 2017/18 and 2018/19

	DF	SS	MS	PROBF	% Explained
Environment (ENV)	17	3.56E+09	2.09E+08	0	71.99555
Genotype (GEN)	29	2.48E+08	8568297	0	5.03137
ENV*GEN	493	1.13E+09	2301330	0	22.97308

	DF	SS	MS	PROBF	% Explained
PC1	45	2.56E+08	5685769	0	25.26421
PC2	43	1.83E+08	4256253	0	18.07174
PC3	41	1.48E+08	3598693	0	14.5691
PC4	39	83677181	2145569	0.00477	8.26249
PC5	37	70252240	1898709	0.02668	6.93688
PC6	35	67737386	1935354	0.02412	6.68856
Residuals	1065	1.36E+09	1275715	NA	0

Based on the present results ETBW9548 (G16), ETBW9550 (G18), ETBW9552 (G20), ETBW9554 (G22) and ETBW9558 (G26) are highly stable bread wheat genotypes for their IPC1 score was very close to zero indicating their low response to interaction and wider adaptation to the test environments. Likewise, bread wheat genotypes like ETBW8751 (G2), ETBW8802 (G5), ETBW8804 (G8), ETBW8996 (G9), ETBW8583 (G10), ETBW8684 (G13), ETBW9553 (G21) and ETBW9555 (G23) are stable for their relative IPC1 scores were closer to zero (Figure, 1). Among tested genotypes ETBW8751 (G2), ETBW8996 (G9), ETBW9553 (G21) and ETBW9554 (G22) were stable as well as highest yielding, as they produced grain yield that ranged from 5.1 t/ha to 5.4 t/ha. ETBW8595 (G12), which is the most unstable genotype was specifically adapted to Asasa-2017 (E1), Kulumsa-2017 (E2), Awelgera-2017 (E7), Debrezeit-2017 (E8), Kulumsa-2018 (E12) and Awelgera-2018 (E13) (Fig. 1).

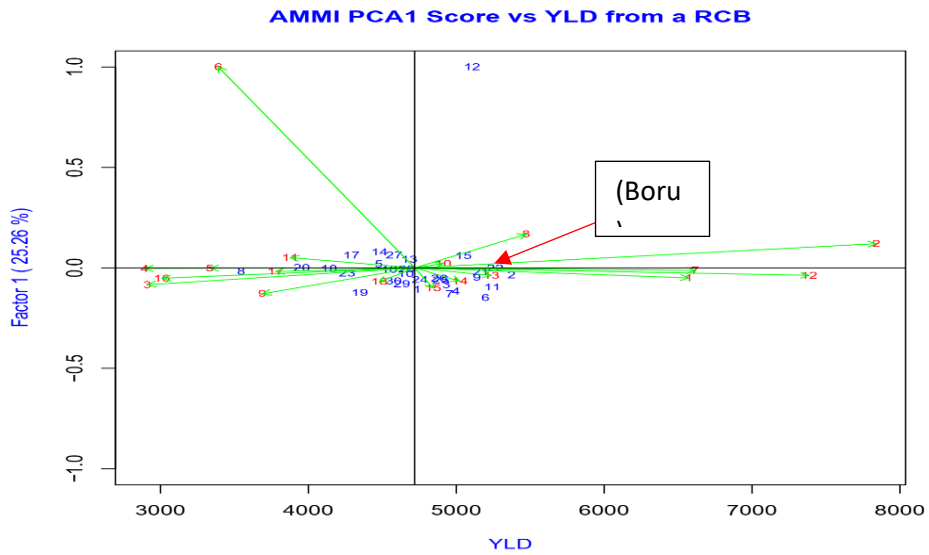

Figure 1, AMMI-1 biplot showing the main effects vs stability (IPC1) view of both genotypes and environments on seed yield. Abbrevations of genotypes are as shown on Table 2, where, Environment 1 (E1)=Asasa-2017; E2=Kulumsa-2017; E3=Arsi Robe-2017; E4=Bekoji-2017; E5=Enewari 2017; E6=Areka-2017; E7=Awelgera-2017; E8=Debrezeyit-2017; E9=Arsi Robe-2018; E10=Asasa-2018; E11=Bekoji-2018; E12=Kulumsa-2018; E13=Awelgera-2018; E14=Holeta-2018; E15=Adet-2018; E16=Areka-2018; E17=Enewari-2018; E18=Shambu-2018.

Quality traits

The priorities of the national wheat research breeding program are high grain yield, disease resistance, and tolerance to abiotic stresses like drought and high temperature, and desirable quality including percent protein content >12%, glutein index >80% etc are associated with good bread making qualities in wheat. Wheat quality may be a very broad subject that may be defined differently by the various stakeholders of the wheat value chain, which makes it a very complex and variable concept. The environment will influence most bread wheat grain traits. When variation in a trait is caused more due to environmentl differences in which the plants are grown it is difficult for the breeder to select the desired genotype. Bread wheat genotypes grown at the same location was analysed for quality analysis and the protein content ranged from 12.14% to 14.83% (Table 3). The recently released variety contains higher protein content than stander check wane and local check Hidasse. Boru had 37.09,73.67, 2.75, 15.5, 33.95, and 83.98 of grain weight, grain hardness, grain diameter, dry gluten, wet gluten, and gluten index respectively.

Table 3. Mean performance of some important quality traits of 28 genotypes and 2 checks tested in 2017 and 2018 cropping season

Genotype	PC (%)	GW (mg)	GH (%)	GD (mm)	DG (%)	WG (%)	GI (%)
Wane	12.14	36.49	62.63	2.74	17.65	38.25	73.13
ETBW 8751	12.68	36.74	74.60	2.88	16.65	36.60	80.28
ETBW 8858	14.06	36.47	72.89	2.70	21.00	40.95	74.57
ETBW 8870	14.03	34.78	74.25	2.66	17.50	38.35	70.31
ETBW 8802	14.12	28.99	84.93	2.55	13.60	31.20	83.27
ETBW 8991	13.19	35.45	76.33	2.82	17.65	38.95	73.63
ETBW 8862	14.14	38.94	70.85	2.78	20.55	41.20	73.04
ETBW 8804	13.68	33.59	78.95	2.69	14.55	34.45	82.65
ETBW 8996	13.83	37.11	67.45	2.81	17.30	39.90	69.47
ETBW 8583	14.02	35.16	80.13	2.69	17.30	36.80	83.84
ETBW 8668	13.22	34.70	67.46	2.68	16.80	38.45	68.00
ETBW 8595	13.26	41.55	70.40	2.87	15.35	36.55	71.76
ETBW 8684	13.01	36.75	78.40	2.85	20.05	41.35	68.84
ETBW 9486	14.32	39.06	73.12	2.90	16.23	39.48	64.34
ETBW 9547	14.62	38.36	82.94	2.80	17.70	38.55	71.34
ETBW 9548	14.17	39.12	79.03	2.85	20.35	41.70	75.01
ETBW 9549	14.83	36.70	77.88	2.81	16.00	36.25	73.34
ETBW 9550	14.40	36.60	78.96	2.83	19.70	42.30	72.49
ETBW 9551	13.29	32.35	74.05	2.68	16.00	34.70	78.79
ETBW 9552	14.22	39.96	81.22	2.51	16.25	35.15	83.31
ETBW 9553	13.67	38.41	77.53	2.93	18.45	37.00	77.95
ETBW 9554	14.37	37.09	73.67	2.75	15.50	33.95	83.98
ETBW 9555	14.17	34.60	70.71	2.65	17.25	39.95	78.69
ETBW 9556	14.28	40.45	53.87	2.94	16.05	36.00	82.44
ETBW 9557	13.65	33.19	77.13	2.59	15.45	35.15	85.73
ETBW 9558	14.27	37.26	71.46	2.83	15.50	33.70	79.76
ETBW 9559	13.91	37.84	76.67	2.82	15.40	33.45	83.92

ETBW 9560	14.62	35.94	64.94	2.73	17.25	39.10	69.49
ETBW 9561	13.93	37.15	84.42	2.88	16.95	35.90	84.94
Hidase	12.30	36.57	38.94	2.70	27.96	38.88	40.28
Mean	13.81	36.58	73.19	2.76	17.46	37.47	75.29
CV (%)	3.21	4.41	4.22	3.12	16.73	8.16	12.50
LSD (0.05)	0.77	4.84	10.50	0.21	8.40	6.01	15.34
R^2	0.80	0.87	0.95	0.81	0.79	0.66	0.62

Note: - PC (%)- percent protein content; GW (grain wheight, mg); GH; - Grain hardness (%); GD: - Grain diameter (mm); DG (%): - Dry glutein; WG (%): Wet glutein; GI (GI): - Glutein index.

Disease resistance

The commercial variety Boru had resistant to moderately resiatnt to yellow rust, leaf rust and stem rust; while the check variety Wane had moderately syssptible to the diseases and the local check Hidasse had very sustible reaction to the diseases (Table 4). Genotypes with slow rusting resistance are highly important to achieve effective breeding for durable resistance to stripe rust (Nzuve*et al*., 2012)**.**

Table 4. The Reaction of the Candidate varieties and Standard Checks to the Major Wheat Diseases

Diseases	**ETBW 9554 (Boru)**	**ETBW 9553**	**Wane (St. Check)**	**Hidasse (L. Check)**
Stem rust (%+ reaction)	5MR	TR	10MS	80S
Yellow rust (%+reaction)	5R	TMR	5MS	60S
Leaf rust (%+ reaction)	0	0	0	0
Septoria (00-99)	21	32	12	56

Where R: resistant, MR: moderately resistant, MS: moderately susceptible, S: susceptible, TMR: Trace moderately susceptible

Variety maintainance

The variety is maintained under the responsibility of the wheat breeder at the Kulumsa Agriculture Research Center.

Conclusion and Recommendation

This paper highlights the information on the newly released bread wheat variety Boru for the purpose of registration as commercial variety in Ethiopia. The variety had higher grain yield, better grain qualities and high level of resitance diseases (moderatelty reistant to resitant reactions) to yellow rust and sterm rust, respectively. It is recommended for production from mid to highland areas of Ethiopia.

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Evaluation of Malt Barley Genotypes for Grain Yield and Malting Quality in the Central Highlands of Ethiopia

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Abstract

A multi-location variety trial comprised of 28 promising malt barley varieties was conducted in four testing sites from 2017 to 2018 seasons with the objective to identify suitable malt barley varieties that satisfy the malt and brewing industry quality requirements and reduce the cost for importing malt barley. The phenological and agronomic data collected were subjected to analysis of variance (ANOVA) using 'R' software. Significant variation between genotype, environment and genotype by environment interaction were observed in all the traits. Genotype, HB 52 X Bahati(G 5) exhibited high mean grain yield (5128 kgha-1) and significantly different for grain yield from one of the improved check, Traveller (4215 kg ha-1). The other promising genotype, Bekoji-1 X Grace (G-8) showed acceptable malt quality for extract (81.8 %), protein (10.0 %), friability (85 %) and lower values for beta-glucan (369 mg/l) with comparable grain yield to the improved checks (Traveller, HB1963). Similarly, genotype Sabin X Beka (G7) showed acceptable malt quality results with lower level of beta-glucan (287mg/l). The "which-won-where" and "Mean vs. Stability" view of GGE biplot showed that, G5 exhibited high mean grain yield and moderate grain yield stability and is the winner genotype in all test environments. Overall, G8 is identified as potential malting barley candidate variety to be tested for more industrial malt quality traits prior to variety release and G5 can be considered as potential parent to be included in the hybridization program for grain yield potential.

Keywords: Biplot, GGE, Grain yield, Malt barley, Malt quality and Stability

Introduction

Barley is one of the most important cereal crops widely grown in the highlands of Ethiopia with annual production of about 2.0 million tons cultivated on an area of about 1 million hectares of land with an average national yield of 2.16 tons/ha (CSA, 2018). In the barley-based farming systems of the central highlands, smallholder farmers have very few alternative crops. One source of income could be growing malting barley, which has dependable local buyers in the country (Bayeh and Berhane, 2011). Both food and malt barley are grown side by side sharing similar agro-ecologies. Traditionally, both six-row and two row barley type are cultivated in the country, but the best malt quality for beer is produced from two row varieties. The share of malt barley is roughly 15-20 % of the total

barley production, which is the major input for beer production (Berhane *et al*., 2016). Malt barley is a high-value crop, with great room for generating high profit to the breweries. However, shortage of good quality malt barley varieties that meet the demand of the local breweries forced the malt factories to depend on malt barley importation. The gap between domestic supply and demand was very large and has become an opportunity to enhance local production and import substitution in the country. According to ERCA, 2017 about 75 thousand tons, covers 70% of total annual demand and cost about 41.5 million USD in 2017.

Malt barley production has not reached to large number of farmers and ocupied significant area coverage, despite the countrys potential to produce substantial amount quality malt barley. There is a relatively huge demand in domestic market for malt barley of reasonable quality, where large number of farmers in the highlands of Ethiopia can commit part of their barley area to malt barley production**.** Even though barley grows in many highland regions of the country, the adoption of themalt barley vartieties is limited to the Arsi highlands and to alessor extent in Bale where farmers can sale their proudce to the Asela malt factory and to the emerging brewery companies such as Heniken, Diageo and Dashen. The lack of adoption of malt barley to other highland barley producing areas is due to limited extension activities by the ministry of agriculture and relevant organizations. Curently, there is an attempt to promote malt barley production in the central highlands of Oromia and Amhra region to provide malt to breweries through contractual production. Therefore, improving the knowledge and skill of farmers through demonstrating new malt barley varieties would be vital to increase production and productivity to fill the existing supply gap in the country. In addition the quality demand from the brweries and the malt factory is a bench mark for the malt barley breeding program. However, most of the nationally released malt barley varieties did not satisfy all the requierments that showed the importance of developing breeding activity to release the malt barley varieties that satisfy the quality parameter demand of the brwereies and the malt factories. On the other hand, despite having good malt quality, registered malt barley varieties like Traveller have low adaptation because of their high susceptibility to foliar diseases and low biomass yield. This demonstrated the urgent need for improved malt barley genotypes among Ethiopian farmers. Since the National Agricultural Research system (NARS) released more than 15 malt barley varieties in the last three decades in collaboration with international centers, it is assumed that there would a posibility to obtain good quality barley varieties that meet the factories requirment and the needs of farmers. The study was aimed to evalaute and identify high yielding and superior quality malt barley genotypes to be cultivated in the central highlands of Ethiopia.

Materials and Methods

A total of twenty eight malt barley genotypes categorized in two sets were used and conducted at four testing sites from 2017 and 2018 cropping seasons (Table 1). Twelve of the genotypes in both 2017 and 2018 and the remaining twenty genotypes were tested in one season. Descriptions of the sites where the genotypes were tested are given in Table 2. The experiments were carried out at Holetta, Bekoji, Kofele and Debreberhane experimental sites in a non-orthogonal set of six environments (site-season combinations). Twenty two of the experimental materials were selected from 2016 and 2017 malt barley preliminary variety trials and the other six genotypes were included as checks (Table 1).

Data were recorded on days to 50% heading, days to 50% maturity, plant height (cm), hectoliter weigh (Kg hl^{-1}), thousand kernel weight (gm) and grain yield (Kg ha^{-1}) from four central rows. Grain yields were adjusted to 12.5% moisture content and converted to kilogram per hectare. Disease data were recorded on scald and net blotch on 0-9 scale and changed to percentage data, where 0=0%, 1=3%,2=12%,3=25%,4=42%, 5=58%,6=75%,7=88%,8=97%,9=100% before transformed using angular transformation for statistical analysis. These traits were subjected to analysis of variance using R- software (R Core Team, 2017) where the environments were considered as random and genotypes as fixed effects, and a mixed effect model ANOVA was used for statistical analysis. The individual and combined analyses of variance for traits were conducted as per the model suggested by Singh & Ceccarelli (1996).

$Y_{ij} = \mu + G_i + B_j + e_{ij}$ and $Y_{ijk} = \mu + G_i + E_j + GE_{ij} + Bk_{(j)} + e_{ijk}$, 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, $Bk_{(j)}$ = 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. GGE bi-plots were performed on grain yield to determine stability of the genotypes using GGE Biplot GUI packages of R- software(R Core Team, 2017).

Quality traits, namely extract content [% DM], protein content [% DM], friability [%] and ß-glucan content [mg/L] for selected genotypes were analyzed using the wet chemistry method in Germany malt quality laboratory "Versuchs- und Lehranstalt für Brauerei in Berlin" on malted grain following the appropriate procedure. Malt extract content was determined according to a small-scale version of the European Brewery Convention (EBC) Methods Manual, Section 4.9.1 (European Brewery Convention, 1998). Moreover, grain samples of all genotypes were analysed at Holetta quality laboratory following Near infrared spectroscopy (NIRs) technique using BrukerTango instrument.

Table 1. Lists of malt barley genotypes and environments used for the trials

Trt	Genotype	Year	Trt	Genotype	Year	Loc	Year	Env
G1	Grace x HB 1307	17-18	G15	KWS_Grinada	2017	Holetta	2017	HO17
G2	Bekoji I xBahati	17-18	G16	KWS-Hobbs	2017	Bekoji	2017	BK17
G3	HB 1307 x Su-Lilly	17-18	G17	KWS-Sassy	2017	Bekoji	2018	BK18
G4	Belgium 2	17-18	G18	KWS_ Canton	2017	Kofele	2017	KF17
G5	HB 52 x Bahati	17-18	G19	KWS-Solicit	2017	Kofele	2018	KF18
G6	IBON 174/03 x Traveller	17-18	G20	IBON-HI13/14-41	2018	D/berhane	2018	DB18
G7	Sabini x Beka	17-18	G21	IBON-HI14/15-45	2018			
G8	Bekoji-1 x Grace	17-18	G22	IBON-HI14/15-56	2018			
G9	IBON 174/03 *	17-18	G23	IBON-HI14/15-96	2018			
G10	Holker	17-18	G24	IBON-HI14/15-102	2018			
G11	HB 1963 *	17-18	G25	IBON-HI14/15-147	2018			
G12	HB 1964	17-18	G26	MBHIBYT-23	2018			
G13	KWS-Dante	2017	G27	Explorer	2017			
G14	KWS-Eileen	2017	G28	Traveller **	2018			

*Improved Check, locally developed; ** = Improved check, Introduced, G1-G12 evaluated for two years, G13-G28 evaluated for one year.

Table 2. Description of testing sites

Site	Longitude	Latitude	Altitude (m)	Rainfall (mm)
Holetta	38°38'E	9°00'N	2400	1100
Bekoji	39°15'E	7°15'N	2830	1082
Kofele	38°45' E	7°00' N	2700	1232
Debreberhane	39°32'E	9°41'N	2800	932

Results and Discussion

The combined analysis of variance showed significant variations (P=0.01) among genotypes, environments and genotypes by environment (Table 3). This suggested that G x E interaction affected selection of genotypes and stability analysis were carried out to identify high yielding and stable genotypes.

Table 3. Mean squares of traits of 28 malt barley genotypes grown at six environments

SV	DF	DHE	DMA	PLH	SC(DF)§	NB(DF)§	TKW	HLW	GYLD
Gen	27	709**	461**	4370**	1719(27)**	572(27)**	295**	35**	11779569**
Env	5	2599**	4063**	4501**	9367(4)**	12017(4)**	1726**	826**	61902099**
Gen:env	87	26**	53**	131**	214(68)**	254(68)**	17**	7**	932567**
Env:rep	12	21**	16ns	107**	188(10)**	61(10)ns	9ns	1ns	2828458**
Residuals	228	9	16	40	74(190)	67(190)	8	4	441982
$CV_{(\%)}$		3.56	2.78	6.61	16.35	39.31	5.82	2.94	16.92
Mean		84.6	143.4	96.0	52.5	20.9	47.5	67.6	3929.7
SE		0.53	0.56	1.12	0.12	0.11	0.39	0.25	0.81

DF=degree of freedom, DHE=days to heading, DMA= days to maturity, PLH=plant height (cm), SC=scald (%), NB=net blotch (%), TKW= thousand kernel weight (g), HLW= hectoliter weight ($Kghl^{-1}$), GYLD= grain yield ($kg\ ha^{-1}$), **, * significant at 5% and 1% probability level, ns=non-significant, §these traits were not recorded at DB18 and mean squares under those traits are angular transformed values

Among the tested genotypes, G5 (HB 52 x Bahati) exhibited the highest grain yield, although the new genotypes did not significantly vary from the checks (IBON 174/03, HB 1963, HB 1964). However, it had significantly highest mean grain yield than the registered European varieties (Explorer and Traveller). Most of the genotypes (G21-G26) that were tested during 2018 cropping season had higher average grain yield comparable to G5. Similarly, among the test genotypes evaluated at all environments, G6 (IBON 174/03 x Traveller) scored better mean grain yield whereas the introduced malt barley materials (G13-G19) found lowest in average grain yield. The maximum hectoliter weight (HLW) was recorded from the check variety G11 (HB1963) followed by genotype G8 (Bekoji-1 x Grace) and G26 (MBHIBYT-23). Differences in TKW were observed between genotypes. The highest was recorded from HB1964 (56.6g) and KWS-Eileen (52.6g). In contrast, introduced malt barley genotypes (viz. G13, G14, G15 G16, G17 and G19) were affected by scald varied from 67 to 72%. This is due to the fact that these materials initially released for different environmental condition (Europe) than Ethiopian barley-growing areas (Table 4). However, materials derived from crossing program had relatively better tolerance to scald. Accordingly, G1, G3, G4, G5, G6, G7 and G8 scored mean scald value of 53, 46, 45, 38, 51, 48 and 54%. Regarding net blotch most of tested materials showed moderate resistant. In contrast, these genotypes which had higher scald values showed lower net blotch scores. As an example, G15, G22 and G27 scored 69, 80 and 74% for scald and 9, 23 and 10% for net blotch, respectively. This may be due to the confounding effect of scald on net blotch. Plant height showed consistently large variation among the malt barley varieties. Similarly, most foreign materials have short plant height, in contrast G7 revealed high mean plant height value of 116 cm followed by G8 (115 cm). G6 (IBON 174/03 x Traveller) and G9 (IBON 174/03) were relatively early whereas G-17 (KWS-Sassy), G14 (KWS-Eileen), G-18 (KWS-Canton) and other European introduced materials were late in days to maturity. Generally, among the malt barley genotypes tested

in all environments, HB 52 x Bahati and IBON 174/03 x Traveller showed grain yield advantage as compared to the recently released check varieties (HB1963 and HB 1964) and better disease resistance (Table 4). Similarly, Bekoji-1 x Grace had comparable mean grain yield value as the standard checks (HB 1963, Traveller) and high values in mean grain physical quality parameters (TKW and HLW). In addition, the newly inserted genotypes (G21-G26) showed similar grain yield with recent check varieties and to confirm their performance over year, these genotypes will be evaluated again in 2019/20 cropping season.

Table 4. Over all mean for eight traits of 28 malt barley genotypes tested during the 2017 and 2018 main cropping season

Trt#	Genotype	DHE	DMA	PLH	SC§	NB§	TKW	HLW	GYLD
G1	Grace x HB 1307	84^{c-g}	143^{d-j}	114^{ab}	53^{d-i}	35^{abc}	49.5^{b-g}	69.8^{ab}	3995^{cd}
G2	Bekoji I xBahati	79^{i-l}	137^{jk}	97^{fgh}	71^{abc}	25^{b-g}	44.1^{hi}	68.3^{a-e}	3972^{cd}
G3	HB 1307 x Su-Lilly	84^{c-g}	139^{h-k}	110^{a-d}	46^{g-j}	30^{b-e}	48.9^{b-g}	68.3^{a-e}	3920^{cde}
G4	Belgium 2	84^{d-h}	138^{ijk}	111^{abc}	45^{hij}	31^{bcd}	47.7^{d-g}	68.9^{a-d}	4049^{bcd}
G5	HB 52 x Bahati	81^{g-j}	141^{f-k}	106^{b-e}	38^{ij}	27^{b-f}	46.6^{ghi}	64.0^{g}	5128^{a}
G6	IBON 174/03 x Traveller	73^{l}	136^{k}	96^{gh}	51^{e-j}	23^{c-g}	51.2^{bc}	67.6^{b-e}	4470^{a-d}
G7	Sabini x Beka	82^{e-i}	140^{f-k}	116^{a}	48^{f-j}	31^{b-e}	50.7^{b-e}	68.6^{a-d}	3931^{cde}
G8	Bekoji-1 x Grace	81^{g-j}	140^{f-k}	115^{ab}	54^{c-i}	29^{b-e}	51.0^{b-d}	70.1^{ab}	4027^{bcd}
G9	IBON 174/03*	75^{kl}	135^{k}	88^{h}	54^{c-i}	28^{b-e}	48.8^{b-g}	67.0^{cde}	4487^{a-d}
G10	Holker	86^{cde}	141^{f-k}	106^{b-f}	48^{f-j}	41^{ab}	47.5^{e-h}	69.6^{abc}	4043^{bcd}
G11	HB 1963*	87^{cd}	145^{c-f}	104^{c-g}	57^{b-h}	28^{b-f}	50.4^{b-e}	70.5^{a}	4785^{ab}
G12	HB 1964	81^{g-j}	140^{f-k}	106^{b-e}	53^{d-i}	30^{b-e}	56.6^{a}	67.1^{cde}	4409^{a-d}
G13	KWS-Dante	96^{b}	149^{bcd}	55^{ij}	67^{a-f}	9^{g}	38.4^{k}	63.8^{fg}	1936^{h}
G14	KWS-Eileen	95^{b}	152^{b}	60^{ij}	65^{a-g}	17^{d-g}	52.6^{ab}	66.9^{b-g}	1905^{h}
G15	KWS_Grinada	94^{b}	146^{b-g}	52^{j}	69^{a-e}	9^{g}	39.0^{ijk}	68.6^{a-e}	2193^{gh}
G16	KWS-Hobbs	97^{ab}	150^{bc}	60^{ij}	63^{a-h}	14^{efg}	38.5^{k}	65.5^{efg}	2870^{fgh}
G17	KWS-Sassy	102^{a}	164^{a}	63^{ij}	67^{a-f}	20^{c-g}	43.1^{ij}	66.0^{d-g}	2691^{gh}
G18	KWS_ Canton	99^{ab}	152^{b}	66^{i}	49^{e-j}	21^{c-g}	43.1^{ij}	66.7^{c-g}	3050^{efg}
G19	KWS-Solicit	96^{b}	148^{b-e}	63^{ij}	72^{a-d}	14^{efg}	37.3^{k}	66.2^{d-g}	2430^{gh}
G20	IBON-HI13/14-41	77^{jkl}	140^{f-k}	88^{h}	66^{a-g}	21^{c-g}	46.8^{e-i}	68.1^{a-e}	3799^{def}
G21	IBON-HI14/15-45	77^{jkl}	137^{ijk}	100^{c-g}	53^{b-j}	23^{b-g}	50.6^{b-f}	69.4^{a-d}	4300^{a-d}
G22	IBON-HI14/15-56	82^{e-j}	136^{jk}	95^{gh}	80^{a}	23^{b-g}	48.3^{b-g}	66.1^{d-g}	4791^{abc}
G23	IBON-HI14/15-96	81^{f-j}	138^{f-k}	101^{c-g}	31^{j}	23^{b-g}	47.5^{c-i}	69.0^{a-e}	4392^{a-d}
G24	IBON-HI14/15-102	78^{i-l}	138^{g-k}	100^{d-g}	48^{e-j}	23^{b-g}	46.4^{f-i}	67.4^{a-f}	4700^{a-d}
G25	IBON-HI14/15-147	77^{i-l}	139^{f-k}	96^{e-h}	78^{a}	23^{b-g}	47.0^{e-i}	69.4^{a-d}	4370^{a-d}
G26	MBHIBYT-23	79^{h-k}	141^{e-k}	102^{c-g}	69^{a-e}	24^{b-g}	47.7^{c-i}	70.0^{abc}	4382^{a-d}
G27	Explorer	87^{c-f}	144^{c-i}	59^{ij}	74^{ab}	10^{fg}	39.5^{jk}	66.0^{d-g}	2775^{gh}
G28	Traveller*	89^{c}	145^{b-h}	88^{h}	48^{e-j}	51^{a}	46.0^{ghi}	66.9^{b-g}	4215^{bcd}

DHE=days to heading, DMA= days to maturity, PLH=plant height (cm), SC=scald (%), NB=net blotch (%), TKW= thousand kernel weight (g), HLW= hectoliter weight (hl g^{-1}), GYLD= grain yield (kg ha^{-1}), §these traits were not recorded at DB18, * = Improved checks

Individual environment means grain yield and malt quality parameters of barley genotype is given in Table 5. Differences in grain yield varied from 3614 – 7026 kg ha^{-1}. Among the genotypes, HB 52 x Bahati (G5) had the highest in average value followed by the check variety (HB1963). This genotype had also better values for extract, protein, friability and beta-glucan (Table 5). This confirmed that HB 1963 variety is an alternative malt barley genotype for the malting industry. Then IBON 174/03 x Traveller had higher mean grain yield values but shown inferior malting quality. On the other hand, Bekoji-1 x Grace and Sabini x Beka showed premium malt qualities, they scored 81.8 and 81.5 for extract, 10.0 and 9.8 for protein, 85 and 78 for friability and 369 and 287 for beta glucan, respectively. These traits are the most important and relevant for the malt factories and breweries (Cu *et al*., 2016). So, that the breeders are working on improving it. Accordingly, the G8 and G7 scored mean grain yield value ranged 2915-5090 kg ha^{-1} and 2804-6248 kg ha^{-1} across the test environments with the high malt quality standard (Table 5). Moreover, G3 showed better values in all malt quality parameters. However, unlike other genotypes these values were recorded using NIRs techniques. So, the values should be further confirmed using wet chemistry method for solid conclusion. Consequently, even if HB 52 x Bahati and IBON 174/03 x Traveller were higher in grain yield performance, we can recommend genotype Bekoji-1 x Grace instead for its premium malt barley quality and acceptable grain yield potential.

Table 5. Individual location average grain yield and malt quality traits performances of the 12 malt barley genotypes

Trt#	Genotype	BK17	BK18	DB18	HO17	KF17	KF18	Mean	Extract %	Protein %	Friability %	Beta glucan (mg/l)
G1	Grace x HB 1307	3370	4820	3013	3611	4159	4872	3995	80.4	7.6	70	462
G2	Bekoji I x Bahati	3651	5813	2640	3101	3947	4822	3972	81.1*	13.5*	68*	333*
G3	HB 1307 x Su-Lilly	4236	6396	3634	2572	4015	2629	3920	84.0*	9.5*	86*	246*
G4	Belgium 2	3873	5926	2972	3325	3784	4426	4049	76.8	13.3	29	1000
G5	HB 52 x Bahati	5304	7026	3614	4293	4675	6046	5128	80.7	8.3	72	699
G6	IBON 174/03 x Traveller	3595	6265	3154	4019	4715	5075	4470	76.7	12.2	37	1000
G7	Sabini x Beka	4127	6248	2804	3441	3633	3287	3931	81.5	9.8	78	287
G8	Bekoji-1 x Grace	3880	5090	2915	4081	4000	3968	4027	81.8	10.0	85	369
G9	IBON 174/03	3874	6667	2348	4236	4855	5144	4487	79.4	10.6	50	1000
G10	Holker	3477	6373	3035	3658	3418	4179	4043	77.6	13	61	420
G11	HB 1963	4005	5818	3686	5355	5198	4252	4785	81.3	8.9	78	510
G12	HB 1964	3645	5350	2927	4277	4584	5625	4409	78.6	11.6	44	1000

*These data were recorded from Near infrared spectroscopy (NIRs) using Bruker Tango instrument, NB= malt quality standards: Extract, >78 %, Friability, >77 %, Beta glucan, <400 mg/l, Protein, 9-11.5

GGE biplot

Significant mean squares for G X E indicated inconsistency of mean grain yield performance of genotypes across environments. According to Yan and Hunt (2001) investigating causes of G X E interaction helps establish breeding objectives and identify areas of optimal cultivar adaptation. The "which-won-where" view of the GGE biplot is important feature for mega environment identification. Therefore, in this study based on the mean grain yield performance, environments fall in to single sector. Six environments (KF17, KF18, BK17, BK18, DB18 and HO17) grouped in one mega environment. The genotypes namely, G5, G6, G9 and G11 that were found high yielding categorized in the other mega environments (Figure 1). G5 (HB 52 x Bahati) is the vertex genotype, which showed higher grain yield than the other genotypes included in the mega environment (Yan and Tinker, 2006). Moreover, no environments fell into sectors that contained the remaining genotypes, which indicates that they were the poorest genotypes in all test environments (Yan, 2001).

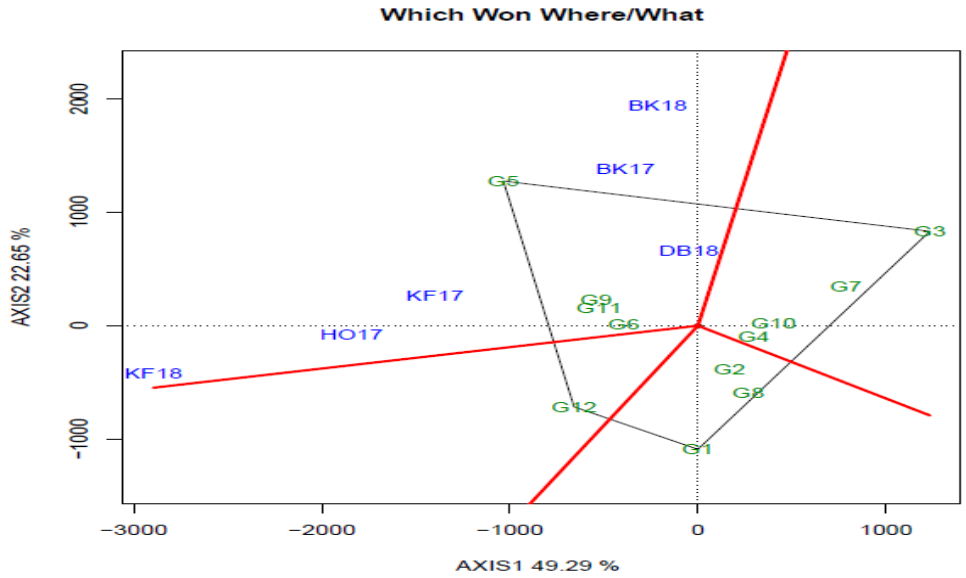

Figure 1. The which-won-where view of the GGE biplot of grain yield of Food barley genotypes based on the G × E data

The GGE biplot explained 72% of the grain yield variation due to GGE (Figure 2). "Mean vs. Stability" view of GGE biplot is 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 presented in Figure 2. G5 showed higher mean grain yield value than the other test genotypes and had moderate stability. The check varieties G9 (IBON 174/03), G11 (HB 1963) and the other test genotype G6 (IBON 174/03 x Traveller) had the next highest mean grain values and these genotypes revealed good stability.

On the other hand, among high malt quality yielding genotypes, G8 (Bekoji-1 x Grace) showed relatively better stability (Figure 2).

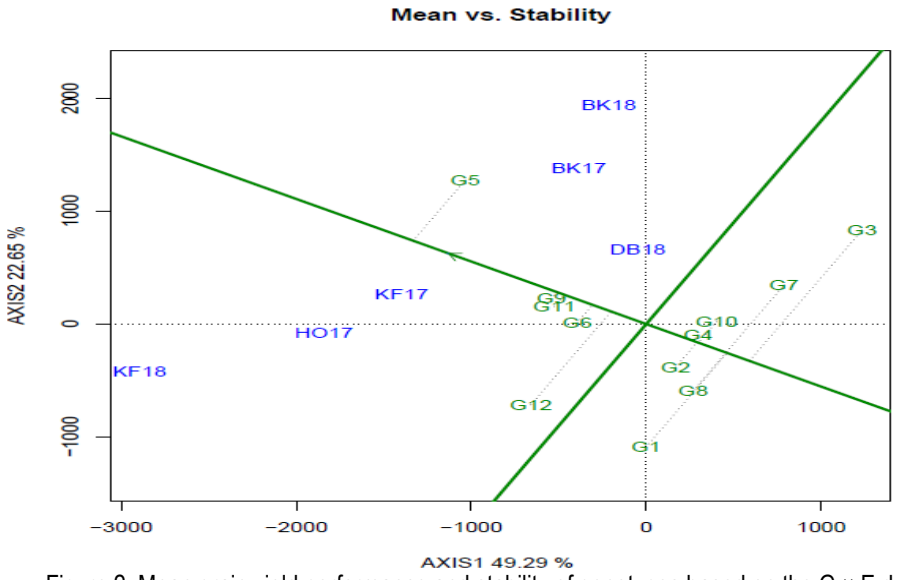

Figure 2. Mean grain yield performance and stability of genotypes based on the G × E data

Conclusion and Recommendation

The major finding from this study was that G8 (Bekoji-1 x Grace) had shown a premium malt and physical grain quality result meeting the standard of the malt industry, which in most cases are missing in our elite varieties. The other genotype G5 (HB 52 x Bahati) showed significantly higher mean grain yield and good malt quality traits, except for friability. The GGE biplot, G5 (HB 52 x Bahati) was the winning genotype in all test environments. Moreover, the "mean vs stability" view of GGE biplot indicated that G5 recorded the highest mean grain yield. In terms of stability, the high yielding genotype (G5) and the high-quality genotype (G8) showed moderate stability across test environments. Overall, Genotypes G8 is identified as potential malt barley candidate variety for further malt quality test prior to variety verification trial. Genotype G5 is included in the crossing block as potential donor parent for its high yielding performance across the test environments. Moreover, G8 (Bekoji-1 x Grace) and G7 (Sabini x Beka) are recommended for the malt barley crossing program as potential parent for their good malt quality traits (high malt extract and low beta-glucan).

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Pulse Crop Research Results

Analysis of Multi-Environment Trials for the Development of Desi Chickpea (Cicer arietinum L.) Varieties for Potential Growing Areas of Ethiopia

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Abstract

Chickpea (Cicer arietinum L.) is an important food legume and a key player in the livelihoods of resource poor farmers in Ethiopia. However, its production and productivity highly influenced by prevailing environmental conditions. As a result, multi environmental yield trials are critical to identify wide adaptable and high yielding varieties. The main objective of the present study was to assess the genotype-by-environmental interaction on the grain yield stability in Desi chickpea genotypes. From 2018 to 2020, a total of 50 Desi chickpea genotypes were evaluated under national variety performance trials in ten potential chickpea growing areas using row column design. The Additive Main Effects and Multiplicative Interaction and Genotype and Genotype by Environment Interaction model were used to investigate genotype by environment interaction (G×E). AMMI model analysis of variance for grain yield showed significant difference ($P \leq 0.01$) for genotypes, environments, and genotypes by environments interactions (G x E). AMMI biplot stability analysis and genotype selection index (GSI) indicated that variety 'Geletu' is one of the most stable and high yielding test genotypes in the multi environment trial. GGE biplot comparison among test genotypes and test environments also confirmed that 'Geletu' and Chefe Donsa are stable genotype and ideal environments, respectively. Therefore, the current results indicated that based on yield performance, Geletu showed better yield with better stability across all test environments and released for commercial production and wider adoption in the potential chickpea growing areas of Ethiopia. This variety was named after the renowned Ethiopian chickpea breeder Dr. Geletu Bejiga.

Keywords: AMMI, Chickpea, GGE, Yield, Multi-environment

Introduction

Chickpea (*Cicer arietinum* L.) is an important grain legume which is cultivated worldwide and a key factor in the livelihoods of resource poor farmers (Jendoubi *et al*. 2017; Roy *et al*. 2010). In many countries, chickpea has great cultural and culinary importance, while also being an excellent source of dietary protein, minerals and vitamins (Ravi and Harte 2009). Eighty percent of global chickpea

production derives from India, Australia and Pakistan (FAOSTAT2018). African countries accounted for 4.55% of global production of which Ethiopia accounted for 70.51% (FAOSTAT, 2018). In 2018, Ethiopian farmers cultivated chickpea on 242,703 hectares, yielding 499,426 tons of grain (CSA, 2018).

However, its production and productivity are highly challenged by low productivity of landraces, several biotic and abiotic stresses, poor farming practices, among others (Dagnachew *et al*. 2020a). To overcome these constraints, the chickpea breeding program in Ethiopia made considerable efforts. Grain yield is a complex quantitative trait, often controlled by many genes, influenced by prevailing environmental conditions, with each gene having a small effect. Chickpea productivity in grain yield is a combined result of the genotype of the variety, the environment and the interaction between genotype and environment. Therefore, in order to identify the most stable and high yielding genotypes, it is important to conduct multi-environment trials (Luquez *et al*., 2002). In Ethiopia all released varieties were developed through rigorous evaluation and critical selection of advanced germplasms and breeding pipe lines for diverse agro morphological traits over years under diverse agro-ecologies in multiple environments (Dagnachew *et al*., 2020b; Asnake and Dagnachew, 2019)

Similarly, the adaptability of any genotype is the product of the inherent capacity of genotype, the environmental factor in which a given genotype is grown and the interplay between the environment and genotype (Zobel, 1990). Thus, the assessment of adaptability and stability parameters supports to define the response of genotypes to environmental variations, sketch realistic conclusion and solidifying the recommendation of new cultivars (Zobel, 1990). As a result, multi environmental yield trials are critical to detect adaptable high yielding cultivars and discover sites that best represent the target environment. Multi-environment trials (MET) are essential because of the existence of genotype by environment interactions (G x E), which complicates genotypes evaluation, and analysis of G x E data from MET trials has been an important component of plant breeding and cultivar recommendation. Several statistical models have been developed for analyzing the adaptability and stability of genotypes over environments. Differences in genotype stability and adaptability to environment can be qualitatively assessed using the biplot graphical representation that scatters the genotypes according to their principal component values (Vita *et al*., 2010).

Additive main effects and multiplicative interaction models (AMMI), and the genotype and genotype by environment interaction (GGE) model, are the most widely used statistical tools to determine the pattern of genotypic responses across diverse environments (Smith and Smith, 1992; Yan and Kang, 2002, 2003). The AMMI model combines ANOVA for main effects of the genotype and environment with principal components analysis of GE interactions. Several AMMI parameters were introduced for studying the stability of genotypes across

multi environments and AMMI stability value (ASV) is a reliable statistic for GE interaction description and simultaneous selection of yield and stability (Purchase *et al*., 2000). Therefore, the main objective of the present study was to assess the genotypic and environmental variables on determination of grain yield stability in Desi chickpea genotypes using AMMI and GGE biplot analyses.

Materials and Methods

Plant materials and test environments

In this study, 50 Desi chickpea genotypes were used (Table 1). The test genotypes were evaluated under pre national and national variety trial for three consecutive years, from 2018 to 2020, in ten potential chickpea growing areas of Ethiopia using row column design with three replications. Each year at each location was considered as a separate environment, resulting in a total of 10 test environments (Table 2). The eco-climatic characteristics of these testing locations are given in Table 2 below. This trial was planted in 30 cm by 10 cm inter and intra row spacing. Data on grain yield and other yield related morphological traits were recorded from central rows of each plot.

Table 1. List of genotypes used in an experiment over the three years

GID	Genotype	GID	Genotype	GID	Genotype
G10	DZ-2012-CK-0253	G23	ICCMABCD-7	G42	MABC-9
G2	DZ-2012-CK-0030	G19	ICCMABCD-23	G41	MABC-4
G3	DZ-2012-CK-0034	G20	ICCMABCD-24	G37	MABC-16
G4	DZ-2012-CK-0039	G21	ICCMABCD-5	G38	Geletu
G5	DZ-2012-CK-0228	G22	ICCMABCD-6	G39	MABC-2
G6	DZ-2012-CK-0230	G18	ICCMABCD-21	G40	MABC-3
G7	DZ-2012-CK-0232	G24	ICCV-10	G36	MABC-14
G8	DZ-2012-CK-0234	G25	ICCV-13108	G35	MABC-13
G9	DZ-2012-CK-0236	G26	ICCV-15105	G43	Minjar
G1	DZ-2012-CK-0029	G27	ICCV-15112	G44	Natoli
G11	ICCMABCA-27	G28	ICCV-16101	G45	Teketay
G12	ICCMABCA-30	G29	ICCV-16107	G46	MABC-18
G13	ICCMABCD-11	G30	ICCV-16109	G47	Dalota
G14	ICCMABCD-14	G31	ICCV09309	G48	Dimtu
G15	ICCMABCD-16	G32	ICCV14106	G49	Dubie
G16	ICCMABCD-18	G33	ICCX-100090-F4(2)	G50	Local check
G17	ICCMABCD-19	G34	MABC-11		

Table 2. Eco-climatic characteristics of testing environments

Test Location	Soil type	Trial Code	Environment Code	Altitude	Rainfall
Adet	Vertisol	AD19CDNPE	E1	2178	517
Akaki	Vertisol	AK19CDNPE	E2	2200	1025
Akaki	Vertisol	AK20CDNPE	E3	2200	1025
Axum	Vertisol	AX19CDNPE	E4	2105	737.6
Chefe Donsa	Vertisol	CD19CDNPE	E5	2522	1150
Chefe Donsa	Verisol	CD20CDNPE	E6	2522	1150
Delgi	Light	DL20CDNPE	E7	1868	1150
Debre Zeit	Vertisol	DZ18CDPPE	E8	1900	850
Debre Zeit	Vertisol	DZ19CDNPE	E9	1900	850
Debre Zeit	Vertisol	DZ20CDNPE	E10	1900	850

Trial codes: DZ, AD, AK,AX,CD and DL stands for Debre Zeit, Adet, Axum, Chefe Donsa and Delgi, respectively, CDPPE = Chickpea Desi pre national variety trial for potential environment, CDNPE = Chickpea Desi national variety trial for potential environment

Data Analysis

The Additive Main Effects and Multiplicative Interaction (AMMI) and Genotype and Genotype by Environment Interaction (GGE) model was used to investigate genotype by environment interaction (G×E). Stastical analysis was performed using GenStat software (GenStat, 2012). The AMMI model analysis of variance (ANOVA) was used to determine the presence or absence of genotype by environment interactions (G×E) for further AMMI stability and GGE biplot analysis. The AMMI model equation is:

$$Yij = \mu + Gi + Ej + \Sigma\lambda k\alpha ik\delta jk + Rij + \varepsilon$$

where Yij is the value of the i^{th} genotype in the j^{th} environment; μ is the grand mean; Gi is the deviation of the ith genotype from the grand mean; Ej is the deviation of the jth environment from the grand mean; λk is the singular value for PC axis k; αik and δjk are the PC scores for axis k of the i^{th} genotype and j^{th} environment, respectively; Rij is the residual and ε is the error term (Gauch, 1992).

AMMI's stability value (ASV) was calculated following the formula proposed by Purchase (1997) as follows:

$$ASV = \sqrt{[(SSIPCA1/SSIPCA2)(IPCA1SCORE)]^2 + (IPCASCORE2)^2}$$

where SS is sum of square, IPCA is interaction principal component axis, SS IPCA1/SS IPCA2 is the weight given to the IPCA1 value by dividing the IPCA1 sum of squares by the IPCA2 sum of scores; and the IPCA1 and IPCA2 scores are the genotypic scores in the AMMI model. The larger the ASV value, the more specifically adapted a genotype is to certain environments. Smaller ASV values indicate more stable genotypes across environments (Purchase, 1997). Genotype Selection Index (GSI) was estimated as:

$$GSI = rASV + rYSI$$

where rASV is the rank of AMMI stability value and rYSI is the rank of mean grain yield of genotypes stability Index across environments.

Results and Discussion

The AMMI model analysis of variance (ANOVA) for grain yield showed highly significant differences ($P \leq 0.01$) for genotypes, environments, and genotypes by environments interactions (Table 3). The first principal component axis of genotype by environment interaction (G×E) was highly significant ($P \leq 0.01$). The first principal component explained 35.1% of the genotype by environment interaction (G×E) and the second principal component revealed 17.6% of the interaction. Similar previous studies suggested the importance of capturing most of the genotype by environment interaction (G×E) sum squares in the first principal component axis to attain accurate information (Crossa *et al*.,1990; Purchase *et al*.,2000).

Table 3. AMMI analysis of 50 chickpea genotypes grain yield performance evaluated across 10 test environments in potential chickpea growing areas.

Source of variation	DF	SS	MS	% G x E Cumulative interaction	% Explained
Genotypes	49	29.39	5.99***		
Environments	9	636.38	70.75***		
G x E Interactions	441	176.44	5.41***		
IPCA-1	57	50.5	8.9***	35.1	35.1
IPCA-2	55	25.36	4.61***	17.6	52.7
IPCA-3	53	20.7	3.90**	14.4	67.1
Residuals	682	168.9	2.4		

*** indicate significance at 0.01 probability levels

Because of its significant contribution to the genotype by environment interaction, the first interaction principal component axis (IPCA-1) and mean grain yield (ton/ha) were used to construct a AMMI biplot graph to gain sufficient information on the stability of individual genotypes in different test environments (Fig.1). The result of AMMI Biplot analysis with IPCA-1 against mean grain yield (ton/ha) indicated that most test genotypes were concentrated near the origin

indicating average performance for grain yield, and those genotypes with IPCA scores very close to zero are stable for most environments (Fig.1). However, genotype G10(DZ-2012-CK-0253) and G8 (DZ-2012-CK-0234) were the most unstable genotypes. Previous reports showed that, the IPCA scores approximate to zero, the more stable the genotype is all over the test environments (Purchase *et al*., 2000). The ideal genotype is one with high productivity and IPCA-1 values close to zero, whereas the undesirable genotype has low stability associated with low productivity (Kempton, 1984; Gauch and Zobel, 1988).

Among the test environments, E2 (Akaki in 2019), E8 (Debre Zeit in 2018) and E4(Axum in 2019) were the most productive environment (Fig.1). In the AMMI-1biplot display, genotypes or environments that fall on a perpendicular and horizontal line of the graph had similar mean yield and similar interaction, respectively. On the other hand, genotypes or environments on the left and right-hand side of the midpoint line have less and higher yield than the grand mean, respectively. The score and sign of IPCA-1 reflect the magnitude of the contribution of both genotypes and environments to genotype by environment interaction (G×E), where scores near zero are the characteristic of stability and a higher score (absolute value) designate instability and specific adaptation to a certain environment (Gollob, 1968).

AMMI biplot based stability estimate showed that genotypes very closer to the biplot origin, particularly, G38 (Geletu), G30 (ICCV-16109), G46 (MABC-18) and G26 (ICCV-15105) were average in grain yield performances across the environments, and they are stable (Fig.2). Other genotypes that are far from the biplot origin were better adapted to specific environments (Wondafrash *et al*., 2015). In the present study, G10 (DZ-2012-CK-0253), G14 (ICCMABCD-14), G47(Dalota), G20(ICCMABCD-24) and G45(Teketay) showed specific adaptation to E5 and E8 (Chefe Donsa-2019 and 2020). Genotype, G22(ICCMABCD-6), G44(Natoli), G27(ICCV-15112), G15(ICCMABCD-16) and G13 (ICCMABCD-11) showed specific adaptation to E6, E9 and E1(Chefe Donsa in 2020, Debre Zeit in 2019 and Adet in 2019). Similarly, G41(MABC-4) and G24(ICCV-10) showed specific adaptation to E7(Delgi).

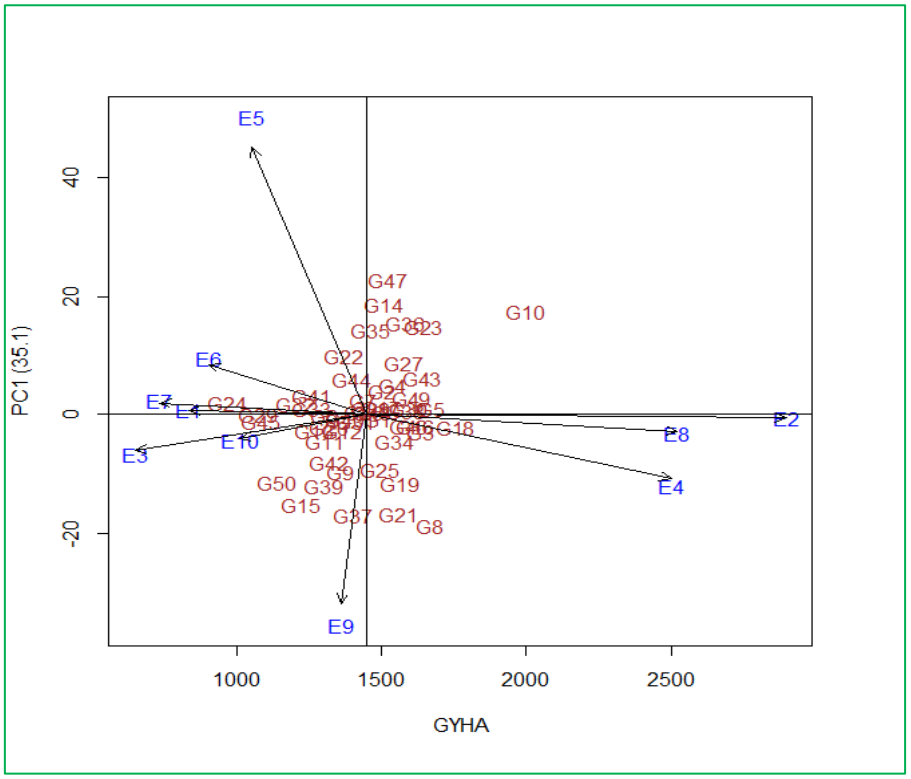

Figure 1. AMMIBiplot of interaction principal component axis (IPCA-1) against mean grain yield ton/ha (GYTHA) of 50 chickpea genotypes evaluated across 10 environments.

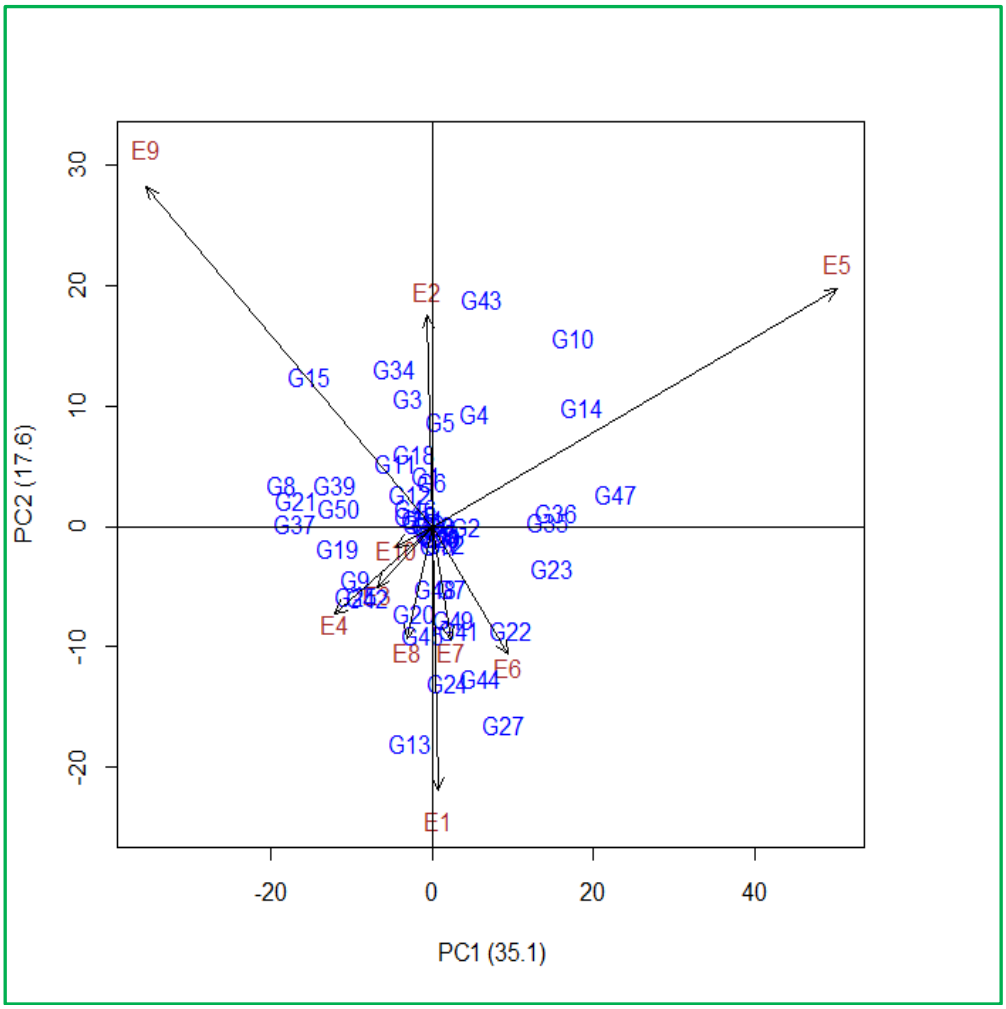

Figure 2 AMMI biplot analysis showing the mega environments and their respective yielding genotypes

AMMI stability Analysis

Genotypes G29 (ICCV-16107), G26 (ICCV-15105), G38 (Geletu), G33(ICCX-100090-F4) and G40 (MABC-3) with least AMMI stability values (ASV) were the most stable genotypes in this study (Table 4). Consistent with AMMI bi-plot based stability estimate, this analysis showed that G47(Dalota), G14 (ICCMABCD-14), G10 (DZ-2012-CK-0253), G8 (DZ-2012-CK-0234), G37 (MABC-16) and G21(ICCMABCD-5) were the most unstable genotypes. Stable genotypes would not inevitably provide the best yield performance and therefore identifying genotypes with high grain yield coupled with consistent stability across growing environments has paramount importance.

Therefore, Genotype Selection Index (GSI) which combine both mean yield and stability in a single index have been introduced to further detect high yielding genotypes with stable yield performance through diverse growing environments

(Mohammadi and Amri, 2008). Genotype Selection Index (GSI) showed the most stable and high yielding genotypes were G38 (Geletu), G30 (ICCV-16109), G16 (ICCMABCD-18) and G46 (MABC-18), whereas, G15 (ICCMABCD-16), G39 (MABC-2), G37 (MABC-16), G24 (ICCV-10) and G50 (Local check) were the least stable and low yielding genotypes in the present study (Table 4). Consistently, the released varieties Geletu, Dimitu and Teketay were moderately stable with average grain yield performance in all environments. Similar result was reported for same released Desi type chickpea in Ethiopia (Dagnachew *et al.*, 2020b, Biru *et al*., 2017).

Table 4. AMMI stability value, mean grain yield (ton/ha) and genotype selection index

GID	MGY	ASV	rASV	rYSI	GSI	GID	MGY	ASV	rASV	rYSI	GSI
1. G38	1.58	1.26	3	13	16	26. G8	1.66	37.58	47	4	51
2. G30	1.59	2.2	7	11	18	27. G12	1.36	6.31	16	35	51
3. G16	1.62	4.19	12	8	20	28. G19	1.56	23.36	38	15	53
4. G18	1.76	7.51	18	2	20	29. G27	1.56	23.36	38	15	53
5. G46	1.6	4.3	13	10	23	30. G36	1.58	30.93	43	12	55
6. G5	1.67	8.97	21	3	24	31. G25	1.49	19.67	33	23	56
7. G26	1.44	0.54	2	28	30	32. G32	1.2	3.59	10	46	56
8. G17	1.5	2.75	9	22	31	33. G20	1.32	8.6	20	37	57
9. G49	1.6	9.34	22	9	31	34. G21	1.56	33.78	45	16	61
10.G3	1.63	12.3	26	7	33	35. G11	1.3	10.57	24	39	63
11.G28	1.46	2.11	6	27	33	36. G44	1.4	17.4	31	32	63
12.G1	1.48	4.6	14	24	38	37. G35	1.46	28.55	41	26	67
13.G31	1.41	2.52	8	30	38	38. G42	1.32	17.27	30	38	68
14.G40	1.37	1.92	5	33	38	39. G14	1.51	38.51	49	20	69
15.G2	1.5	8.23	19	21	40	40. G22	1.37	21.61	35	34	69
16.G48	1.47	5.26	15	25	40	41. G41	1.26	10.96	25	44	69
17.G43	1.64	22.56	36	6	42	42. G47	1.52	45.6	50	19	69
18.G4	1.53	13.93	28	18	46	43. G9	1.35	19.83	34	36	70
19.G7	1.44	6.91	17	29	46	44. G45	1.08	9.42	23	48	71
20.G34	1.55	16.1	29	17	46	45. G13	1.27	18.9	32	42	74
21.G23	1.65	29.82	42	5	47	46. G24	0.97	13.57	27	50	77
22.G33	1.26	1.74	4	43	47	47. G37	1.4	34.02	46	31	77
23.G10	2	38.31	48	1	49	48. G39	1.3	24.29	40	41	81
24.G29	1.08	0.14	1	49	50	49. G50	1.14	23.1	37	47	84
25.G6	1.3	3.81	11	40	51	50. G15	1.22	33.03	44	45	89

GID= Genotype Identification; MGY=Mean grain yield(ton/ha), ASV=Ammi stability value; rASV=rank of Ammi stability value; rYSI= rank of yield stability index; and GSI= Genotype Selection Index

Environment and genotype evaluation

Among the 10 test environments considered in this study, E5 (Chefe Donsa in 2019) and E2 (Akaki in 2019) were the most discriminating (informative) environment, whereas E10 (Debre Zeit in 2018) was the least discriminating environment (Fig.3 and 4.). Similarly, E5 (Chefe Donsa-2019) was the most representative environment, while E10 (Debre Zeit in 2018) was the least representative of all test environments. Recently, similar result was reported in Desi chickpea in Ethiopia (Dagnachew *et al*., 2020). The concentric circles on the GGE biplot help to visualize the length of the environment vectors, which is a measure of the discriminating ability of the environments (Yan and Tinker, 2006; Dabessa *et al*., 2016). Similarly, a test environment that has a smaller angle with the Average-Environment Axis (AEA) is more representative of other test environments (Yan *et al*, 2011). Therefore, test environments that are both discriminating and representative are good test environments for selecting generally adapted genotypes.

In the present study the most discriminating and representative environment was E5 (Chefe Donsa-2019) for selecting wide adaptable genotypes. Discriminating but non-representative test environments are useful for selecting specifically adapted genotypes if the target environments can be divided into mega-environments (Yan and Tinker, 2006). Test environments that are consistently non-discriminating (non-informative) provide little information on the genotypes and, therefore, should not be used as test environments (Yan and Tinker, 2006).

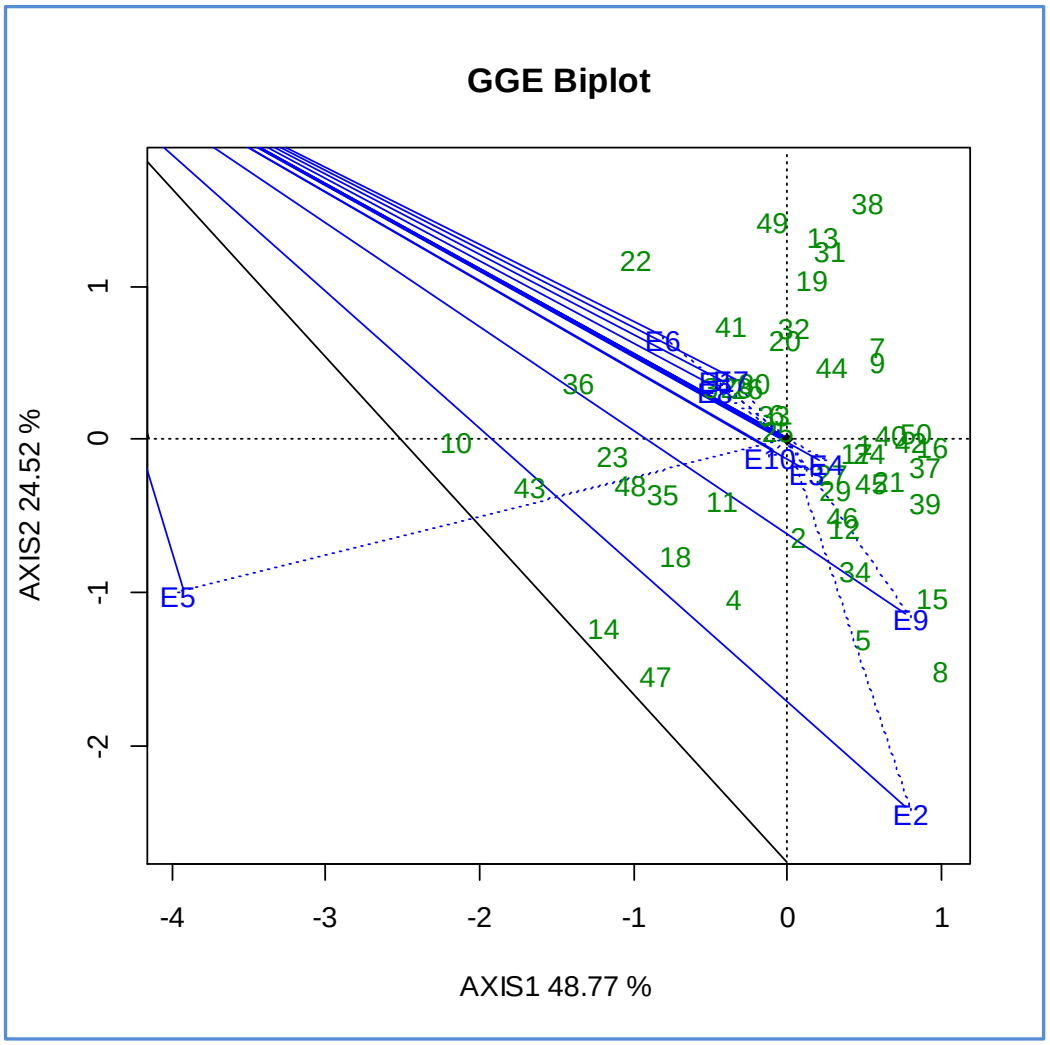

Figure 3. GGE biplot analysis showing the test environments and genotypes

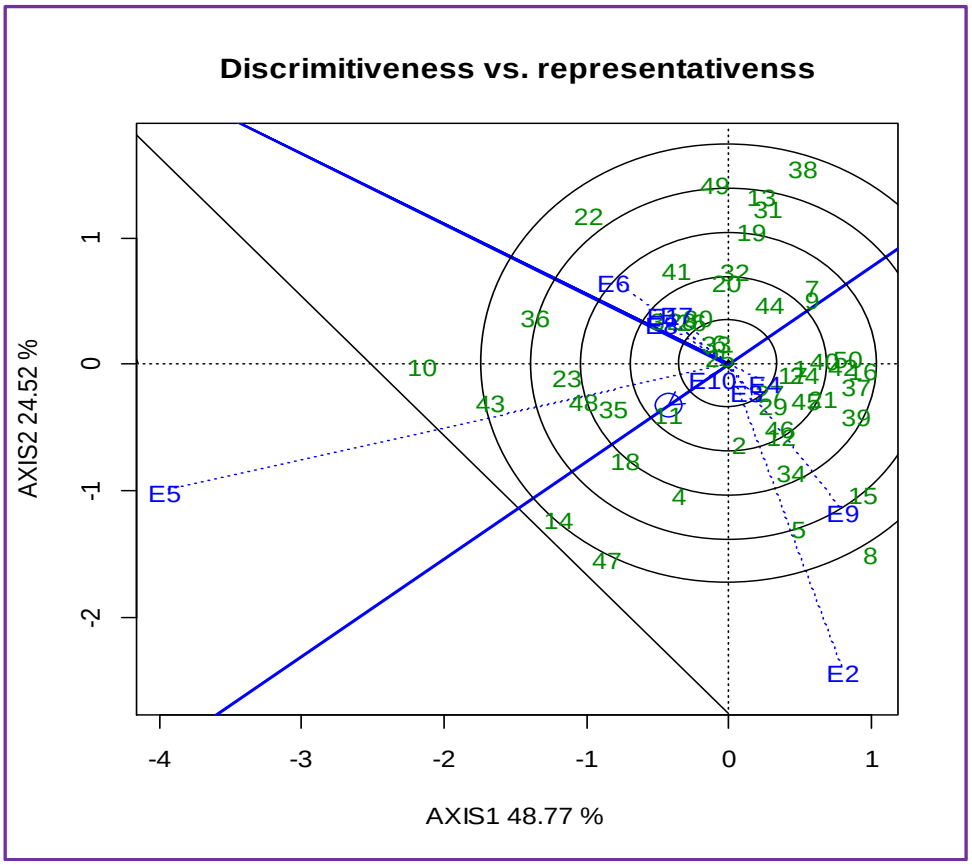

Figure 4. The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness the test environment

Mega environment differentiation

In this study, the equality lines divided the GGE biplot into 3 mega-environments, and the winning genotype for each mega-environment is the one located on the respective vertex (Figure 5). The first mega environment with E5(Chefe Donsa in 2019) was the best environment for high grain yield, and the winning genotype for this mega environment was G10(DZ-2012-CK-0253) with the best mean grain yield of all test genotypes. However, the second mega environment with E10 (Debre Zeit in 2018) was the most unsuitable environment for grain yield, and the winning genotype for this mega environment was one of the most unstable genotypes in this study G8 (DZ-2012-CK-0234). The third mega environments were represented with test genotype with average grain yield performance, but with moderate to high stability and the winning genotype for this mega environment was G38 (Geletu) with best stability and good mean grain yield. Consistent to this result, both the heat map (Figure 6) and the dendrogram (Fig.7) split the test environment into three similar mega environments. One of the most attractive features of a GGE biplot is its ability to show the which-won-where pattern of a genotype by environment dataset, and it can address important

concepts such as mega-environment differentiation and specific adaptation (Yan and Tinker, 2006).

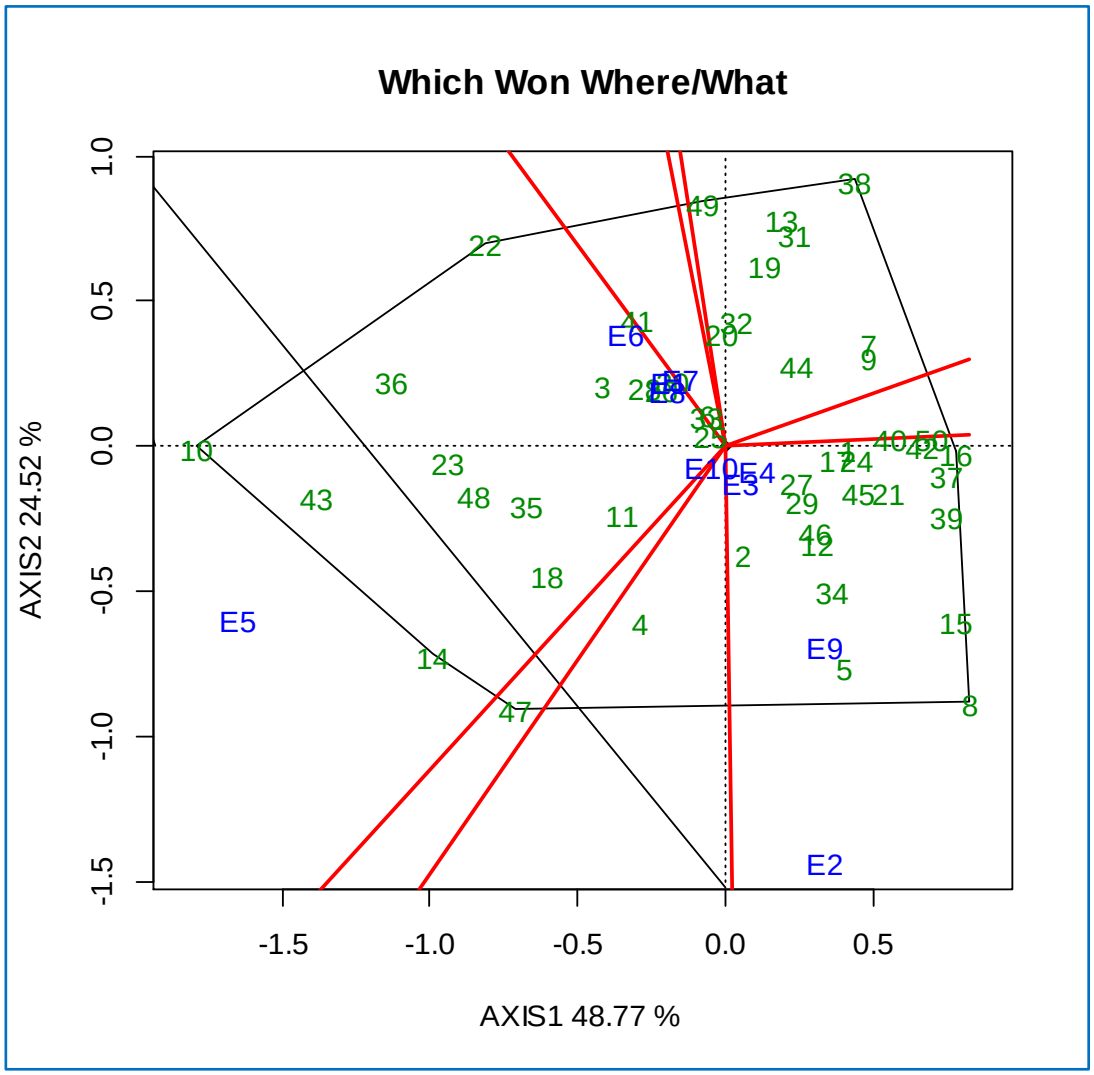

Figure 5. The which-won-where view of the GGE biplot to show which genotypes performed best in which environments

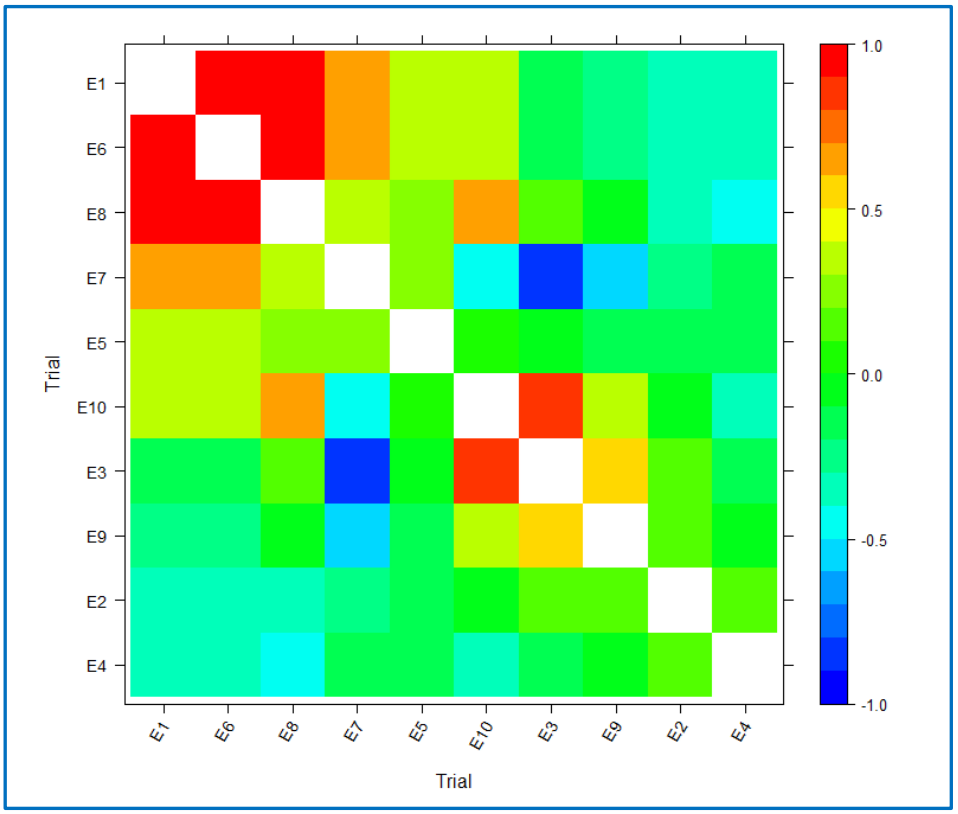

Figure 6. Heatmap showing similarity test environments (E1 to E10).

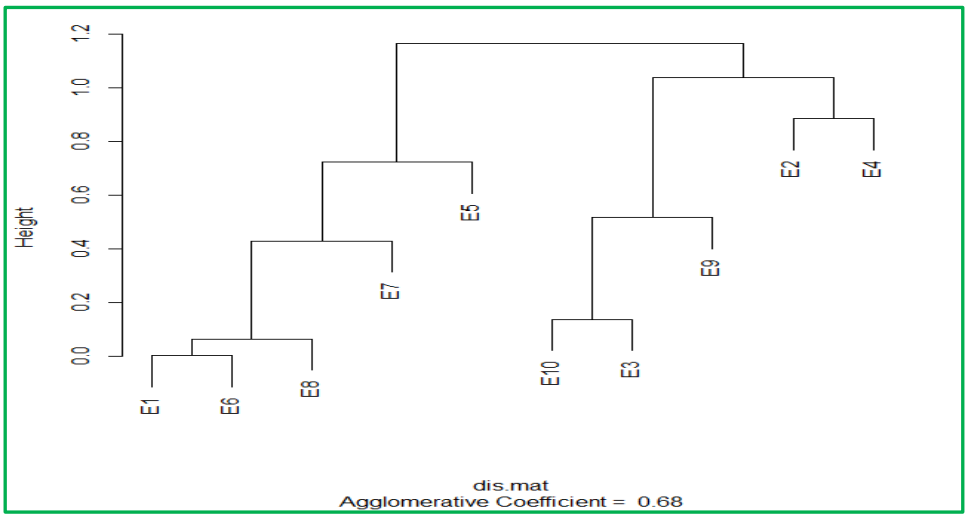

Figure 7. Dendrogram showing the three mega environments (E1 to E10).

Conclusion and Recommendation

AMMI biplot stability analysis and genotype selection index (GSI) showed the most stable and high yielding genotypes in the present study were Geletu, ICCV-16109 and ICCMABCD-18. Both AMMI and GGE biplot analyses also indicated, for selecting wide adaptable genotypes, the most discriminating (informative) and representative environment was Chefe Donsa. Besides, GGE biplot, heatmap and dendrogram analyses were split the 10 test environments into 3 representative mega-environments. Interestingly, GGE biplot comparison among test genotypes and test environments also revealed Chefe Donsa and Geletu were ideal environments and stable genotypes, respectively. Generally, the current results indicated that based on yield performance, AMMI and GGE biplot analyses, and GSI indices, Geletu showed better yield with better stability across all test environments and released commercial production and recommended as wide adaptable variety for wider adoption in the potential chickpea growing areas of Ethiopia. This variety was named after the renowned Ethiopian chickpea breeder Dr. Geletu Bejiga from the Ethiopian Institute of Agricultural Research (EIAR), Ethiopia.

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BLUP Model based Stability Analysis of Multi-environment Trials of Lentil Variety 'Furi' for Potential Growing Areas of Ethiopia

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Abstract

Lentil (Lens culinaris Medic) is one of the most important pulse crops in Ethiopia that is dominantly produced in the crop-livestock based farming systems. However, the national average seed yield of the crop is very low as compared to its potential yield. This yield gap between achieved and potential yield is mainly due to varietal and environmental variability. To understand genotype by environment interaction in lentil and identify the best wide adaptable genotype across the potential growing areas, ttwenty-five lentil genotypes were evaluated over three seasons (2016 – 2018) at 8 locations resulting in 11 environments in row column design. A factor analytic model was fitted to the pattern of genotype by environment (GxE) interaction using RASReml package and predicted yield (t/ha-1) values for all genotypes under evaluation were obtained. The model adequately explained 90.6% of the GxE variance at an FA-2 of yield data. Environment and genotype evaluation based on GGE biplots has revealed a number of discriminative and representative environments while identifying ideal and high performing genotypes. Environment Db18LN was most discriminating followed by EN17LN, SN18LN and DZ16LP, whereas CD16LP and DZ16LP were found to be representative test site. Genotypes 6(DZ-2012-Ln-0218) was identified as high yielder and stable than other test genotypes with 11% yield advantage over the standard check "Derso" and so was proposed for verification in the year 2020 for release as new variety. In the year 2021, it then registered with variety name "Furi" on the national catalogue of Ministry of Agriculture of the country.

Keywords: Analytic, Factor, ASReml package, GGE, Lentil**,** stability

Introduction

Lentil (*Lens culinaris* Medic) is the important pulse crops in Ethiopia that is dominantly produced in the crop-livestock based farming systems of the central, north and northwest highlands of Ethiopia where vertisols are dominating. The crop can also grow in the lowland parts of the country provided that early maturing, resistant/tolerant to rust and low moisture stress varieties are developed. Lentil has multiple uses in the country. The crop is good sources of dietary protein.

It is also a rich source of essential vitamins, minerals, and important amino acids like lysine. The crop is also endowed with unique property in maintaining and improving soil fertility through symbiotic biological nitrogen fixation. Thus, it leaves substantial amount of residual nitrogen for subsequent crops and adds plenty of organic matter to maintain and improve soil health and fertility (Gaur *et al*., 2010). Hence, Ethiopian farmers usually grow the crop in rotation with cereals.

Besides being key components in the diets؛ lentil also attract higher market prices than other staple crops, making them an important source of income for farmers. Despite the above facts, the national average seed yield of the crop is very low, 1.42 ton/ha (FOSTAT 2018) as compared to its potential yield (2.5t/ha). This yield gap between achieved and potential yield of lentil in Ethiopia could be partially due to varietal and environmental variability. Regarding environmental variability, testing genotypes of annual crops for grain yield on a multi-locational or multi-year basis frequently shows GE interaction that complicates the selection or recommendation of materials. According to Annicchiarico (1997), it is possible to cope with genotype by year or genotype by location by year interaction effects only through selection for yield stability across environments defined as location by year combinations.

Kanouni, *et al* (2015) stated that GE analysis is important tool that help to identify superior varieties and their adaptation to and stability in diverse agro ecologies. In line to this fact, Padi, (2007) also observed that differential performance of chickpea under diverse environmental conditions decreases yield stability. Inefficiency in the GE analysis of variance may also result in wrong selection of genotypes for yield. There are many models for conducting GE whose applicability depends on the experimental data, the number of environments, and the accuracy of collected data and environmental information.

Earlier research work done in advancing GE by authors such as Gauch 1992; Imrie and Hacker 1993; Kang and Gauch 1996; Cooper and Hammer 1996 have contributed significantly to the understanding and make use of the Biplot analysis as a tool. However, the way GE is measured and addressed between different users of different sectors varies. In this regard, Yan and Tinker (2006) stated that, biometricians and quantitative geneticists concentrate primarily on quantification of GE, while breeders and other practitioners are often concerned primarily with matching genotypes with environments.

The primary aim of a plant breeding in multi environment trials (MET) is selection either of potential new varieties or potential parents (Yan and Tinker, 2006). Selection requires definition of the trait(s) of interest and formation of an appropriate index based on these traits. Although it has been argued that environments (that is trials) can be regarded as traits in METs it is clear that this

assumption may not be generally applicable, particularly for those METs which span several years of testing. Trial locations are usually chosen to represent a target ‘‘environment’’. The target environment could be an agro-ecological zone of commercial significance, or an environment classified by disease pressure or other biotic or abiotic factors. The trait of interest would therefore be the yield performance for the set of trials that align with the target environment (Yan and Tinker, 2006). In this study, we used average of grain yield ton per hectare of genotypes determined for individual environments using best linear unbiased prediction (BLUPs) fitted by factor analytic model in ASReml package, and biplot analysis implemented by GGE biplot with the aim to understand genotype by environment interaction in lentil, identification of best wide adaptable genotype across locations in the potential growing area of Ethiopia

Materials and Methods

Description of eco-location and genotypes

A study was undertaken by using germplasm of different genetic background to determine their level of GE in their biological yield responses. Twenty-five lentils advanced breeding genotypes including check varieties were evaluated each over three seasons between 2016 and 2018 at 8 locations resulting in 11 environments. The test genotypes were derived from series of trials called Preliminary Varity Trial (PVT) and National Varity Trial (NVT) tested at potential environments. Row - Column design with three 3 and 4 replications for PVT and NVT was used respectively. Each genotype was planted on four rows of 4m long in 20cm by 2cm inter and intra row spacing. Production was all under rain fed condition. The geographic information of testing sites is presented in Table 1.

Table 1. List of test environments, number of genotyped used, and their respective geographic information.

Test Site	Environment	No Genotypes	No Replication	Altitude (m.a.s.l)	Latitude (°N)	Longitude (°E)
Akaki	AK16LP	25	3	2207	8.87	38.85
Akaki	AK17LN	14	4	2207	8.87	38.85
Chefe Donsa	CD16LP	25	3	2450	8.96	39.1
Chefe Donsa	CD17LN	14	4	2450	8.96	39.1
Dabat	Db18LN	14	4	2557	12.97	37.77
Debre Zeit	DZ16LP	25	3	1910	8.73	39
Debre Zeit	DZ18LN	14	4	1910	8.73	39
Enewari	EN17LN	14	3	2667	9.88	39.15
Hosanna	HS18LN	14	4	2295	7.55	37.86
Kokate	KK18LN	14	4	2140	6.87	37.82
Sinana	SN18LN	14	4	2439	7.11	40.22

NB: PVT = Preliminary variety Trial, NVT = National Variety Trial, AK16LP=Lentil PVT at Akaki in 2016, AK17LN=Lentil NVT at Akaki in 2017, CD16LP=Lentil PVT at Chefe Donsa in 2016, CD17LN=Lentil NVT at Chefe Donsa in 2017, Db18LN=Lentil NVT at Dabat in 2018, DZ16LP=Lentil PVT at Debre Zeit in 2016, DZ18LN=Lentil NVT at Debre Zeit in 2018, EN17LN=Lentil NVT at Enewari in 2017, HS18LN=Lentil NVT at Hosanna in 2018, KK18LN=Lentil NVT at Kokate in 2018, SN18LN=Lentil NVT at Sinan in 2018

Table 2. List of genotypes over test years of 2016, 2017 and 2018 respectively

Code	Genotypes	Source	Remark
1	Denbi	MSI	Released variety
2	Derso	MSI	Released variety
3	DZ-2012-Ln-0020	Introduction	Advanced line
4	DZ-2012-Ln-0050	Introduction	Advanced line
5	DZ-2012-Ln-0054	Introduction	Advanced line
6	DZ-2012-Ln-0218	Introduction	Advanced line
7	DZ-2012-Ln-0219	Introduction	Advanced line
8	DZ-2012-Ln-0228	Introduction	Advanced line
9	DZ-2012-Ln-0231	Introduction	Advanced line
10	DZ-2012-Ln-0232	Introduction	Advanced line
11	DZ-2012-Ln-0233	Introduction	Advanced line
12	DZ-2012-Ln-0234	Introduction	Advanced line
13	DZ-2012-Ln-0235	Introduction	Advanced line
14	DZ-2012-Ln-0236	Introduction	Advanced line
15	DZ-2012-Ln-0237	Introduction	Advanced line
16	DZ-2012-Ln-0238	Introduction	Advanced line
17	DZ-2012-Ln-0239	Introduction	Advanced line
18	DZ-2012-Ln-0240	Introduction	Advanced line
19	DZ-2012-Ln-0241	Introduction	Advanced line
20	DZ-2012-Ln-0242	Introduction	Advanced line
21	DZ-2012-Ln-0243	Introduction	Advanced line
22	DZ-2012-Ln-0244	Introduction	Advanced line
23	DZ-2012-Ln-0245	Introduction	Advanced line
24	DZ-2012-Ln-0255	Introduction	Advanced line
25	Local check	Own gene pool	Local check

Data Collection

Crop phenological traits

Days from sowing to the stages when 50% of the plants have started flowering was recorded from each plot as days to 50% flowering (DTF). Similarly, days from sowing to the stages when 90% of the pods mature was recorded from each plot as days to 90% maturity (DTM) and measurement of plant height in cent meter (PLH) was taken from five randomly selected plants from the ground to the tip using a ruler at maturity.

Grain yield and yield component traits

Hundred seed weight (HSW) of randomly selected hundred seeds weighed on a sensitive balance in gram was taken. Biomass yield (BMY) weight of all above ground plant part per plot was taken in gram and then converted to ton per hectare. Weight of seeds harvested from central two rows per plot in gram was taken and then converted to ton per hectare as grain yield (YLD). Grain harvest index (GHI) was also calculated as the ratio of grain yield to biological yield.

Data analysis

The genetic merit of each genotype for all traits was evaluated being combined over environments by best linear unbiased prediction (BLUP) using restricted maximum likelihood (REML) for variance component estimation in R. Pearson correlation was used to evaluate the association among traits. Factor analytic model was fitted using ASReml-R package and the predicted yield (tha^{-1}) values for all genotypes under evaluation were obtained base on procedures demonstrated by Kelly et.al. (2017). GGE biplot analysis was performed using R GGEBiplotGUI package of version 1.0.9 (Frutos *et al* 2014) using the BLUPs mean produced from factor analytic output. The GGE biplot methodology was used to analyse genotype performance for each environment, genotype stability, representative environment, and discriminating power of each environment.

Results and Discussion

Significant differences were observed among test genotypes for all of the characters under study indicated presence of considerable amount of variability in the tested genotypes. This variation could be exploited to improve yield (Table 3). High heritability was observed for all traits ranging over 85% for biomass yield t/ha to 98% for days to 50% flowering. Genotype DZ-2012-Ln-0245 get flowered early within 53 days, while genotype DZ-2012-Ln-0236 flowered lately within 68 days. The earliest maturing genotype DZ-2012-Ln-0218 matured within 107 days, while late maturing genotype DZ-2012-Ln-0020 matured in 125 days. Variety Denbi was the tallest (36.24 cm) followed by genotype DZ-2012-Ln-0238 (36.27 cm). On the other hand, genotype DZ-2012-Ln-0243 (28.71 cm) was the shortest among all.

Genotype DZ-2012-Ln-0228 had large seed size (3.7 cm) followed by DZ-2012-Ln-0243, and DZ-2012-Ln-0244 (3.6 cm). Local check on the other hand, had small seed size (2.1 cm). The highest grain harvest index (37%) was obtained from genotype DZ-2012-Ln-0218 which is now known by the variety name “Furi”. Conversely, genotype DZ-2012-Ln-0235 had the smallest grain harvest index (16%). Variety Derso had the maximum biological yield (6.44 t/ha), while local check scored the minimum biological yield (3.99 t/ha). Genotype DZ-2012-Ln-0218 was found to be high performing in grain yield (2.33 t/ha), while genotype DZ-2012-Ln-0237 performed poorly in grain yield (0.86 t/ha).

Table 3. Mean values, and variance components viz of traits for different lentil genotypes across test Environments.

Genotype	DTF	DTM	PLH	HSW	GHI	BMY	YLD
Denbi	57	111	36.42	2.4	0.33	5.76	2.13
Derso	56	109	35.35	2.8	0.32	6.44	2.09
DZ-2012-Ln-0020	64	125	32.50	3.2	0.21	4.57	1.01
DZ-2012-Ln-0050	55	109	34.81	2.9	0.35	5.95	2.07
DZ-2012-Ln-0054	57	111	33.13	3.0	0.33	5.26	1.82
DZ-2012-Ln-0218	55	107	35.47	2.9	0.37	6.30	2.33
DZ-2012-Ln-0219	58	118	30.13	2.8	0.29	4.36	1.17
DZ-2012-Ln-0228	61	123	32.22	3.7	0.20	4.98	1.10
DZ-2012-Ln-0231	57	118	32.99	3.3	0.24	4.79	1.15
DZ-2012-Ln-0232	62	121	32.73	3.3	0.22	4.66	1.05
DZ-2012-Ln-0233	61	117	31.48	3.2	0.29	5.38	1.65
DZ-2012-Ln-0234	63	122	32.99	3.5	0.18	5.11	0.97
DZ-2012-Ln-0235	66	123	32.90	3.3	0.16	5.00	0.88
DZ-2012-Ln-0236	68	125	30.86	2.7	0.22	4.31	0.86
DZ-2012-Ln-0237	68	124	30.18	3.3	0.19	4.49	0.86
DZ-2012-Ln-0238	58	114	36.27	3.0	0.31	5.58	1.79
DZ-2012-Ln-0239	54	109	30.81	3.3	0.28	4.92	1.53
DZ-2012-Ln-0240	55	109	31.64	2.6	0.29	4.89	1.48
DZ-2012-Ln-0241	55	110	28.90	3.2	0.31	4.39	1.48
DZ-2012-Ln-0242	55	112	30.79	3.1	0.33	4.51	1.58
DZ-2012-Ln-0243	54	108	28.71	3.6	0.31	4.63	1.50
DZ-2012-Ln-0244	60	116	35.32	3.6	0.28	5.70	1.76
DZ-2012-Ln-0245	53	111	30.13	2.7	0.29	4.31	1.22
DZ-2012-Ln-0255	55	109	29.72	3.1	0.34	4.25	1.48
LOCAL CHECK	55	107	30.14	2.1	0.28	3.99	1.22
Grand Mean	58	115	32.264	3.1	0.28	4.98	1.45
Heritability	98%	97%	89%	97%	92%	85%	96%
Genotype Variance	20.64	40.89	6.30	0.16	0.00	0.59	0.21
Residual Variance	5.40	10.47	9.52	0.10	0.00	1.15	0.12
LSD	2.83**	4.24**	2.73**	0.32**	0.07**	1.11**	0.41**
CV	3.97	2.82	9.57	10.37	22.74	21.57	23.76
No of Environments	**11**	**9**	**6**	**11**	**9**	**10**	**11**

NB: DTF= days to 50% flowering, DTM = days to90% maturity, HSW = hundred seed weight in gram, PLH = plant = height in cm, BMY= biomass yield ton per hectare, GHI = Grain harvest index, YLD= grain yield ton per hectare.

The estimates of correlation coefficients among the yield and its attributing traits are given in Table 4. Days to 50% flowering displayed positive and significant correlation between days to 90% maturity and hundred seed weight while days to 90% maturity was found positively and significantly correlated with days to 50% flowering and hundred seed weight. Plant height showed positive and significant correlation with biomass yield, grain harvest index, and grain yield. Hundred seed weight showed also positive and significant correlation with days to 50% flowering and days to 90% maturity. Biomass yield showed positive and significant correlation with plant height, grain harvest index, and grain yield; grain harvest index showed positive and significant correlation with plant height, biomass yield, and grain yield.

In the current study grain yield was positively and significantly correlated with plant height, biomass yield and grain harvest index and hence indicated that these traits were positively associated because of linkages of genes governing the characters at coupling phase and direct selection of these traits may ultimately improve the seed yield. These results were conformity with the findings of Hussan *et al*. (2018), Chowdhury *et al*. (2019), and Kishor *et al*, (2020). On the other hand, grain yield was negatively and significantly correlated with days to 50% flowering, days to 90% maturity and hundred seeds weight entailing that early maturing genotypes compromises yield performance of the genotypes. It also follows the same analogy with hundred seed weight that genotypes with larger seed gives lower grain yield and conversely small seeded genotypes gives higher grain yield.

Table 4. Phenotypic correlation coefficients among different yield and yield component traits in lentil genotypes

	DTF	DTM	PLH	HSW	BMY	GHI	YLD
DTF	1						
DTM	0.691**	1					
PLH	-0.086ns	-0.094ns	1				
HSW	0.389**	0.404**	0.044ns	1			
BMY	-0.138ns	-0.259*	0.697**	0.041ns	1		
GHI	-0.717**	-0.556**	0.342**	-0.439**	0.393**	1	
YLD	-0.490**	-0.487**	0.642**	-0.233*	0.831**	0.820**	1

NB: ** = significant at 1% and * = significant at 5% probability level, ns=non-significant
Note: DTF= days to 50% flowering, DTM = days to90% maturity, HSW = hundred seed weight in gram, PLH = plant = height in cm, BMY= biomass yield ton per hectare, GHI = Grain harvest index, YLD: grain yield ton per hectare

A Multi-Environment Trial (MET) analysis was undertaken across the set of 11 environments using the raw data. Accordingly, factor analytic model was fitted using ASReml-R package and the predicted yield (t/ha) values for all genotypes under evaluation were obtained base on procedures demonstrated by Kelly et.al. (2017). A factor analytic model adequately explained 90.58% of the GxE variance at an FA-2 for yield (Table 5). These results demonstrate the complex nature of cross-over GxE interaction present for these data. The FA-2 model provides a satisfactory fit for most environments except KK18LNPE and EN17LNPE suggesting that these sites were generally not as well correlated with the other sites (environments). In addition, these sites had lower genotype variance than residual variance (table 5).

Table 5. Precent of Variations Explained by the Model in the Experiment

Environment	fac_1	fac_2	all	Genotype Variance	Residual Variance	Heritability	Mean yield t/ha
AK16LPPE	88.04	0.41	88.5	0.295	0.055	94%	1.06
AK17LNPE	83.44	16.6	100	0.110	0.342	49%	2.95
CD16LPPE	82.87	17.1	100	0.204	0.095	87%	1.78
CD17LNPE	73.66	23.8	97.5	0.158	0.126	79%	1.94
Db18LNPE	89.31	4.72	94	0.636	0.228	92%	1.95
DZ16LPPE	82.79	3.19	86	0.395	0.053	96%	1.34
DZ18LNPE	86.38	13.6	100	0.159	0.038	94%	0.90
EN17LNPE	66.48	33.5	100	0.043	0.131	50%	3.08
HS18LNPE	82.76	0.56	83.3	0.020	0.009	89%	0.72
KK18LNPE	59.8	40.2	100	0.006	0.016	61%	0.82
SN18LNPE	94.65	5.35	100	0.080	0.329	49%	1.75
Cumulative			90.58%				

NB: AK16LPPE=Lentil PVT at Akaki in 2016, AK17LN=Lentil NVT at Akaki in 2017, CD16LPPE=Lentil PVT at Chefe Donsa in 2016, CD17LNPE=Lentil NVT at Chefe Donsa in 2017, Db18LNPE=Lentil NVT at Dabat in 2018, DZ16LPPE=Lentil PVT at Debre Zeit in 2016, DZ18LNPE=Lentil NVT at Debre Zeit in 2018, EN17LNPE=Lentil NVT at Enewari in 2017, HS18LNPE=Lentil NVT at Hosanna in 2018, KK18LNPE=Lentil NVT at Kokate in 2018, SN18LNPE=Lentil NVT at Sinan in 2018, PVT = Preliminary variety Trial, NVT = National Variety Trial

The dendrogram using the REML estimate between environments correlation matrix as the similarity measure using the total effect is given in Fig 1. Two clusters were formed at a cut-off about 0.25 for the fitted value of yield data. The heat map plot to provide further evidence that the clusters suggested from the dendrogram appear to describe the pattern of cross-over GxE is presented in Fig 2. A dendrogram classified the sites/Environments into two groups. The first group consisted of 6 environments (AK16LPPE, HS18LNPE, Db18LNPE, DZ18LNPE, KK18LNPE and DZ16LPPE). These environments had showed yield performance of low to medium magnitude. The second group of environments consisted of 5 environments such as AK17LNPE, CD16LPPE,

CD17LNPE, EN17LNPE and SN18LNPE. Yield performance of genotypes in the second group is generally higher indicating the suitability of the testing sites. The heat map of an experiment depicted strong positive correlation among environments in general except environment KK18LNPE that had weak positive correlation with few environments.

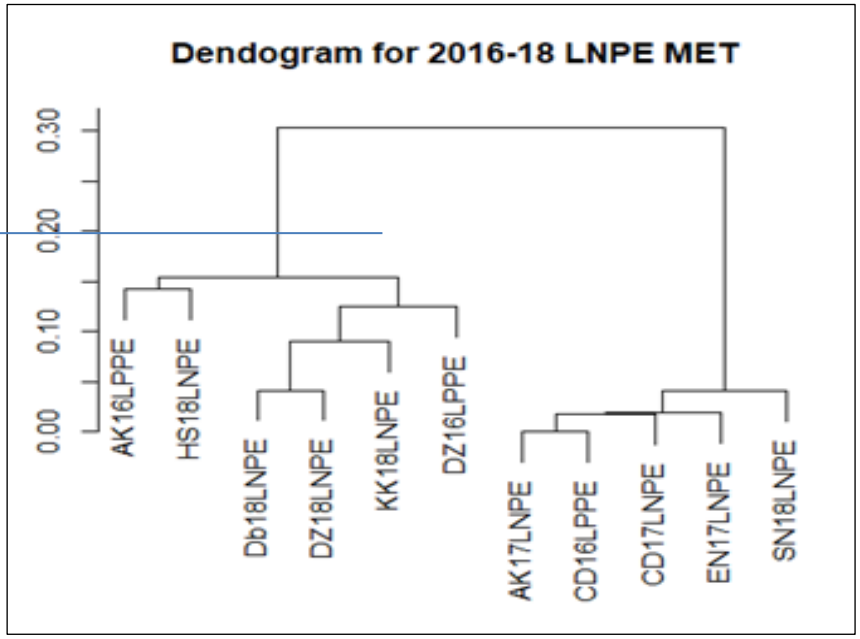

Figure 1. Dendrogram of the dissimilarity matrix of the additive effects for yield data.

Note: AK16LPPE=Lentil PVT at Akaki in 2016, AK17LN=Lentil NVT at Akaki in 2017, CD16LPPE=Lentil PVT at Chefe Donsa in 2016, CD17LNPE=Lentil NVT at Chefe Donsa in 2017, Db18LNPE=Lentil NVT at Dabat in 2018, DZ16LPPE=Lentil PVT at Debre Zeit in 2016, DZ18LNPE=Lentil NVT at Debre Zeit in 2018, EN17LNPE=Lentil NVT at Enewari in 2017, HS18LNPE=Lentil NVT at Hosanna in 2018, KK18LNPE=Lentil NVT at Kokate in 2018, SN18LNPE=Lentil NVT at Sinan in 2018, PVT = Preliminary variety Trial, NVT = National Variety Trial

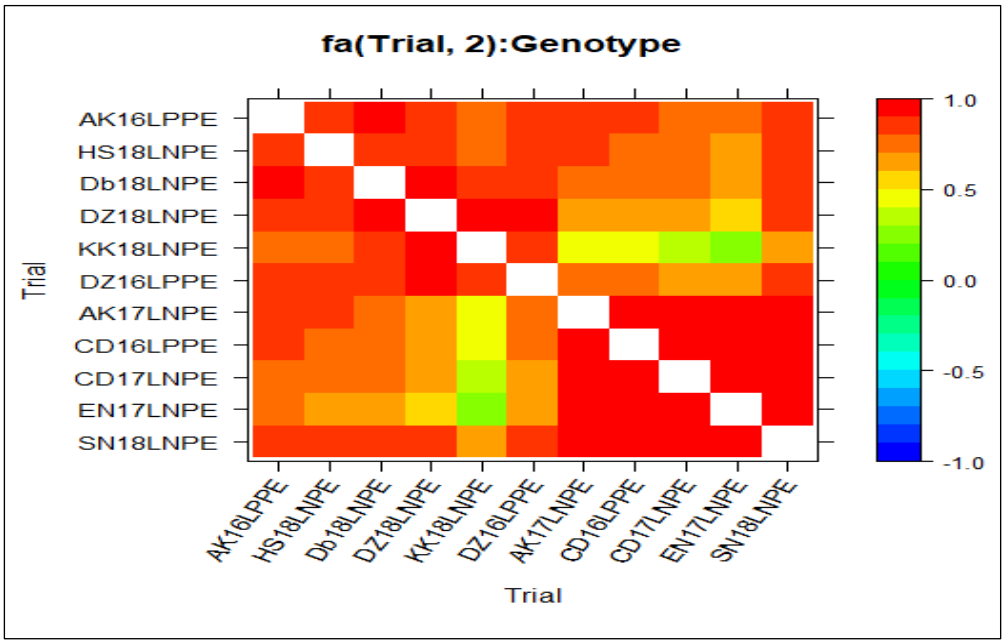

Figure 2. Heat map of mean yield (t/ha)

NB: AK16LPPE=Lentil PVT at Akaki in 2016, AK17LN=Lentil NVT at Akaki in 2017, CD16LPPE=Lentil PVT at Chefe Donsa in 2016, CD17LNPE=Lentil NVT at Chefe Donsa in 2017, Db18LNPE=Lentil NVT at Dabat in 2018, DZ16LPPE=Lentil PVT at Debre Zeit in 2016, DZ18LNPE=Lentil NVT at Debre Zeit in 2018, EN17LNPE=Lentil NVT at Enewari in 2017, HS18LNPE=Lentil NVT at Hosanna in 2018, KK18LNPE=Lentil NVT at Kokate in 2018, SN18LNPE=Lentil NVT at Sinan in 2018, PVT = Preliminary variety Trial, NVT = National Variety Trial

An interactive biplot implementation in R for modeling genotype-by-environment interaction in measuring the performance of trials (environments) in which 25 lentil genotypes were tested based on the suggestion given by Yan and Tinker (2006) and Frutos *et al*, (2014) are illustrated as follows using yield data of Table 3.

Environment Evaluation Based on GGE Biplots

In evaluating relationships among test environments, the environment-vector view of the GGE biplot for the data in Table 6 was used. It is based on an environment-centered (centering = 2) GE table without any scaling (scaling = 0), and it is environment-metric preserving (SVP = 2) and its axes are drawn to scale (default feature of GGE Biplot GUI) (Frutos, *et al*, 2014). This biplot explained 96% of total variation of the environment-centered GE table. Assuming that it adequately approximates the environment centered two-way table Figure. 3. The lines that connect the test environments to the biplot origin are called environment vectors. According to Equation given by Kroonenberg, (1995) the cosine of the angle between the vectors of two environments approximates the correlation between them. The genotypes were represented on the biplots as the points derived from their scores for the first two components, and the environments as

the vectors from the biplot origin to their points. The cosine of angle between a pair of environment vectors approximates correlation between them (Yan and Kang, 2003). An acute angle (<90^o) indicates a strong positive correlation; an angle close to 90^o indicates the environments are not correlated, whereas an obtuse angle close to 180^o represents a strong negative relationship (Kroonenberg, 1995). These graphic analyses were done using R GGE Biplot GUI package of version 1.0.9 as presented by Frutos *et al* (2014).

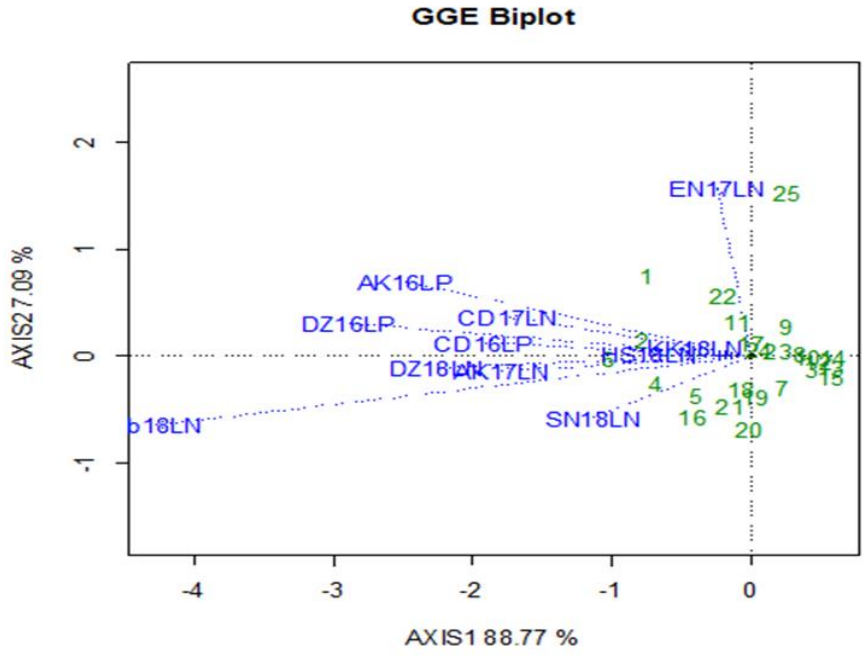

Figure 3. The environment-vector view of the GGE biplot to show similarities among test environments

Table 6. Mean yield (ton ha^{-1}) of 25 lentil genotypes tested at eleven environments in years between 2016 and 2018.

GID	Genotype	Environments										
		AK16LP	AK17LN	CD16LP	CD17LN	Db18LN	DZ16LP	DZ18LN	EN17LN	HS18LN	KK18LN	SN18LN
1	DENBI	2.19	3.33	2.07	2.46	2.76	2.38	1.44	3.88	0.90	0.95	1.81
2	DERSO	2.00	3.32	2.55	2.28	2.93	2.32	1.47	3.44	0.85	0.93	1.97
3	DZ-2012-Ln-0020	0.53	2.41	1.37	1.41	0.66	0.77	0.23	3.09	0.49	0.70	1.43
4	DZ-2012-Ln-0050	1.80	3.36	2.36	2.00	2.89	2.10	1.33	3.19	0.97	0.93	2.02
5	DZ-2012-Ln-0054	1.43	3.09	2.08	1.99	2.37	1.66	1.11	3.05	0.77	0.85	1.91
6	DZ-2012-Ln-0218	2.05	3.54	2.61	2.71	3.29	2.97	1.63	3.23	0.85	0.92	2.13
7	DZ-2012-Ln-0219	0.64	2.55	1.28	1.51	1.05	1.41	0.40	2.95	0.54	0.72	1.57
8	DZ-2012-Ln-0228	0.69	2.47	1.60	1.51	0.79	0.63	0.32	3.23	0.52	0.72	1.43
9	DZ-2012-Ln-0231	0.89	2.54	1.33	1.62	0.93	1.02	0.42	3.42	0.56	0.75	1.42
10	DZ-2012-Ln-0232	0.63	2.44	1.45	1.47	0.72	0.72	0.28	3.19	0.51	0.71	1.42
11	DZ-2012-Ln-0233	1.16	2.83	2.05	2.33	1.49	1.48	0.64	3.37	0.73	0.77	1.59
12	DZ-2012-Ln-0234	0.52	2.38	1.34	1.40	0.58	0.68	0.20	3.15	0.48	0.70	1.39
13	DZ-2012-Ln-0235	0.39	2.31	1.27	1.32	0.42	0.57	0.11	3.09	0.45	0.68	1.36
14	DZ-2012-Ln-0236	0.43	2.30	1.27	1.33	0.38	0.48	0.10	3.18	0.45	0.68	1.33
15	DZ-2012-Ln-0237	0.33	2.29	1.16	1.29	0.41	0.70	0.09	3.01	0.44	0.67	1.38
16	DZ-2012-Ln-0238	1.41	3.10	1.98	2.05	2.50	1.63	1.27	2.92	0.88	0.86	1.99

17	DZ-2012-Ln-0239	1.10	2.78	2.07	1.87	1.45	1.16	0.57	3.31	0.63	0.79	1.59
18	DZ-2012-Ln-0240	1.05	2.83	1.82	1.66	1.69	1.43	0.76	3.04	0.61	0.77	1.73
19	DZ-2012-Ln-0241	0.87	2.74	1.86	1.68	1.48	1.27	0.58	2.93	0.60	0.76	1.70
20	DZ-2012-Ln-0242	0.85	2.82	1.92	1.57	1.68	1.29	0.68	2.75	0.58	0.73	1.80
21	DZ-2012-Ln-0243	1.06	2.84	1.86	1.56	1.84	1.64	1.01	2.93	0.66	0.84	1.80
22	DZ-2012-Ln-0244	1.43	2.93	2.35	2.28	1.68	1.33	0.75	3.63	0.73	0.83	1.58
23	DZ-2012-Ln-0245	0.85	2.59	1.39	1.62	1.09	1.24	0.47	3.24	0.57	0.75	1.51
24	DZ-2012-Ln-0255	1.00	2.66	1.74	1.78	1.35	1.36	0.50	3.24	0.60	0.77	1.58
25	Local check	1.23	2.38	1.65	1.45	0.49	1.43	0.43	4.29	0.54	0.79	1.08

Note: AK16LP=Lentil PVT at Akaki in 2016, AK17LN=Lentil NVT at Akaki in 2017, CD16LP=Lentil PVT at Chefe Donsa in 2016, CD17LN=Lentil NVT at Chefe Donsa in 2017, Db18LN=Lentil NVT at Dabat in 2018, DZ16LP=Lentil PVT at Debre Zeit in 2016, DZ18LN=Lentil NVT at Debre Zeit in 2018, EN17LN=Lentil NVT at Enewari in 2017, HS18LN=Lentil NVT at Hosanna in 2018, KK18LN=Lentil NVT at Kokate in 2018, SN18LN=Lentil NVT at Sinan in 2018, PVT = Preliminary variety Trial, NVT = National Variety Trial

Accordingly, all the tested environments were displayed on the second and third quadrants of the GGE Biplot. The largest angle formed between environments EN17LN and Db18LN; EN17LN and SN18LN were slightly larger than 90°, implying that the GE is moderately large. The remaining environments had angle less than 90° implying strong positive correlation among themselves. The presence of close associations among test environments suggests that the same information about the genotypes could be obtained from fewer test environments, and hence the potential to reduce testing cost. If two test environments are closely correlated consistently across years, one of them can be dropped without loss of much information about the genotypes (Yan and Tinker, 2006). Thus, some of the test environments such as Akaki (AK16LP, AK17LN), Chefe Donsa (CD16LP, CD17LN), Debre Zeit (DZ16LP, DZ18LN) and Dabat (Db18LN) can be dropped as they generate the same information about the genotype. On the other hand, the angles formed between EN17LN and KK18LN and also between EN17LN and DZ18LN close to 90^{o} and hence have no correlation. The discriminating ability of test environments is shown in figure 4. The concentric

circles on the biplot help to visualize the length of the environment vectors, which is proportional to the standard deviation within the respective environments and is a measure of the discriminating ability of the environments. Therefore, among the eleven environments, Db18LN was most discriminating (informative) followed by DZ16LP and AK16LP. KK18LN was least discriminating followed by HS18LN as these environments are located around the origin of the graph (Figure. 4).

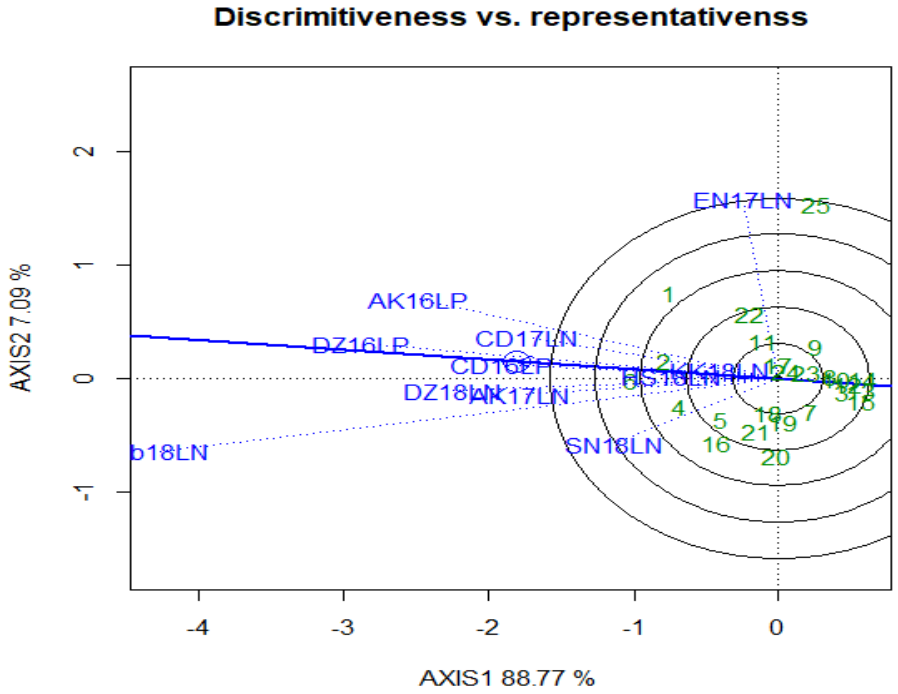

Figure 4. The discrimination and representativeness view of the GGE biplot

Regarding representativeness the test environments Yan and Tinker (2006) stated that the average environment represented by the small circle at the end of the arrow has the average coordinates of all test environments. The Average Environment Axis (AEA) is the line that passes through the average environment and the biplot origin. Accordingly, a test environment that has a smaller angle with the AEA is more representative of other test environments. Thus, CD16LP and DZ16LP are most representative whereas EN17LN and SN18LN least representative. Test environments that are both discriminating and representative like DZ16LP is good test environments for selecting generally adapted genotypes. Discriminating but non-representative test environments such as Db18LN are useful for selecting specifically adapted genotypes if the target environments can be divided into mega-environments.

Within a single mega-environment, the ideal test environment should be most discriminating (informative) and at the same time most representative of the target

environment. Fig. 5 defines an “ideal test environment”, which is the center of the concentric circles. It is a point on the AEA with a distance to the biplot origin equal to the longest vector of all environments (“most informative”). DZ16LP is closest to this point and is, therefore, best, whereas KK18LN was the poorest for selecting cultivars adapted to the whole region.

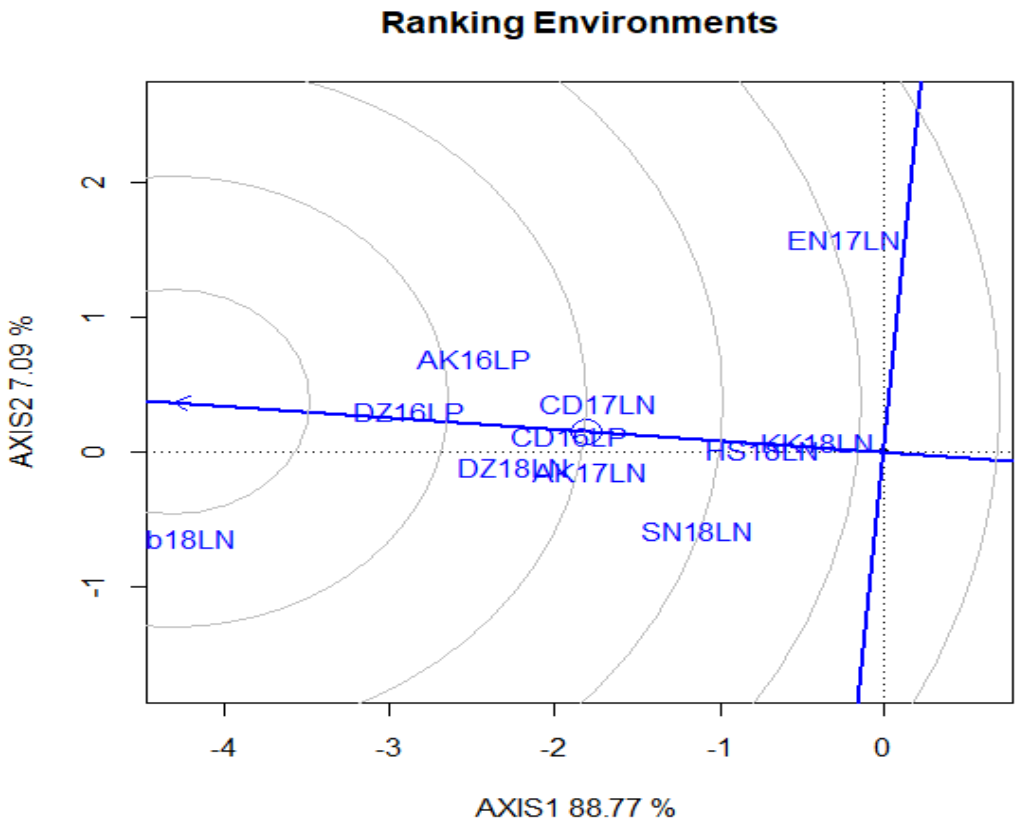

Figure 5. The discrimination and representativeness view of the GGE biplot to rank test environments relative to an ideal test environment.

Genotype Evaluation Based on GGE Biplots

To evaluate the mean performance and stability of the genotypes within a single mega-environment, the data should be genotype-metric preserving (SVP = 1) for appropriate genotype evaluations (Yan and Tinker, 2006). Accordingly, the single-arrowed line called Average Environment Coordinate (AEC) abscissa (or AEA) points to higher mean yield across environments. Thus, genotype 6 was fond to be the highest with the potential grain yield of 3.54 (t/ha^{-1}) at AK17lN, followed by 1 and 2 whereas genotype14 had the lowest mean yield. The AEC ordinate points to greater variability (poorer stability) in either direction. Thus, genotype 25 was highly unstable whereas 17 were highly stable. Genotype 25 was

highly unstable because it had lower than expected yield in environments DZ18LNPE and AK16LPPE but higher than expected yield in AK17LNPE, and EN17LNPE environments (Fig 6).

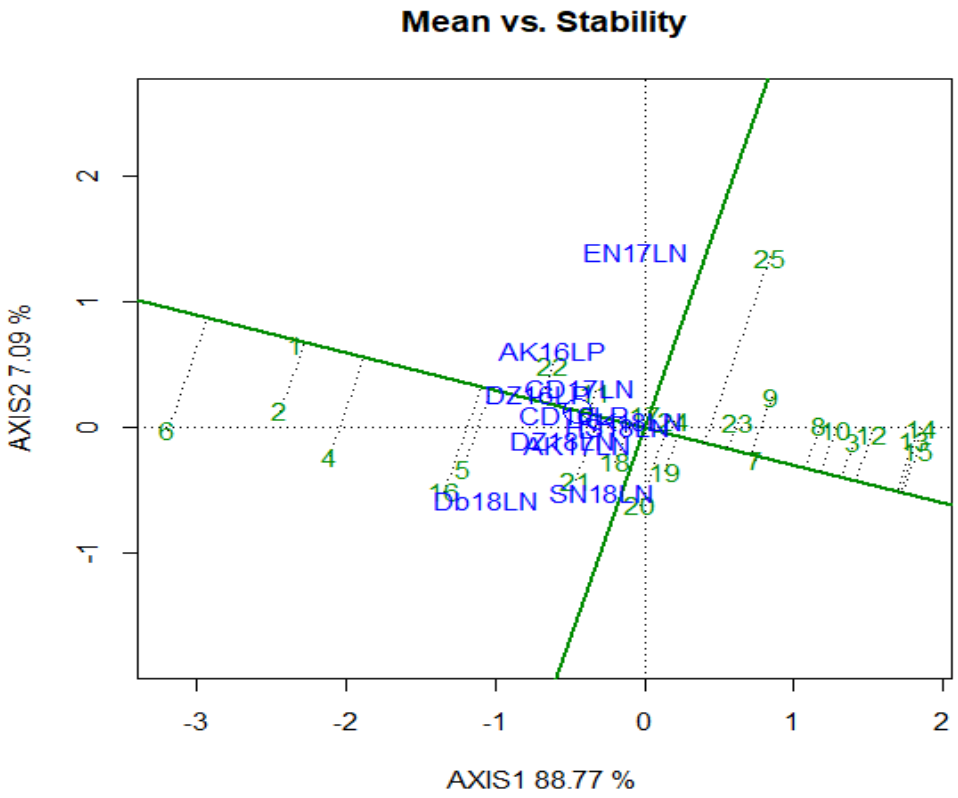

Figure 6. The average-environment coordination (AEC) views to show the mean performance and stability of the genotypes.

Ranking Genotypes Relative to the Ideal Genotype

A genotype is said to an ideal if it had both high mean yield performance and high stability across environments. Figure 7 defines an "ideal" genotype (the center of the concentric circles) to be a point on the AEA ("absolutely stable") in the direction towards the pointing of the arrow and has a vector length equal to the longest vectors of the genotypes on AEA ("highest mean performance"). Therefore, genotypes located closer to the 'ideal genotype' are more desirable than others. Thus, genotype 1, 6 and 2 were more desirable than the other genotypes. However, genotypes 1 and 2 are released variety and thus no need of discussing about them. On the other hand, genotype 14 was the poorest genotype because it consistently performed poorly across environments.

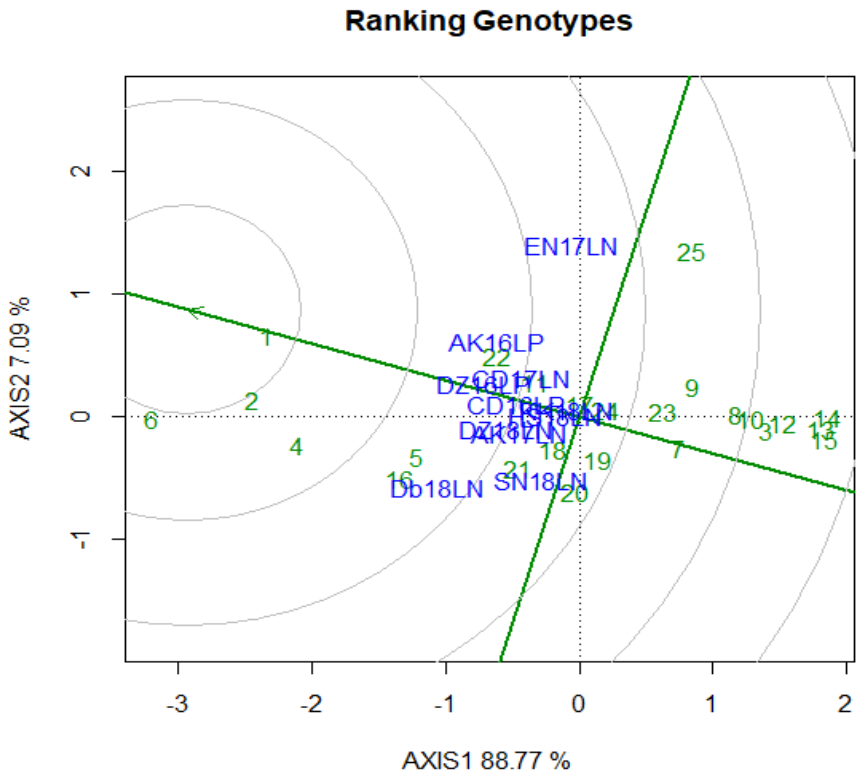

Figure 7. Ranking cultivars based on both mean performance and stability for experimental set A

Which-won-where

One of the most attractive features of a GGE biplot is its ability to show the which-won-where pattern of a genotype by environment data set (Yan and Tinker, 2006). The polygon formed by connecting the markers of the genotypes that are farthest away from the biplot origin, such that all other genotypes are contained in the polygon. Figure 8 also contains a set of lines perpendicular to each side of the polygon. These perpendicular lines divide the biplot into several sectors. The winning genotype for each sector is the one located at the respective vertex. Genotypes located at the vertices of the polygon reveal the best or the poorest in one or other environment (Yan and Tinker 2006; Fructos *et al*, 2014).

Seven sectors were created with genotype's code number 6, 1, 25, 14, 20 and 16 as the vertex genotype. Environments EN17LN fell in the sector in which genotype 25 was the vertex cultivar. Meaning that genotype 25 was the best cultivar for EN17LN. The other ten environments fell in the sector in which genotype 6 was the vertex cultivar, which mean that genotype 6 was the best cultivar for these ten environments. No environments fell into sectors with genotype 14 and 20 as the vertices, indicating that these cultivars were not the paramount in any of the environments.

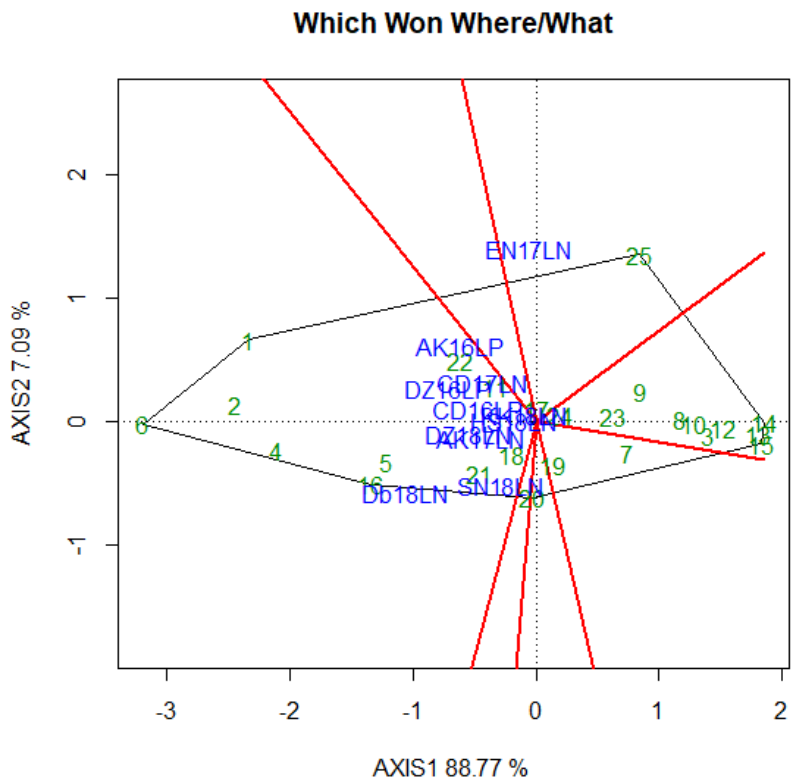

Figure 8 The which-won-where view of the GGE biplot

Conclusion and Recommendation

A multi-environment trial (MET) analysis was undertaken across the sets of 11 environments for estimating the GxE effects with BLUPs by using factor analytic (FA) models, and thereby conducting GGE biplot analysis based on BLUPs of FA models. As a result, both informative and representative test environments were identified and also superior genotypes of high and stable performance were known within target environment. So, plant breeders can therefore, have such a more robust platform for evaluation of crop cultivars with greater confidence in selecting superior cultivars across a range of environments without minding about the limited amounts of seeds of test genotypes and size of experimental plots as unbalanced structure of test genotypes can easily be analyzed and BLUPs determined with FA model.

Above all, in the present study genotypes DZ-2012-Ln-0218 was identified as high yielder and stable than other test genotypes. It gave 11% yield advantages over the standard check Derso, and 91% over the local check. Moreover, it showed better overall performance giving 3.54 ton/ha of grain yield at Akaki substation

in 2017 cropping season. It was also found highly stable genotypes across the test environments as it ranked first, second and fourth in 7, 3 and 1 environments out of eleven growing environments (table 6). As a result, it was proposed for verification in the year 2020 for release as new variety and in the year 2021 it then registered with variety name "Furi" on the national catalogue of Ministry of Agriculture of Ethiopia. The recommended adaptation area for production of the variety Furi is characterized as mid to high altitude areas in sub moist agro ecological zones of Ethiopia like Akaki, Chefe Donsa, Dabat, Debre Zeit, Enewari, Hosanna, Kokate, Sinana and similar environments situated on altitude ranging over 1900 – 2440 m.a.s.l.

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Genotypic and Environmental Variables on Determination of Grain Yield Stability Analysis of Desi Chickpea (Cicer arietinum L) Advanced Lines in Ethiopia

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Abstract

Chickpea (Cicer arietinum L) is one of the most important food legumes in Ethiopia. However, its production and productivity are highly constrained by several biotic and abiotic stresses. As yield is a complex quantitative trait influenced by prevailing environmental conditions, multi environmental yield trials is critical to detect wide adaptable and high yielding cultivars. The objective of the present study was to assess the genotypic and environmental variables on determination of grain yield stability on desi chickpea genotypes evaluated from 2016 to 2018 in 11 test environments. The AMMI model analysis of variance for grain yield indicated presence of highly significant differences ($P \leq 0.01$) among test genotypes, environments, and genotypes by environments interactions (G x E). AMMI biplot stability analysis and genotype selection index (GSI) showed the most stable and high yielding genotype is DZ-2012-CK-0311(G22). Both AMMI and GGE biplot analyses also indicated that, for selecting wide adaptable genotypes, the most discriminating (informative) and representative environment was Akaki 2017(E2). GGE biplot and heatmap analysis reduced the 11 test environments into 4 representative mega-environments. The GGE biplot comparison among test genotypes and test environments also revealed that Akaki 2017(E2) and DZ-2012-CK-0311(G22) were an ideal environment and stable genotype, respectively. Therefore, DZ-2012-CK-0311(G22) can be proposed for release as wide adaptable variety for similar environments. Akaki can also be used as the most discriminating and representative environment for screening and selecting wide adaptable Desi type genotypes in the breeding program

Keywords: Chickpea, Yield, Multi-environment, AMMI, GGE

Introduction

Chickpea (*Cicer arietinum* L) is one of the most important food legumes in different parts of the world. It mainly serves as a good source of dietary protein, vitamins and minerals and also improves soil fertility through symbiotic association with Rhizobium (Acharjee and Sarmaha, 2013). Ethiopia is the largest

producer, consumer and exporter of chickpea in Africa, annually producing above 515,000 metric tons on about 241,000 hectares of land with an average productivity of around 2 tons/ha (FAOSTAT, 2018). However, the production and productivity of chickpea is highly constrained with diverse biotic and abiotic stresses to exploit its full genetic potential (> 5tons/ha).

In Ethiopia, two types of chickpeas are produced in nearly balanced proportion having typical values by the consumer groups. Chickpea breeding program have focused mainly on developing high yielding varieties, with good level of resistance to major biotic and abiotic stresses. However, yield is a complex quantitative trait, often controlled by many genes, influenced by prevailing environmental conditions, with each gene having a small effect. In order to identify the most stable and high yielding genotypes, it is important to conduct multi-environment trials (Luquez *et al*.,2002). Accordingly, in Ethiopia all released varieties were developed through rigorous evaluation and critical selection of advanced germplasms and breeding lines for diverse agro morphological traits over years under diverse agro-ecologies in multiple environments (Asnake and Dagnachew, 2019).

Adaptability of any genotype is the product of the inherent capacity of genotype, the environmental factor in which a given genotype is grown and the interplay between the environment and genotype (Zobel, 1990). Thus, assessing the adaptability and stability parameters helps to define the response of genotypes to environmental variations, sketch realistic conclusion and solidify the recommendation of new cultivars (Zobel, 1990). As a result, multi environmental yield trials are critical to detect adaptable high yielding cultivars and discover sites that best represent the target environment. Multi-environment trials (MET) are essential because of the existence of genotype by environment interactions (GxE), which complicates genotypes evaluation, and thus analysis of G x E data from MET trials has been an important component of plant breeding and cultivar recommendation.

So far, several statistical models have been developed for analyzing the adaptability and stability of genotypes over environments. Differences in genotype stability and adaptability to environment can be qualitatively assessed using the biplot graphical representation that scatters the genotypes according to their principal component values (Vita *et al*., 2010). Additive main effects and multiplicative interaction models (AMMI), and the genotype and genotype by environment interaction (GGE) model are the most widely used statistical tools to determine the pattern of genotypic responses across diverse environments (Smith and Smith, 1992; Yan and Kang, 2002, 2003). Therefore, the main objective of the present study was to determine the genotype by environment interaction, yield performance and stability of Desi type chickpea Advanced lines evaluated over years in diverse growing environment using AMMI and GGE biplot analyses.

Materials and Methods

Plant materials and experimental design

In the present study, a total of 27 Desi type chickpea genotypes such as 23 advanced lines, three released varieties and one local check were used (Table 1). These genotypes were evaluated under two different sets of experiments from 2016 to 2018 for three consecutive years. The first experiment, Desi chickpea preliminary variety trial (PVT), was executed for one year in four different locations using randomized complete block design (RCBD) with three replications, whereas the second experiment, Desi chickpea national variety trial (NVT), was executed for two years in a total of seven different locations using RCBD design with four replications. In both trials, each genotype was planted using 30cm and 10cm inter and intra row spacing, respectively. Data on grain yield and other yield related morphological traits were recorded from central rows of each plot.

Table 1. List of genotypes used in an experiment over the three years (2016- 2018)

GID	Genotype	GID	Genotype	GID	Genotype
G1	Dalota	G10	DZ-2012-CK-0039	G19	DZ-2012-CK-0238
G2	Dimtu	G 11	DZ-2012-CK-0040	G20	DZ-2012-CK-0253
G3	Teketay	G 12	DZ-2012-CK-0228	G21	DZ-2012-CK-0254
G4	DZ-2012-CK-0028	G13	DZ-2012-CK-0230	G22	DZ-2012-CK-0311
G5	DZ-2012-CK-0029	G14	DZ-2012-CK-0232	G23	DZ-2012-CK-0312
G6	DZ-2012-CK-0030	G15	DZ-2012-CK-0233	G24	DZ-2012-CK-0313
G7	DZ-2012-CK-0032	G16	DZ-2012-CK-0234	G25	DZ-2012-CK-12S-2-042
G8	DZ-2012-CK-0033	G17	DZ-2012-CK-0236	G26	DZ-2012-CK-0027
G9	DZ-2012-CK-0034	G18	DZ-2012-CK-0237	G27	Local Check

GID stands for genotypic identification

Test environments

In 2016 cropping season, the preliminary variety trial (PVT) was executed in four different locations at Debre Zeit, Akaki, Minjar and Alem Tena. Using the same test genotypes, in 2017 cropping season the national variety trial (NVT) was executed at Akaki, Arsi Robe, Enewari and Jari. Similarly, in 2018 cropping season, the NVT was repeated at Debre Zeit, Delgi and Jari. In both trials, each year at each location was considered as a separate environment, resulting a total of 11 different test environments for this study. The eco-climatic characteristics of these testing sites are given in Table 2 below.

Table 2. Eco-climatic characteristics of testingenvironments

Testing sites and years	Soil type	Trial Code	Environment Code	Altitude (m.a.s.l)	Rainfall (mm)	Temp. (°C)
Akaki 2016	Vertisol	AK16CD_PVT	E1	2200	1025	7-26.5
Minjar2016	Light	MN16CD_PVT	E11	1810	867	10-28
D/Zeit 2016	Vertisol	DZ16 CD _PVT	E6	1900	851	8-26.3
A/Tena 2016	Light	AT16 CD_PVT	E4	1575	728	12.9-29.8
Akaki 2017	Vertisol	AK17CD_NVT	E2	2200	1025	7-26.5
A/Robe 2017	Vertisol	AR17CD_NVT	E3	2400	1200	8-24
Enewari 2017	Vertisol	EN17 CD_NVT	E8	2667	1405.5	8-26.3
Jari 2017	Light	JR17 CD_NVT	E9	1820	750	15-27
D/Zeit 2018	Vertisol	DZ18 CD_NVT	E7	1900	851	6-27
Delgi 2018	Light	DL18CD_NVT	E5	1868	1151	14.3-29.7
Jari 2018	Vertisol	JR18 CD_NVT	E10	1820	750	15-27

CD, PVT, NVT and E stand for Chickpea Desi, Preliminary variety Trial, National Variety Trial and Environment respectively.

Data analysis

The Additive Main Effects and Multiplicative Interaction (AMMI) and Genotype and Genotype by Environment Interaction (GGE) models were used to investigate genotype by environment interaction (G×E). Stastical analysis was performed using GenStat software (GenStat, 2012). The AMMI model analysis of variance (ANOVA) was used to determine the presence or absence of genotype by environment interactions (G×E) for further AMMI stability and GGE biplot analyses. Genotype Selection Index (GSI) was estimated as

$$\text{GSI} = rASV + rYSI$$

Where rASV is the rank of AMMI stability value and rYSI is the rank of mean grain yield of genotypes stability Index across environments.

Results and Discussion

The AMMI model analysis of variance (ANOVA) for grain yield indicated highly significant differences ($P \leq 0.01$) for genotypes, environments, and genotypes by environments interactions (GxE). The first principal component axis of genotype by environment interaction (G×E) was also highly significant ($P \leq 0.01$). The first principal component explained above 45 % of the genotype by environment interaction (G×E) and the second principal component revealed 12.2 % of the interaction. Similar previous studies suggested the importance of capturing most of the genotype by environment interaction (G×E) sum squares in the first principal component axis to attain accurate information (Crossa *et al*., 1990; Purchase *et al*., 2000).

Table 3. AMMI analysis of 27 chickpea genotypes grain yield performance evaluated across 11 environments

Source of variation	DF	SS	MS	% G x E Cumulative Interaction	% Explained
Genotypes	26	36.31	1.40***		
Environments	10	305.2	27.75***		
G x E Interactions	260	75.61	0.44***		
IPC-1	36	43.5	1.21***	45	45
IPC-2	34	11.74	0.35ns	12.2	57.2
IPC-3	32	10.9	0.34ns	11.3	68.5
Residuals	451	119.59	0.26		

** indicate significance at 0.01 probability levels. ns indicates significance at 0.05 and 0.01probability levels, and mean grain yield = 2.2 ton/ha, and C.V.= 23.40

In this study, because of the significant contribution of the first IPCA to the genotype by environment interaction, this axis (IPCA) and mean grain yield (ton/ha) were used to construct a AMMI biplot graph to gain sufficient information on the stability of individual genotypes in different test environments (Fig.1).The result of AMMI biplot analysis with IPCA-1 against mean grain yield (ton/ha) indicated that most test genotypes were concentrated near the origin indicating average performance for grain yield, and had IPCA scores close to zero, being stable across most environments(Fig.1). However, genotype DZ-2012-CK-0254(G21) and DZ-2012-CK-0232 (G14) were the most unstable genotypes. Previous reports show that as the IPCA scores close to zero, the more stable the genotype is all over the test environments (Purchase *et al*., 2000). However, genotypes that are far from the biplot origin are considered as better adapted to specific environments (Wondafrash *et al*., 2015). The ideal genotype is one with high productivity and IPCA-1 values close to zero, whereas the undesirable genotype has low stability associated with low productivity (Kempton, 1984; Gauch and Zobel, 1988).

Besides, test environment Akaki 2016 (E1) and Arsi Robe 2017 (E3) were the most productive environment, while Minjar 2016(E11) and Enewari 2017(E8) were the least productive environments for Desi type chickpea in this particular study. Moreover, Debre Zeit 2018 (E7) and Jari 2017(E9) were moderately productive environments. In the AMMI-1biplot display, genotypes or environments that fall on a perpendicular and horizontal line of the graph had similar mean yield and similar interaction, respectively. Likewise, genotypes or environments that fall on the left and right-hand side of the midpoint of the abscissa (x-axis) had respective less and high grain yield performance than the overall mean. The score and sign of IPCA-1 reflect the magnitude of the contribution of both genotypes and environments to genotype by environment

interaction (G×E), where scores near zero are the characteristic of stability and a higher score (absolute value) designate instability and specific adaptation to a certain environment (Gollob, 1968).

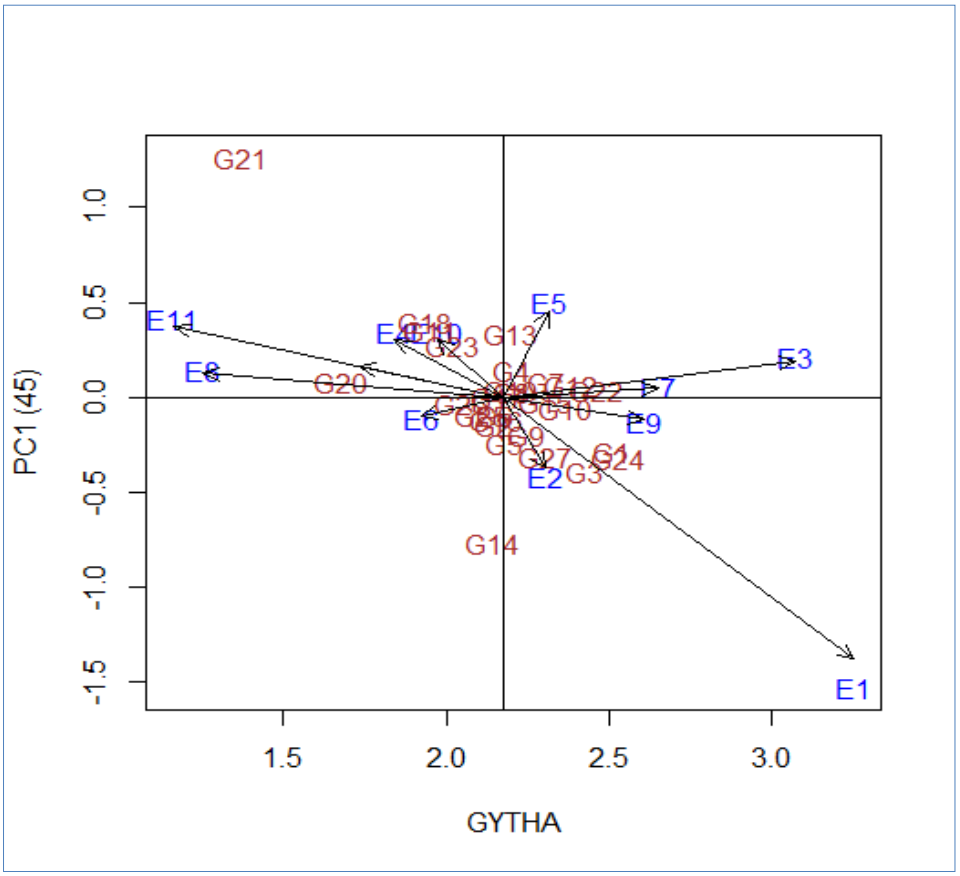

Figure 1. AMMI Biplot of interaction principal component axis (IPCA-1) against mean grain yield ton/ha (GYTHA) of 27 chickpea genotypes evaluated across 11 environments.

AMMI stability Analysis

AMMI stability value was computed to determine the genotypes stability across environments (Table 4). Based on this analysis, test genotype with least AMMI stability value (ASV) is regarded as the most stable. Accordingly, test genotypes such as G8 (DZ-2012-CK-0033), G6(Local check), G19(DZ-2012-CK-0238), G22(DZ-2012-CK-0311) and G17(DZ-2012-CK-0236) had low AMMI stability values (ASV) and were stable. Similar to AMMI bi-plot based stability estimate, this analysis also showed that G21(DZ-2012-CK-0254), G14 (DZ-2012-CK-0232), G18(DZ-2012-CK-0237) and G27 (DZ-2012-CK-0027) were the most unstable genotypes. The three released varieties, Dimitu, Dalota and Teketay were moderately stable with AMMI stability value ranging from 0.79 for Dimitu to 1.18 for Teketay.

However, stable genotypes would not always provide the best yield performance and therefore identifying genotypes with high grain yield coupled with stability across growing environments has paramount importance. Therefore, Genotype Selection Index (GSI) which combine both mean yield and stability in a single index have been introduced to further detect high yielding genotypes with stable yield performance (Mohammadi and Amri, 2008). GSI showed that the most stable and high yielding genotypes were DZ-2012-CK-0311(G22), DZ-2012-CK-0033 (G8), DZ-2012-CK-0032 (G7) and DZ-2012-CK-0233(G15), whereas, DZ-2012-CK-0254(G21), DZ-2012-CK-0237 (G18), DZ-2012-CK-0040 (G11), DZ-2012-CK-0232 (G14), and DZ-2012-CK-0312(G23) were the least stable and low yielding genotypes. The released varieties Dalota, Teketay and Dimitu were moderately stable with average grain yield performance in all environments, which agrees with the result reported by Biru *et al*. (2017).

Table 4. AMMI stability value, mean grain yield (ton/ha) and genotype selection index.

GID	Genotype	Mean grain yield ton/ha	ASV	rASV	rYSI	GSI
G22	DZ-2012-CK-0311	2.46	0.15	**4**	3	7
G8	DZ-2012-CK-0033	2.20	0.12	1	11	12
G7	DZ-2012-CK-0032	2.31	0.31	6	7	13
G15	DZ-2012-CK-0233	2.30	0.35	8	8	16
G10	DZ-2012-CK-0039	2.37	0.36	11	6	17
G12	DZ-2012-CK-0228	2.38	0.40	12	5	17
G19	DZ-2012-CK-0238	2.20	0.15	3	14	17
G1	Dalota	2.51	1.08	19	2	21
G17	DZ-2012-CK-0236	2.16	0.21	5	16	21
G24	DZ-2012-CK-0313	2.53	1.22	21	1	22
G26	Local Check	2.04	0.14	2	22	24
G9	DZ-2012-CK-0034	2.25	0.75	15	10	25
G4	DZ-2012-CK-0028	2.20	0.53	14	12	26
G6	DZ-2012-CK-0030	2.15	0.36	9	18	27
G27	DZ-2012-CK-0027	2.43	1.45	24	4	28
G3	Teketay	2.30	1.18	20	9	29
G16	DZ-2012-CK-0234	2.15	0.44	13	17	30
G25	DZ-2012-CK-12S-2-042	2.11	0.36	10	21	31
G5	DZ-2012-CK-0029	2.18	1.03	17	15	32
G20	DZ-2012-CK-0253	1.68	0.32	7	26	33
G2	Dimtu	2.15	0.79	16	19	35
G13	DZ-2012-CK-0230	2.20	1.24	22	13	35
G23	DZ-2012-CK-0312	2.02	1.04	18	23	41
G14	DZ-2012-CK-0232	2.14	2.87	26	20	46
G11	DZ-2012-CK-0040	1.95	1.31	23	24	47
G18	DZ-2012-CK-0237	1.94	1.48	25	25	50
G21	DZ-2012-CK-0254	1.37	4.73	27	27	54

ASV=Ammi stability value, rASV=rank of Ammi stability value, rYSI= rank of yield stability index, and GSI= Genotype Selection Index

Environment and Genotype Evaluation Based on GGE Biplots

Test environments that are both discriminating and representative are good test environments for selecting generally adapted genotypes. Among the 11 test environments considered in this study, Akaki, 2016 (E1) and Akaki, 2017(E2) were the most discriminating (informative), whereas Delgi 2018 (E5) was the least discriminating environment (Fig.2 and 3.). Likewise, E2 (Akaki 2017) was the most representative environment, while Delgi 2018 (E5) was the least representative of all test environments. The concentric circles on the GGE biplot

help to visualize the length of the environment vectors, which is a measure of the discriminating ability of the environments (Yan and Tinker,2006; Dabessa *et al*., 2016). Similarly, a test environment that has a smaller angle with the Average-Environment Axis (AEA) is more representative of other test environments (Yan *et al*, 2011).

Therefore, in this study the most discriminating and representative environment was Akaki 2017 (E2) for selecting wide adaptable genotypes. Discriminating but non-representative test environments are useful for selecting specifically adapted genotypes if the target environments can be divided into mega-environments (Yan and Tinker, 2006). Test environments that are consistently non-discriminating (non-informative) provide little information on the genotypes and, therefore, should not be used as test environments (Yan and Tinker, 2006). GGE biplot comparison among test genotypes and environments revealed that DZ-2012-CK-0311(G22) was stable genotype while Akaki 2017(E2) was an ideal environment (Fig.5).

An "ideal" genotype (the center of the concentric circles) should have both high mean performance and high stability across environments and genotypes located closer to the 'ideal genotype' are more desirable and stable than others (Yan and Tinker, 2006). Besides, previous workers also reported that environments and genotypes that fall in the central (concentric) circle are considered as ideal environments and stable genotypes, respectively (Yan and Kang, 2002). Moreover, DZ-2012-CK-0228(G12), DZ-2012-CK-0233 (G15) and DZ-2012-CK-0032 (G7) were genotypes with high yield and good stability across all environments (Table 5 and Fig 4). However, DZ-2012-CK-0254(G21), DZ-2012-CK-0253(G20) and DZ-2012-CK-0237 (G18) were the most unstable and low yielding genotypes compared to the rest of the test genotypes.

Table 5. Mean grain yield (ton/ha) of 27 chickpea genotypes evaluated at 11 environments from 2016 to 2018.

GID	Genotype	Environments										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
G24	DZ-2012-CK-0313	4.06	2.85	3.21	2.00	2.21	2.18	2.80	1.47	2.97	1.93	1.27
G22	DZ-2012-CK-0311	3.48	2.79	3.61	2.10	2.30	2.03	2.69	1.60	2.82	1.98	1.32
G1	Dalota	4.01	2.77	3.13	1.96	2.21	2.16	2.79	1.30	2.93	1.90	1.24
G27	DZ-2012-CK-0027	4.05	2.70	3.09	1.93	2.21	2.14	2.77	1.28	2.88	1.88	1.22
G12	DZ-2012-CK-0228	3.35	2.60	3.55	2.03	2.33	1.95	2.63	1.71	2.67	1.92	1.29
G15	DZ-2012-CK-0233	3.44	2.75	3.28	1.98	2.24	2.07	2.72	1.41	2.81	1.90	1.25
G3	Teketay	3.76	2.66	3.19	1.94	2.25	2.08	2.73	1.17	2.81	1.88	1.23
G2	Dimtu	3.59	2.61	3.14	1.91	2.24	2.05	2.71	1.34	2.75	1.85	1.21
G10	DZ-2012-CK-0039	3.62	2.44	3.22	1.92	2.26	2.02	2.68	1.33	2.71	1.85	1.22
G7	DZ-2012-CK-0032	3.30	2.44	3.30	1.93	2.28	1.96	2.63	1.44	2.62	1.85	1.22
G9	DZ-2012-CK-0034	3.53	2.36	3.15	1.88	2.23	1.99	2.66	1.46	2.64	1.82	1.19
G14	DZ-2012-CK-0232	4.20	2.49	2.48	1.70	2.11	2.23	2.84	0.97	2.89	1.74	1.09
G16	DZ-2012-CK-0234	3.38	2.48	3.08	1.85	2.24	2.00	2.67	1.13	2.65	1.80	1.18
G19	DZ-2012-CK-0238	3.23	2.33	3.22	1.88	2.28	1.93	2.61	1.40	2.56	1.81	1.19
G5	DZ-2012-CK-0029	3.67	2.42	2.88	1.80	2.20	2.07	2.72	0.99	2.71	1.78	1.15
G8	DZ-2012-CK-0033	3.23	2.33	3.15	1.86	2.27	1.94	2.62	1.36	2.57	1.80	1.18
G6	DZ-2012-CK-0030	3.33	2.17	3.14	1.83	2.27	1.91	2.59	1.40	2.51	1.78	1.17
G25	DZ-2012-CK-2012S-2-0042	3.30	2.27	3.08	1.82	2.26	1.94	2.62	1.32	2.55	1.77	1.16
G4	DZ-2012-CK-0028	3.07	2.27	3.10	1.83	2.26	1.93	2.61	1.33	2.54	1.78	1.16

GID	Genotype	Environments										
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11
G13	DZ-2012-CK-0230	2.91	2.28	3.16	1.85	2.28	1.92	2.60	1.42	2.53	1.79	1.17
G17	DZ-2012-CK-0236	3.22	2.04	3.22	1.82	2.33	1.81	2.52	1.47	2.36	1.75	1.16
G26	Local Check	3.13	2.16	2.95	1.76	2.25	1.92	2.60	1.24	2.49	1.73	1.12
G23	DZ-2012-CK-0312	2.71	2.08	3.28	1.84	2.33	1.79	2.50	1.46	2.34	1.76	1.17
G11	DZ-2012-CK-0040	2.55	1.97	3.32	1.82	2.35	1.72	2.45	1.50	2.25	1.74	1.16
G18	DZ-2012-CK-0237	2.46	1.91	3.20	1.78	2.33	1.73	2.46	1.43	2.23	1.71	1.13
G20	DZ-2012-CK-0253	2.31	1.61	3.07	1.66	2.34	1.62	2.37	1.38	2.02	1.61	1.06
G21	DZ-2012-CK-0254	0.85	0.71	3.10	1.47	2.46	1.19	2.04	1.49	1.32	1.41	0.95

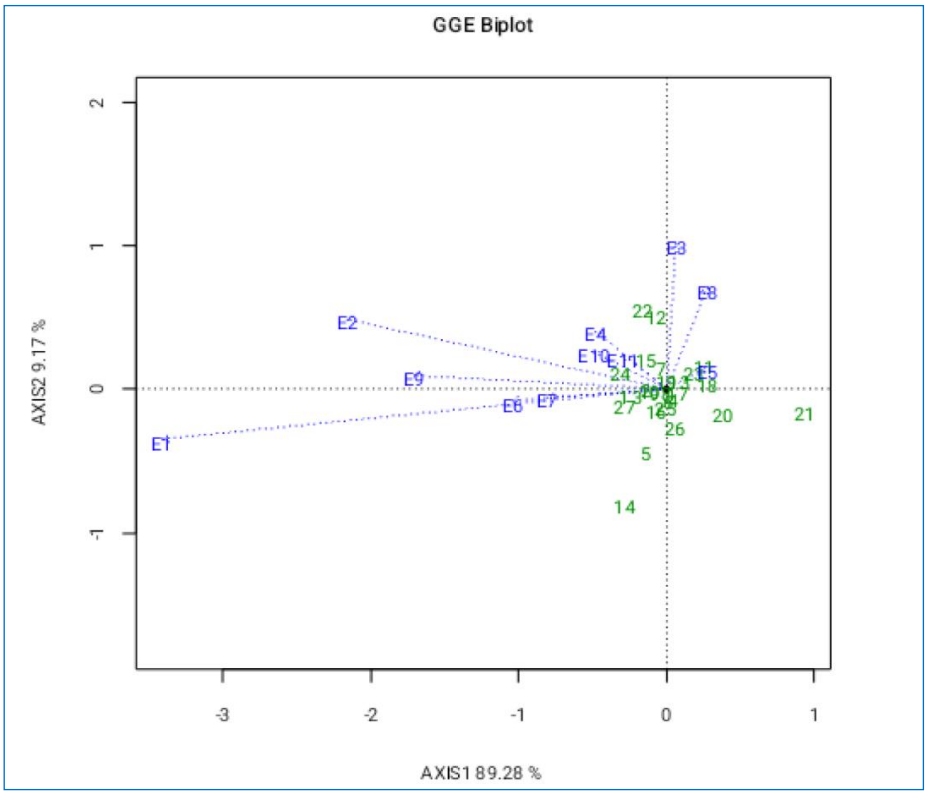

Figure 2. GGE biplot analysis showing the test environments and genotypes

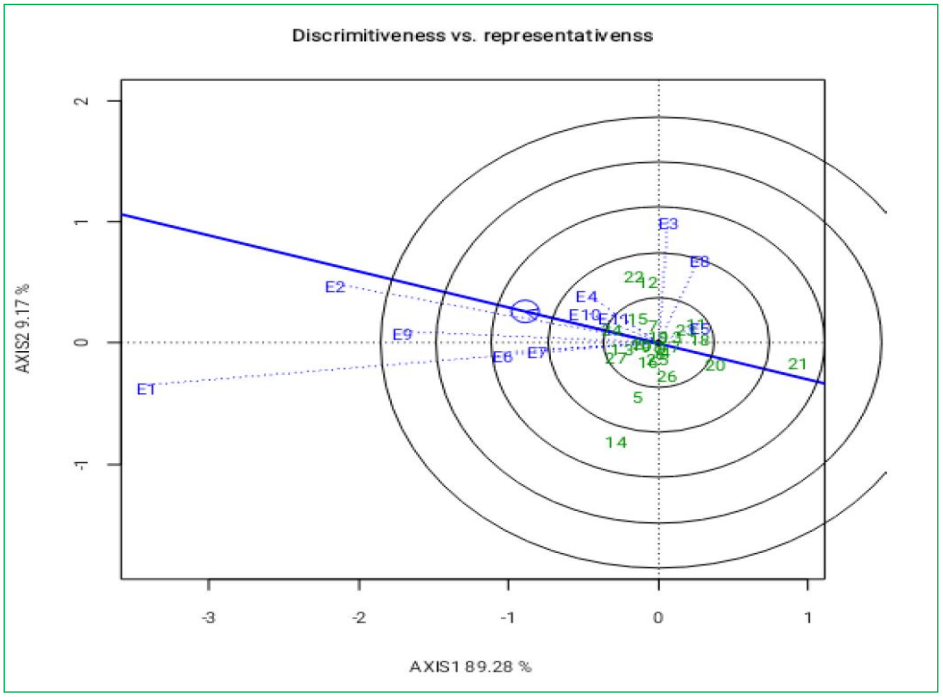

Figure 3. The discrimination and representativeness view of the GGE biplot to show the discriminating ability and representativeness the test environment

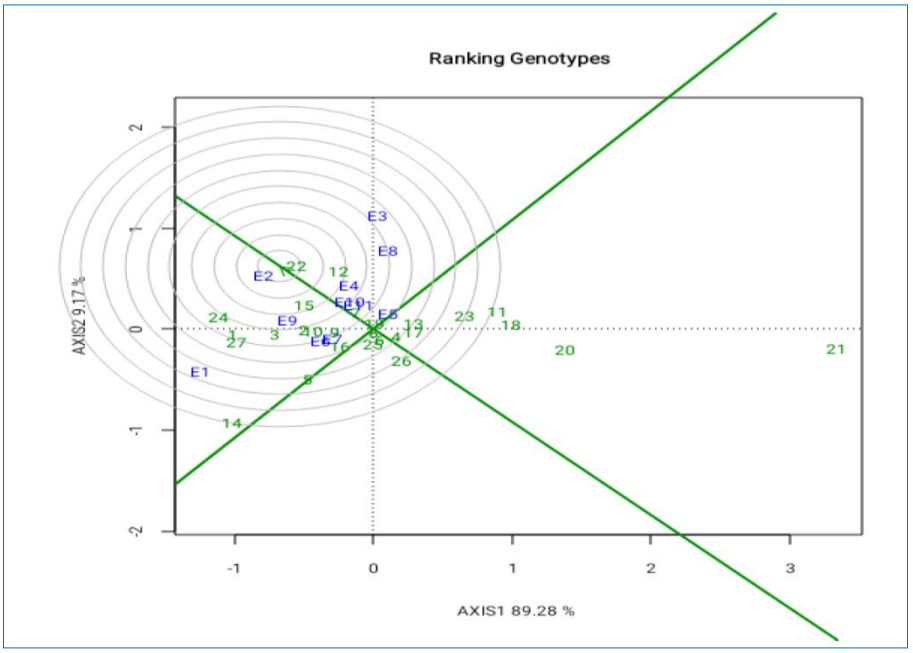

Figure 4. The average-environment coordination (AEC) view to rank genotypes relative to an ideal genotype (the center of the concentric circles).

Mega environment differentiation

One of the most attractive features of a GGE biplot is its ability to show the which-won-where pattern of a genotype by environment dataset, and it can address important concepts such as mega-environment differentiation and specific adaptation (Yan and Tinker, 2006). In this analysis, the equality lines divided the GGE biplot into 4 mega-environments, and the winning genotype for each mega-environment is the one located on the respective vertex (Fig 5). The first mega environment with Akaki 2017(E2) and Jari 2017 (E9) was the best environment for high grain yield and the winning genotype in this mega environment was G24 (DZ-2012-CK-0313) with the best mean grain yield of all test genotypes. However, the mega environment with Delgi 2018(E5) was the most unsuitable environment for grain yield, and the winning genotype DZ-2012-CK-0254(G21) in this mega environment was the most unstable genotype. The other two mega environments were represented with test genotype that had average grain yield performance, but with moderate to high stability. Similar to this result, the heatmap also showed four mega environments (Fig 6).

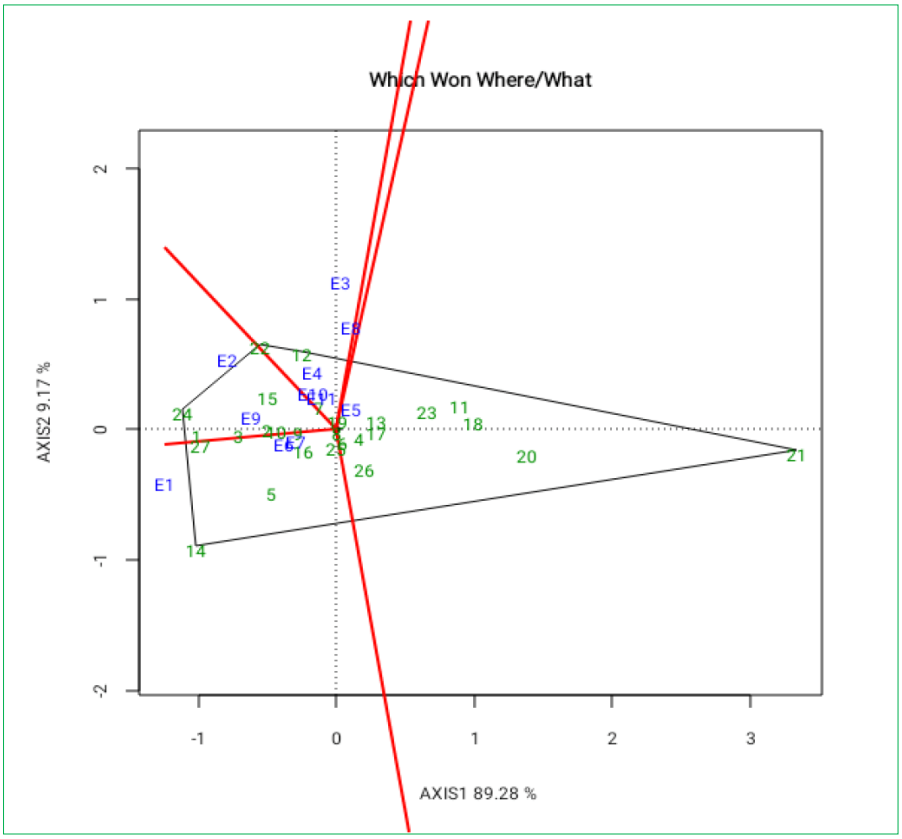

Figure 5. The which-won-where view of the GGE biplot to show which genotypes performed best in which environments

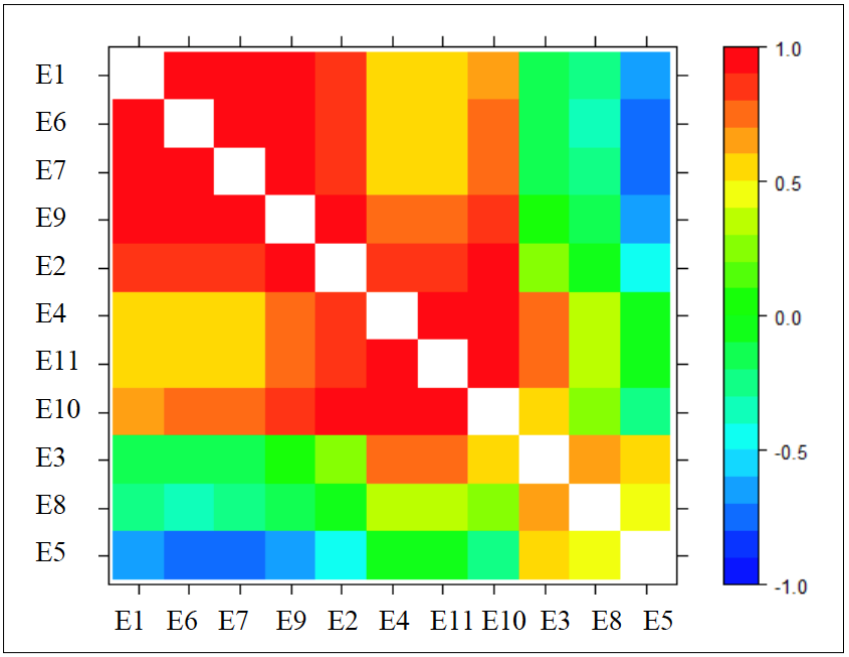

Figure 6. Heatmap showing similarity test environments (E1 to E11).

Conclusion and Recommendation

The AMMI model analysis of variance (ANOVA) for grain yield indicated highly significant differences ($P \leq 0.01$) for genotypes, environments, and genotypes by environments interactions (G x E). Therefore, grain yield and the first principal component axis were used to construct a biplot graphs because of its significant contribution to the genotype by environment interaction (G×E). AMMI biplot stability analysis and genotype selection index (GSI) showed that the most stable and high yielding genotype was DZ-2012-CK-0311(G22). Both AMMI and GGE biplot analyses also indicated, for selecting wide adaptable genotypes, the most discriminating (informative) and representative environment was Akaki 2017(E2). GGE biplot and heatmap analysis reduced the 11 test environments into 4 representative mega-environments. Interestingly, GGE biplot comparison among test genotypes and test environments also revealed that Akaki 2017(E2) and DZ-2012-CK-0311(G22) were an ideal environment and stable genotype, respectively. Generally, the current results indicated that based on yield performance, AMMI and GGE biplot analysis, and GSI indices, DZ-2012-CK-0311(G22) showed better yield with better stability across all test environments and can be proposed for release as wide adaptable variety to similar agro ecologies in the country. Besides, Akaki 2017(E2) can be considered as the most discriminating and representative environment for screening and selecting wide adaptable Desi type genotypes in the breeding program.

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Performance of Newly Released Early Maturing Soybean Variety 'Guda' in Ethiopia

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Abstract

Soybean (Glycine Max) is a cheap source of protein, oil and other micronutrients in Ethiopia. However, its current productivity is very low as compared to its genetic potential. In Ethiopia, most of the released varieties are medium and late maturing type. There are also few early maturing varieties in Ethiopia. However, most are very low yielder. In 2021, Jimma agricultural research center released high yielding and early maturing variety HAR/PR142-15-SB by the name Guda. Prior to release, this variety was evaluated in series multi-location trials. In the national variety trial (NVT), ten soybean genotypes along with two standard checks were evaluated for two years across at five locations using a randomized complete block design with four replications. Data analysis over years and over locations indicated that variety Guda is the most stable and high yielder genotype as compared with other test genotypes. Guda exhibited 17% and 26 % yield advantages over the recently released checks; Gazale and Nova, respectively. Besides, GGE biplot model analysis showed that Guda (JM-HAR/PR142-15-SB) is an ideal genotype with high grain yield and stability across test environments. This variety was also found to be tolerant to major soybean diseases and has attractive seed color/luster. Therefore, popularization and dissemination of this variety for larger scale production will play significant role in increasing the production and productivity of soybean in moisture deficit areas of the country.

Keywords: Early, Soybean, Guda, Moisture, Stress

Introduction

Soybean (*Glycine max)* is self-fertilized crop and it was originated from China (Martin *et al.,* 1976*). Soybean* is one of the crops with high demand at global level due to its versatile use. Soybean has the potential of enhancing farmers' income and can be used as a protein source in food and feed products (Singh *et al*., 2008). Soybean is relatively a new crop in Africa. It was introduced to SSA in the 19th (Giller and Dashiell, 2006). Adaptation trial of soybean begun in Ethiopia in the late 1950s; however, there is report which indicate the country import soy product in 1945 (William and Akiko, 2009).

Production of soybean in Ethiopia is increasing from time to time. In the past seven years, soybean cultivation area and production in Ethiopia has increased exponentially, from about 31854.7 ha and 636,531.01 quintal in the 2005 (CSA,2005/ 2006) to 38072.7 ha and 1,256,232.0 quintal in 2018/ 19 (CSA, 2018/2019). In Ethiopia, soybean is gaining importance in recent years. The area seeded to soybeans is expected to increase due to increased demand of domestic processing industries and increased demand for use in animal feed. Ethiopia is strategically located closer to the world's largest consumers. This is good opportunity for the country to target soybean as potential export commodity. But the productivity of soybean is still low (2.3t/ha) as compared to the potential (4 t/ha).

One of the reasons for the low soybean yield might be lack of high yielding varieties to specific agro ecologies. Since the inception of soybean research in Ethiopia, 32 soybean varieties were released for different agro ecologies. However, most of the released varieties were medium and late maturing. There were few early maturing varieties like Nova, and Williams, nevertheless, these varieties have low yield and low biomass, which necessitate development of high yielding early maturing varieties adaptable to the different agro ecologies of the country. In the last couple of years, soybean production in the country has increased. However, most of the expansion was in high rainfall areas, soybean growing in moisture stress areas is very limited. On the other hand, world climate change has caused expansion of dry spell in most soybean producing area which resulted in poor yield of previously known varieties. This necessitated the need for continuous selection and breeding for early maturing soybean varieties.

Materials and Methods

Variety Guda was evaluated at various stages of variety testing at different locations (Table 1). From 2018 to 2019, the national variety trial was executed at five different locations; Jimma (Tiro-afeta), Gofa, Humera, Mehoni and Sirinka. The trial was planted in a 40 cms between rows and 5 cms within row spacing. The experimental design used was randomized complete block design with 4 replications. Fertilizer NPS at the rate of 121kg/ha was applied at planting. All other cultural practices were done as recommended for soybean. Brief geographical and weather description of the test locations is given in Table 1.

Table 1. Description of experimental locations

Test locations	Altitude (m.a.s.l)	Annual rainfall (mm)	Temperature (0c)	
			Min	Max
Mehoni (L1)	1571	300-750	18	25
Tiro-afeta (L2)	1768	1829	18	26
Gofa (L3)	1774	1298	13.04	28
Sirinka (L4)	1749	680-1200	18	27
Humera (L5)	585	620	20.4	37.6

Genotypes origin and pedigree

Most of the test genotypes were introductions from USA, while the four genotypes namely, Guda (HAR/PR142-15-SB), JM-PR142/G99-15-SB, JM-HAR/G99-15-SD-2, JM- and JM-DAV/PR142-15D are recombinant inbred lines developed by Jimma Agricultural research center. The other two genotypes, Gazale and Nova were released varieties in Ethiopia (Table 2). Variety Guda with a pedigree name of JM-HAR/PR142-15-SB is a recombinant inbred line developed by Jimma research center through hybridization. The homozygous line was developed from a cross between an early maturing variety Hardee with promising line PR-142 through selection from segregating generations using a modified single seed decent method.

Table 2. Descriptions of soybean genotypes used in the study

GID	Genotype name	Origin/source
G1	Gazale (C1)	Improved/released in Ethiopian
G2	PI200488	USA
G3	JM-HAR/PR142-15-SB	RIL by JARC
G4	PI417116	USA
G5	JM-PR142/G99-15-SB	RIL by JARC
G6	PI506764	USA
G7	JM-HAR/G99-15-SD-2	RIL by JARC
G8	Nova (C2)	Improved/released in Ethiopian
G9	JM-DAV/PR142-15D	RIL by JARC
G10	Delsoy 4710	USA

Results and Discussion

Based on the over years and over locations combined data analysis, the maximum grain yield was obtained from variety Guda (2.11t/ha), followed by JM-HAR/G99-15-SD-2 (1.98 t/ha) and JM-PR142/G99-15-SB (1.97 t/ha), which exhibited a yield advantage of 17% and 26%; 9% and 19%; and 9 % and 18 % over the standard checks, Gazela and Nova, respectively (Table 3). In terms of maturity period, variety Guda with 98 days to maturity had relatively shorter maturity period than the standard check Gazale. In soybean, earliness is one of the

most important traits for improvement. In this trial, the early maturing soybean genotypes were observed to produce good grain yield in most of the environments. The maximum number of seeds per plant was observed from Guda next to the check Nova, while the smallest numbers of seed per plant were observed from the genotypes PI506764. Moreover, Guda also gave better hundred seed weight and good resistance /tolerance levels for soybean rust and bacterial blight (Table 3).

Table 3. Combined mean yield (t/ha) and other parameters of Guda in national soybean variety trial

GID	Genotype	DTF	DTM	PH	NP	NSP	SH	RST	CB	HW	Yield
G1	Gazale(C1)	47.5	102	53.9	43.4	113	1.4	1.2	1.5	18.3	1.81
G2	PI200488	42.6	86.6	38.4	31.5	80.0	2.5	1.3	2.1	18.2	1.41
G3	JM-HAR/PR142-15-SB Guda	45.0	97.5	56.5	43.5	113.4	1.4	1.3	1.7	15.7	2.11
G4	PI417116	41.9	85.5	30.8	26.2	57.2	2.8	1.0	1.4	19.1	1.11
G5	JMPR142/G99-15-SB	47.9	101.3	54.5	38.8	105	1.2	1.2	2.2	17.3	1.97
G6	PI506764	41.1	88.8	29.6	23.5	56.8	2.2	1.3	1.9	18.4	1.30
G7	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
G8	Nova(C2)	43.6	86.3	54.5	50.2	129.2	2.1	1.4	1.7	12.9	1.67
G9	JM-DAV/PR142-15D	45.9	96.2	41.3	40.7	100.2	1.7	1.0	2.0	17.3	1.79
G10	Delsoy 4710	40.8	86.7	41.7	34.9	95.2	1.7	1.0	1.5	16.0	1.43
	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*	*34.9*	*60*	*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% pod maturity, PH = plant height, NP = Number of pods per plant, NSP = Number of seeds per plant, SH= shattering, RST= rust, CB = common bacteria blight, HW= hundred seeds weight

Performance and stability

The GGE biplot method consists of a set of biplot interpretation methods to evaluate genotype and test-environment (Yan *et al*., 2007). 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). Hence G3(Guda) scored the highest mean grain yield performance and stable across environments followed by G7 and G5 (Figure 1). The "which-won-where" views of the GGE biplot is an effective feature for mega-environment analysis (Yan *et al*., 2007). 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, G3(Guda), G7, G1, G6, and G2 performed best in their respective environments (Figure 2).

The ideal genotype is the one that with the highest mean performance and absolutely stable (Yan and Kang, 2003,) and genotype that fall in the center of the

concentric circles is an ideal genotype. If a given genotype is located closer to an ideal genotype, it is the most desirable genotype. Hence, G3(Guda), G5 and G7 are relatively ideal in terms of higher-yielding ability and stability as compared to other genotypes. While genotypes G6, G2, and G4 were located distant from the first concentric circle and are low yielding and unstable genotypes (Figure 3). In addition to its good stability and high yielding ability, Guda has comparable protein and oil content with the standard checks Gazale (Table 4).

Therefore, based on the overall performance, the candidate variety JM-HAR/PR142-15-SB was released in 2021 by the name Guda. Unlike other early maturing varieties, this variety has big seed size as distinct character for the variety that differentiates it from others. Moreover, it has attractive seed luster (Table 5). Guda is adoptable from low to mid altitude soybean growing agro ecologies, in areas with moisture deficit with annual rainfall as low as 300-620mm (Table 2). The variety also suit to high rainfall areas. It could be used for double cropping. 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 plant early maturing soybean variety late in the season usually early to mid-July and can get reasonable yield; which otherwise, is impossible for medium and late maturing soybean varieties

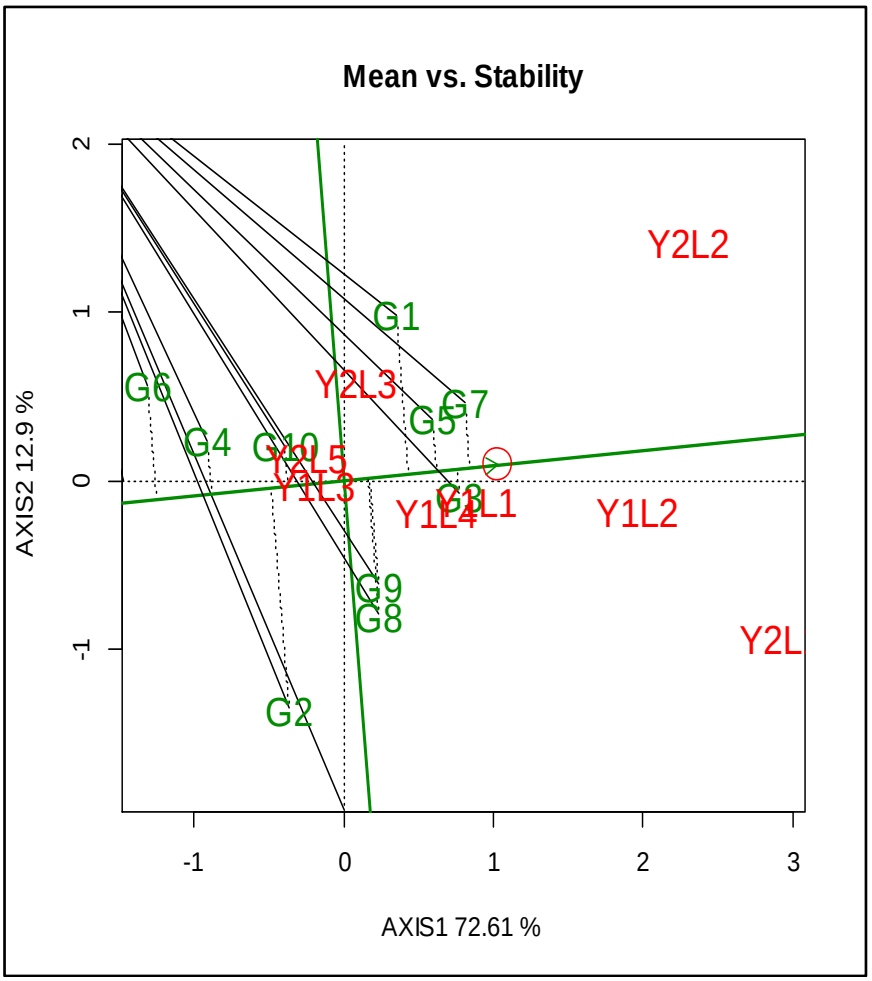

Figure 1. Mean grain yield performance and stability of test genotypes based on the over years and over location data. Y1= year 1=2018 and Y2= year 2=2019

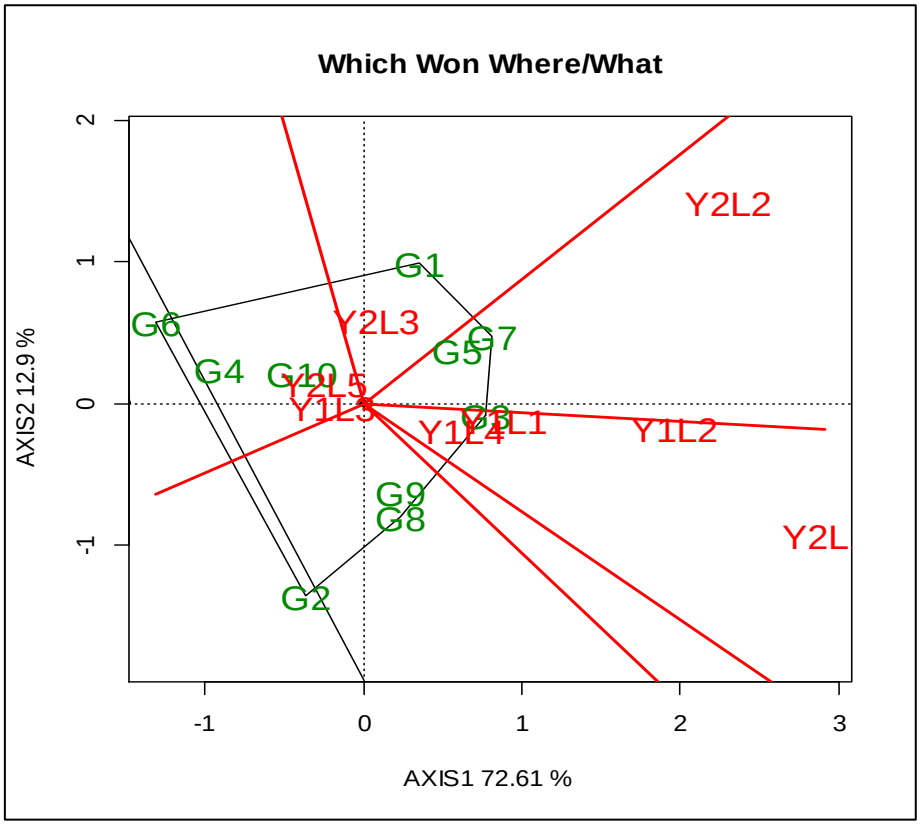

Figure 2. Polygon showing which genotypes won in which environment

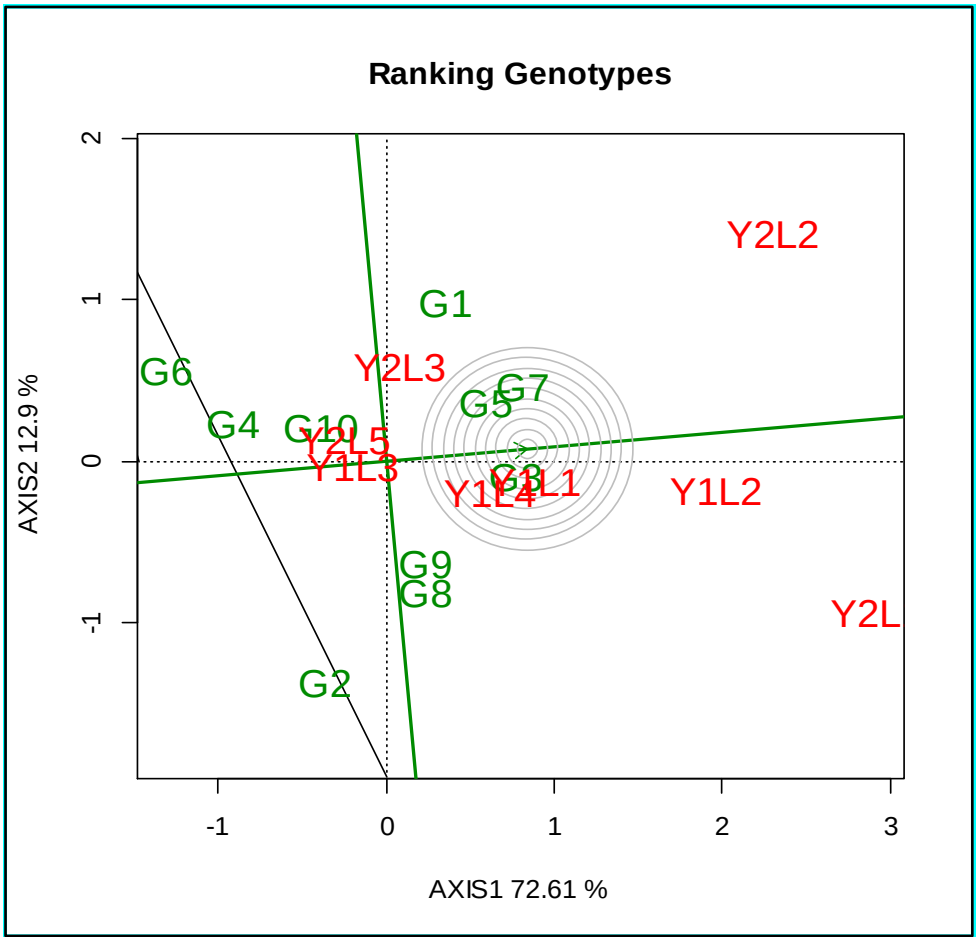

Figure 3. Ranking of the genotypes based on the ideal genotype

Table 4. Mean of protein and oil for the candidates and checks

Protein and oil	Standard check-1 (Gazale)	Standard check-2 (Nova)	Proposed varieties
			Guda
Protein	38.84	36.81	36.92
Oil	20.73	21.09	21.44

Table 5. Main morphological characteristics of the variety Guda

Variety Name	Seed coat Color	Leaf Shape	Seed hilum color	Flower color	Morphological characteristics			
					Pubescence color	Pod color	Seed luster	Pubescence density
Guda	Yellow	Intermediate	Black	Purple	Tawny	Light brown	1	Semi dense

Seed luster scoring system is 1-5 scale (1=luster or attractive,5= an attractive

Conclusion and Recommendation

The newly released soybean variety Guda is an early maturing variety with mean days to maturity of 98 days, high yielder, tolerant to major leaf disease of soybean, and attractive seed color and luster. It has comparable oil and protein content to the checks. The variety has the capacity to increase productivity and production of soybean if it is properly addressed to soybean growers in the area of adaptation and similar agro ecologies. We therefore recommended demonstration and popularization of the varieties to small scale farmers and commercial farms. Variety development has value if and only if enough quantity of seed is multiplied and distributed to users in both quality and quantity. Therefore, all stakeholders in soybean value chain should do their at most effort to multiply the seed. Jimma research center who is the breeder and maintainer of the variety should multiply enough breeder and pre basic seed.

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Performance of Recently Registered Commercial Soybean Variety 'SCS-1' in Ethiopia

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Abstract

Soybean (Glycine max L.) is the most important oil crop globally and is becoming among the top list oil crop in Ethiopia. Therefore, it is very important to look for high yielding and disease resistant varieties adaptable to different agroecologies. The variety 'SCS-1' was released in Zimbabwe by the name 'Nyala'. It was introduced to Ethiopia in 1992 by CIMMYT as part of the test materials for identifying effective green manures, along with other non-edible forage legumes. From 2018 to 2019, this variety was evaluated in a multi-location variety trial along with fourteen soybean genotypes using a randomized complete block design with four replications across at five locations. The combined analysis across locations and over years indicated as SCS-1performed better than the check and other test genotypes. The variety SCS-1 gave high yield advantage of 19.2 % over the standard check, Pawe 3. This variety was found to be resistant to major soybean diseases including soybean rust and bacterial blight. It has also attractive seed color/luster. Moreover, it has better protein content and comparable oil content with the standard check. The GGE analysis also showed that SCS-1 the most productive and stable genotypes across soybean growing environment. Therefore, in 2021 variety SCS-1 was officially registered to be used as commercial soybean variety in Ethiopia.

Keywords: Soybean, Variety, Stability, Yield, Disease, Quality

Introduction

The cultivated soybean (*Glycine max*) is self-fertilized crop and it was derived from China wild type (Franca Neto and henning, 1994; Carter *et al*., 2004). It is a medium-altitude crop and well adapted to areas located in altitudes ranging from 1300 to 1800m and receiving rainfall of 900 to 1300 mm (Wang etal. 2020). The crop also does well in some areas as low as 500 m and as high as 1900m that receive a well distributed average rainfall of 550 to 700 mm throughout the growing period (Hammer and Haralson, 1975; Shurtleff and Aoyagi, 2009). The productivity of soybean in Ethiopia is low as compared to its genetic potential mainly because of the low dissemination and adoption of improved technology. Ethiopia has great opportunity to increase the production and productivity of soybean. The average soybean productivity in Ethiopia is 2.3t ha^{-1} (CSA, 2019/2020), which is lower than the potential yield of about 4.0 t ha^{-1}.

In Ethiopia, there are two approaches of variety development; by technology generation and adaptation. The former requires long years of testing genotypes (from nursery up to variety verification). The latter is considered a fast track for variety release. This approach requires introduction of commercial varieties from abroad, testing in variety adaptation trial and register. A number of varieties were released with the former approach and were being used by end users. The latter approach of introducing commercial varieties and registration to farmers has not been well practiced so far on soybean in Ethiopia.

Since the inception of soybean research in Ethiopia in 1960s, a number of varieties were released for different agro ecologies. However, the potential yield for soybean is not attained so far. The major reason is lack of high yielding varieties that are resistant or tolerant to the newly emerging diseases in Ethiopia; mainly soybean rust and bacterial blight. Most of the Varieties released in the past are not resistant/tolerant to these diseases. In addition to this, the growing food processing and oil industries need good quality soybean varieties. As a result of the reasons mentioned above, continuous development of new varieties to overcome the yield gap due to biotic and a biotic factors and newly coming demand of the local and international soybean market is mandatory for soybean research team.

The Variety, SCS-1 is a released variety in Malawi and Zimbabwe. It was introduced to Ethiopia in 1992 from CIMMYT Zimbabwe, as part of the test materials for identifying effective green manures, along with other non-edible forage legumes, such as Mucuna, Lablab and Crolotaria. During evaluation of the variety by soil department on farmer's field a decade ago, the farmers retained the seed and started using as local variety informally because of its high yield, adaptability and attractive seed color. Till now it is used as variety in Kersa and Tiro Afeta woredas of Jimma zone. The variety was later handed over to soybean breeding department for yield test because of its good yielding ability.

Material and Methods

The variety SCS-1 along with 14 soybean genotypes and check were tested in national variety trial for two years (2018 and 2019) at five different locations: Jimma, Metu, Tepi, Assosa and Gonder/Metema (Table1) using randomized complete block design (RCBD) with four replications. The experiment was planted in a 4m length plot in 4 rows; where the middle two rows are harvestable. 60cms between rows and 5cms within row spacing was used. NPSB fertilizer at the rate of 121kg/ha was applied at planting. All other cultural practices were carried on as recommended for soybean. The variety was proposed for registration to be evaluated by national variety release committee. The national variety release technical committee evaluated the verification trials for yield performance, uniformity, disease reaction and other quality for release.

Table1. Descriptions of the experimental locations

Location	Altitude	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
Metu	1558	8°19' 0" N	35°35' 0"E	12.7°c	28.9	1829
Assosa	1580	10° 03' 0"N	34° 59'0"E	14°C	39°C	1,275
Tepi	1200	7° 03' 0"N	35° 18'0"E	15.4°C	29.9°C	1685.9
Metema	685	NA	NA	NA	NA	1942

Results and Discussion

Yield and agronomic performance and reaction to major diseases

Mean grain yield and other agronomic traits performance of the candidate variety over locations and years from multi location trials is given below (Table 2 and 3). The mean yield performance across 5 environments showed that the variety, SCS-1 was the top yielder with high yield advantage (19.2 %) over the check, Pawe 3 (Table 3). Besides, this variety was resistant/tolerant to major soybean diseases, particularly rust and bacterial blight. It has also attractive seed color/lusters (Table 5). The variety has average height, with reasonable number of branches and is resistant to lodging. As a result, grain yield of SCS-1 can be maximized by increasing plant population per hectare.

Table 2. Combined mean grain yield (t/ha) and other agronomic traits performance of the test genotypes over locations and over years

S.No.	Genotypes	DF	DM	PH	NOP	NOS	NSP	LG	Rust	Blight	HSW	GY
1	Essex-1	56.11	117.72	67.06	33.19	76.26	2.25	1.28	1.06	1.17	16.21	2.40
2	SCS-1	57.83	117.17	63.44	38.76	80.98	2.07	1.22	1.61	1.67	15.13	2.85
3	H-7	52.42	114.19	48.44	27.84	61.20	2.18	1.06	1.39	1.67	16.97	2.42
4	JM-ALM/H3-15-SH	56.94	120.83	72.67	37.86	77.63	2.08	1.03	1.56	1.67	15.63	2.31
5	PR-143-(14)	58.75	117.53	60.28	38.69	83.55	2.07	1.01	1.22	1.56	15.19	2.27
6	BRS 283	53.14	114.33	87.36	35.83	76.33	2.06	1.89	1.00	1.28	17.39	2.29
7	Pawe 3 (C1)	64.14	126.53	75.71	43.97	111.88	2.30	1.61	1.11	2.17	14.07	2.39
8	H-3	59.19	116.44	62.54	37.77	74.97	1.96	1.00	1.17	1.33	14.85	2.51
9	JM-DAV/PR142-15-SA	53.78	113.83	48.92	31.28	68.51	2.19	1.07	1.33	1.83	13.58	2.32
10	JM-ALM/H3-15-SC-1	56.44	116.58	57.02	32.92	73.76	2.19	1.01	1.33	1.83	14.07	2.38
11	PI417129B	57.08	117.17	51.53	32.13	71.54	2.23	1.08	1.67	1.78	12.17	2.32
12	PI416810	52.11	111.64	59.97	34.43	77.50	2.15	1.01	1.17	1.06	12.89	2.23
13	PI587905	53.08	108.75	45.03	34.42	66.49	1.93	1.19	1.00	2.33	12.75	2.11
14	PI594538A	49.06	106.14	37.22	29.74	57.10	1.93	1.00	1.17	1.94	17.55	2.18
15	PI417089A	53.44	111.36	75.63	33.53	65.38	2.02	1.39	1.00	1.22	17.60	2.47
	Mean	55.57	115.35	60.85	34.82	74.87	2.11	1.19	1.25	1.63	15.07	2.36
	Min	49.06	106.14	37.22	27.84	57.1	1.93	1	1	1.06	12.17	2.11
	Max	64.14	126.53	87.36	43.97	111.88	2.3	1.89	1.67	2.33	17.6	2.85
	LSD	2.08	2.42	3.22	4.30	16.73	0.25	0.17	0.31	0.30	1.34	0.32
	CV %	8.09	4.52	11.44	26.67	48.22	26.4	32.3	54.7	40.63	19.30	24.8

DF= days to flower, DM= Days to maturity, PH = plant height, NOP= number of pods per plant, NOS= number of Seeds per plant, LG= lodging, SH= shattering, HSW = hundred seed weight, GY=grain yield (ton/ha)

Table 3. Mean grain yield (t/ha) across locations of the candidate variety and check; and, % yield increase over the check

Test years	Locations	Candidate variety	Standard check
		SCS-1	Pawe-03
2018 and 2019	Jimma	2.84	1.51
	Metu	2.62	2.38
	Gonder	2.31	3.16
	Asosa	2.81	2.27
	Tepi	3.70	2.66
Mean		2.86	2.40
Mean % yield advantage over the check		19.20	

Quality performance

The primary objective of the introduction of the variety in 1992 was to use for soil fertility improvement. Since then, farmers around Tiro Afeta and kersa wereda; Jimma zone used to include the variety for production; because of its high yield potential and attractive seed size and color. Farmers sell the variety in a better price than other released varieties in local market because of the big seed size, attractive seed size and color, milk and yoghourt quality when farmers use the variety in their dish, among others. SCS-1 has better protein content and comparable oil content with the standard check (Table 4). Because of the different quality parameters, it possesses, the variety is expected to have better preference by the emerging local and international market. After thorough evaluation by the national variety release committee, the candidate variety SCS-1 was accepted for registration to be used as commercial soybean variety in Ethiopia.

Table 4. Mean of protein and oil for the candidates and checks

Protein and oil Content %	Standard check-1 (Pawe-3)	Candidate variety SCS-1
Protein	37.47	40.13
Oil	22.02	19.04

Table 5. Main morphological characteristics of the candidate's variety

Candidates	Seed coat color	Leaf Shape	Hilum color of seed	Flower color	Morphological characteristics			
					Pubescence color	Pod color	Seed luster	Pubescence density
SCS-1	Yellow	Intermediate	Yellow	White	Gray	Light brown	1	Semi dense

Seed luster scoring system is 1-5 scale (1=luster or attractive, 5= unattractive

Recommendation domain of the variety

SCS-1 is adaptable from low to medium altitude soybean growing agro ecologies of the country with an altitude ranging from 685-1754 masl with mean annual

rainfall of 1561mm to 2910 mm; mean annual temperature of 26^{o}C to 33^{o}c. The variety is adaptable at Jimma, Metu, Tepi, Assosa and Metema and similar soybean growing agro ecologies of Ethiopia**.**

Conclusion and Recommendation

The variety SCS-1, which is commercial variety in Zimbabwe was introduced for soil fertility improvement purpose in Ethiopia. The variety was handed over to soybean breeding team by soil and water research department. It was tested in national variety trial over five locations for two years period and was found to be promising with yield advantage of 19.2% over the check variety Pawe3. In addition to its high yielding ability, it is tolerant to major leaf diseases such as soybean rust and bacterial blight**.** It contains high protein and reasonable oil content. The variety adapts from low to mid altitude soybean growing areas of Ethiopia. Therefore, in 2021 variety SCS-1 was officially registered to be used as commercial soybean variety in Ethiopia.

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Participatory Variety Selections of Newly Released Soybean Varieties in Southwestern Parts of Ethiopia

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Abstract

Soybean (Glycine max L.) is highly demanded legume crop in the world and becoming economically important in Ethiopia. The productivity of soybean in Ethiopia is low as compared to its genetic potential mainly due to the low dissemination and adoption of improved technology. This study was conducted to identify soybean varieties based on the farmer's preference and selection criteria. In 2020 and 2021 cropping season, eight soybean varieties were evaluated on a 21m2 plot at the Decha Nede peasant association, Tiro afeta wereda in Jimma zone, and at the Banchure peasant association in Bedele wereda, Buno-Bedele zone. The trial was replicated at three farmers' fields at each location. A total of 40 farmers (5 female and 35 male) and 6 development agents participated in the selection. Selection criteria used by farmers were grain yield, pod load, seed number/pod, early maturity, disease tolerance, medium plant height, big seed size, and attractive seed color. On the basis of the above selection criteria set by farmers, Melko Bonsa-01 ranked first, followed by Coker 240. Grain yield data also showed these varieties were the first and the second highest yielding varieties in all test locations. Therefore, we recommend Melko Bonsa-1 and Coker 240 varieties to widely disseminate and popularize in similar agro ecologies to increase soybean production and productivity in the country.

Keywords: Soybean, Varieties, Dissemination, Farmer, Selection

Introduction

Soybean (*Glycine max* (L.) is also called king of bean, first discoverer in in East Asia and was domesticated around 5000 years ago (Carter *et al*., 2004). It grown in mid and low land agro-ecological conditions. Approximately half of the world's oilseed production and a quarter of the protein used for human and animal consumption comes from soybeans (Wang *etal.*,2020). According to the USDA National Nutrient Database, soybeans have more protein, lipids, minerals (P, K, Ca, Fe, Zn), and vitamins (thiamine, riboflavin, vitamins C and E) than chickpeas, mung beans, lentils, cowpeas, pigeon peas, and kidney beans.

Soybean is an ideal crop for cereal crops rotation by supporting sustainable crop production. It plays significant role for food security and improving nutritional status. In addition to the direct utilization of soybean in daily diet for human being; it serves as one of the feed components in livestock and poultry and poultry husbandry business. Soybean is becoming an important cash crop in sub- Saharan

Africa (SSA), including Ethiopia. Currently, the demand of soybean is extremely high as compared to the domestic supply in SSA, and the gap is often supported through import from other countries. It is the mandate of different actors in soybean value chain to fill this gap. Ethiopia has great opportunity to increase the domestic production and reduce import, if farmers use adoptable varieties and improve their productivity by implementing recommended agronomic practices both under ran-feed and irrigated agriculture. The average soybean productivity in Ethiopia is 2.3 t ha^{-1} (CSA, 2019/2020), which is lower than the potential yield of about 4.0 t ha^{-1}.

One of the strategies to enhance the productivity of soybean in farmers' fields is through the development and utilization of improved soybean varieties accompanied by productivity enhancing technologies. Several factors may have accounted for the limited adoption of new varieties. First, breeders' selection criteria may not match the needs and preferences of farmers. According to Bellon (2002), participatory variety selection (PVS) is a breeding approach which provides a wide choice of varieties for farmers to evaluate in their own environment using their own resources for increasing production. PVS approach enable farmers make their own analysis and decisions based on their perceptions and criteria. It also helps to identify and assess traits that are important to farmers as a feed back to breeders to include in future variety selection. PVS has proven to be successful in field evaluation of the finished or pr-released varieties leading to increase in on-farm varietal diversity (Tshewang *et al*., 2010). The participatory methods and tools enable to incorporate participants ideas in future research activities and helping them to acquire skills, knowledge (De Boef, and Thijssen, 2007). Even though 32 improved soybean varieties were released so far from the Ethiopian soybean breeding program, the promotion and dissemination to farmers is very weak. Hence PVS is an important tool to introduce and adopt improved soybean varieties to the farmers. The present study was therefore conducted to enable farmers to select the varieties based on their preference.

Materials and Methods

Study Area

Description of study treatment

In 2020-2021 cropping season, a total of eight varieties including seven released and one elite variety introduced from USA were tested in a 21 m^2 single plot at Decha Nede peasant, Bedele werda in Jimma zone and at Banchure peasant association, Bedele woreda in Jimma zone (Table1). The trial was replicated on three farmers' field at each wereda. Spacing between rows and plants were 60cm and 5cm, respectively. NPS fertilizer was applied at the rate of 121 kg ha^{-1} during

sowing. All other agronomic practices were applied as per the recommendation for soybean.

Table 1. List of soybean varieties used for the study

Variety	Year of Releases
Coker-240	1981/2
Clarck-63k	1981/2
5002t	USA introduced lines (elite variety)
Nyala	2014
Gazelle	2015
Melko Bonsa-1	2020
AFGAT	2007
Hawassa-04	2012

Data Collection

Selected farmers evaluated the performance of test varieties at full seed (R6 stage) and at physiological maturity (R7 stage). Before the commencement of variety selection by farmers, brief description of the varieties and the information required from farmers were given to farmers by soybean researchers. Framers visited the whole field and set selection criteria before they start selecting varieties. The selection criteria set by farmers were pod load, disease tolerance, seed size and color. The researcher gave direction to farmers to rank the varieties in a 1-5 scale based on selection criteria set by farmers. Plant height, earliness in maturity, disease tolerance, number of seeds/pods, seed size and seed color were the selection criteria set by farmers. 40 farmers (5 female and 35 male) and 6 development agents participated in selection of the varieties. In addition to this, grain yield and other important agronomic data were taken by researchers. The combined mean yield and other agronomic data were analyzed. Farmers' preference data was subject to a 'preference ranking' and all the varieties are ranked for six important traits based on the farmers' selection criteria. Overall ranking was done for each variety for many traits.

Results and Discussion

Based on farmers selection criteria; Melko bonsa-01, Coker 240 and Nyala were the three varieties selected to be used by farmers (Table 2). Farmer's assessment of varieties to different parameters set by farmers is as follows. Good to very good score on pod load and number of seeds/pod were given to variety Melko Bonsa-1,Coker 240 and Afgat; while the least score was given to 50002-T; Good to very good score on earliness in maturity were given to variety Nyala, Coker 240 and Melko Bonsa-1, while the least score was given to Afgat; Very good score on plant height were given to variety Nyala, Coker 240 and Melko Bonsa-1, while the least score was given to Afgat; Good to very good score on seed size were

given to variety Melko Bonsa-1,Coker 240 and Nyala, while the least score was given to Afgat; Good to very good score on seed size were given to variety Melko Bonsa-1,Coker 240 and Gazella, while the least score was given to 5002-t.

Table 2: Farmers scores and ranks of eight soybean varieties using six selection criteria at Tiro-Afeta and Bedele

Variety Name	Pod load	Seed per plant	Early maturity	Plant height	Seed size	Seed color	Mean	Rank
Coker-240	2.00	2.00	2.00	1.00	1.00	1.00	1.50	2
Clarck-63k	3.00	3.00	4.00	4.00	5.00	4.00	3.83	7
5002t	5.00	5.00	4.00	1.00	5.00	5.00	4.17	8
Nyala	3.00	3.00	1.00	1.00	2.00	3.00	2.17	3
Gazelle	3.00	3.00	3.00	1.00	3.00	2.00	2.50	4
Melko Bonsa-1	1.00	1.00	2.00	1.00	1.00	1.00	1.17	1
AFGAT	2.00	2.00	5.00	5.00	4.00	4.00	3.67	6
Hawassa-04	3.60	3.60	4.00	3.00	3.00	3.00	3.37	5
Mean	2.83	2.83	3.13	2.13	3.00	2.88	2.80	

Remark: 1= very good, 2= good, 3= average, 4= poor and 5 = very poor

The mean yield performance of the varieties ranges from 2.06 t/ha (5002t) -2.63 t/ha (Melko Bonsa-01 and Coker –240) at Tiro afeta; while yield ranges from 1.64 t/ha (Coker 240) - 2.02(Melko Bonsa-01 t/ha at Bedele at farmers' field. Based on the combined mean the variety, Melko bonsa-01 was the top yielding variety followed by Coker 240 and Clarke 63k with yield of 2.46t/ha,2.24t/ha and 2.16t/ha respectively (Table 3).

Table 3. Yield performance (t/ha) of eight soybean varieties at Tiro-Afeta and Bedele in 2020-2021 cropping season

Varieties	Tiro afeta		Bedele		Over all mean	Rank
	Location 1	Location 2	Location 1	Location 2		
5002t	2.05	2.08	1.56	1.81	1.91	8.00
AFGAT	2.36	1.79	1.94	1.90	2.01	7.00
Clarck-63k	2.48	2.06	1.87	2.14	2.16	3.00
Coker-240	2.81	2.46	1.86	1.43	2.24	2.00
Gazelle	2.52	2.21	1.77	1.71	2.12	5.00
Hawassa-04	2.29	2.00	1.84	2.38	2.13	4.00
Melko Bonsa-1	2.81	2.46	2.59	1.81	2.46	1.00
Nyala	2.38	2.17	2.13	1.48	2.09	6.00

Melko Bonsa -1 and Coker 240 which were among the three farmers selected varieties were found to be among the three high yielders based on grain yield data. Therefore, the seed of these varieties should be provided to farmers to be under production at Tiro Afeta and Bedele wereda and similar areas. In addition to this, the selection criteria used by farmers generate information to soybean breeders for future variety selection and breeding.

Conclusion and Recommendation

For the rapid dissemination of technologies, participatory variety selection is of paramount importance. As a result, the high yielding soybean varieties, Melko bonsa-1and Coker 240, which were selected as first and second by farmers recommended to be used by farmers in Tiro Afeta and Bedele wereda for large scale dissemination and popularization. It is essential to strengthen the seed system and produce enough early-generation seeds, as popularizing these two varieties has a significant impact on increasing soybean production and productivity in the country. In addition to this, the selection criteria used by farmers can provide information for soybean breeders for future variety selection and breeding.

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Agronomy Research Results

Effects of Seed Rate and Nitrogen Fertilizer Levels on grain quality and fertilizer Utilization Efficiency of Durum Wheat

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Abstract

Due to low soil nutrients, durum wheat productivity and quality grain are insufficient to the domestic demands. In addition, a seed rate recommendation for durum wheat is dates long back, and they no longer reflect the current agro-climatic variability and changes. Thus, application of optimum nitrogen fertilization and seed rate are essential to ensure high yield and quality wheat production. To achieve these, field experiment was conducted at Minjar and Chefe Donsa sites from 2018 to 2020 years. The study revealed that yield components such as number of productive tillers, spike length, number of kernels per spike, plant height, biomass yield, grain yield protein contents and test weight were significantly affected by nitrogen fertilization rate at both locations, but in case of seed rate did not show a significant effect on the durum wheat traits. Compared to the control (without N), application of the highest rate (138 kg/ha), grain yield improved by 53 and 57% at Minjar and Chefe Donsa, respectively. The grain protein content was also increased by about 6% at Minjar and 7.5% at Chefe Donsa with application rate of 138 kg N/ha but statistically similar with 92 kg N/ha rate at Minjar. From the current result, N rate was a significant effect on the protein content however, at Chefe Donsa the protein content has not been complemented for a minimum quality standard (11.0%) that sated by processors. Thus, farmers and processors are well aware that Chefe Donsa is unwise to quality durum wheat production.

Keywords: Agronomic use efficiency, grain protein, durum wheat, yield

Introduction

Durum wheat (*Triticum turgidum* L. Variety durum) is one of the cultivated cereal crops in Ethiopia. It is exclusively cultivated in rainfed (*Meher*), sown in early to mid-July and harvested in mid-October to end of November depending on the cultivar maturity and the length of growing period (Bizuwork and Yibekal, 2020). In the early 1980, before the introduction of improved bread wheat varieties into the country, it was the dominant wheat crop produced and that covered 60 to 70% of wheat cultivated land and the remaining 30 to 40% was covered by bread wheat (*Triticum aestivum*). However, those imported bread wheat varieties from the international wheat and maize breeding programs, due to their wide adaptation

with satisfactory yield potential, farmers gave less attention to durum wheat cultivation even though the crop is important. Currently, in turn about 80% of the arable land is devoted to wheat (Nagassa *et al.*, 2019).

But with the current privatization policy and immerging of the past processing industry in the country (Eshete *et al*., 2018), there is an increasing demand of durum wheat grains for the raw materials of the processors. However, the domestic production of durum wheat has been insufficient to the domestic demands (Gebreselassie *et al*., 2017). Because of this surplus production of durum wheat in the context of proper wheat management, yield and quality grain being the principal goal.

Application of optimum nitrogen fertilizer rate is an essential to ensure high yield and quality wheat production (Grant *et al.*, 2001). Crops require nitrogen by large, because it is one of the formation of chlorophylls, which is the most important and associated with photosynthesis process and it makes up to 1 to 4 presents of dry matter of the crop (Nursuaidah *et al*., 2014). Moreover, it helps many essential compounds, growth and development for many cereal crops, without proper use of nitrogen fertilizer, crops slow growth and development. In addition, it is the major nutrient influencing yield and improving grain quality mainly by its effects on the grain protein concentration and composition (Gooding and Davies, 1997; Ehdaie *et al*., 2003; Lopez-Bellido *et al.*, 2005; Ierna *et al*., 2015).

In Ethiopia, several nitrogen fertilizer rate studies in various durum wheat growing areas and recommended nitrogen fertilizer rates ranges from 100 kg/ha to 169 kg/ha, depending on the soil type and crop rotation system (EIAR, 2004). The crop rotation system, legume-cereals based, supplies 80 kg N ha^{-1} to the soil in every season (Werner, 2005), which complements 30% of the fertilizer demand of cereals like wheat, tef, barley. However, currently in the country, legume-cereals based crop rotation systems are under threat because most legume crops are affected by soil borne and foliar diseases (Mitiku, 2017; Tolosa, 2018; Adane, 2019). Thus, farmers have been forced to shift their rotation system cereals to cereals and cereals to root crops (tef-wheat, tef-maize, wheat-onion, and tef-onion). These rotation systems can increase the durum wheat nitrogen requirement budget.

Seed rate is the number of plants in a unit area of land for optimum crop production. It depends up on the growing season, soil productivity, sowing time, method of sowing. Thus, optimization of seeding rate is considered the major factor determining crop yield and quality traits (Loveras *et al.*, 2004). Also, an important cropping factor for crop producers and best decisions need to be made (Slafer and Satorre, 1999). In Ethiopia, several studies have been done and most published research suggested seed rate ranges from 100 kg/ha to 125 kg/ha (EIAR,

2004) but this previous seed rate recommendation was not taken to account the sowing date, cultivars and soil type. Crop response to seed rate can be measured by the abilities of cultivars to compensate for low or high plant density. For instance, traditionally farmers are extended the sowing date of durum wheat by one to two weeks from the research recommendation on Vertisol areas to reduce the risk of excess watering, however, delay in sowing after the optimal sowing date, consistently reduce yield because decreases individual plant growth and effective tiller production in durum wheat (Gooding and Davies, 1997; Fielder, 1998). Thus, optimization of nitrogen fertilizer rate and seeding rate management are the priorities to enhance durum wheat production to meet the domestic demand of the country. Therefore, the current investigation was designed for determining optimum seed rate together with N fertilizer for the production of acceptable quality grain of durum wheat.

Materials and Methods

Description of the study areas

The study was conducted in two locations (Minjar and Chefe Donsa), which represented two environmental conditions within the East Shewa Zone of Amhara and Oromiya regions, respectively. The geographical location of Minjar is 8°46′33.5″ N and 39°16′40.7″ E with 2257.7 meter above sea levels whereas Chefe Donsa is located 8º 85‘70” N, 39º 80’ 60” E and 2400 meter above sea level. The selected soil physico-chemical properties of the experimental sites, Minjar and Chefe Donsa, are presented in Table 1. The rainfall amounts of 417.12 mm in 2018, 552.6 mm in 2019 and 48 mm in 2020 in Minjar and at Chefe Donsa 680.6 mm in 2018, 738.33 mm in 2019 and 711.33 in 2020 cropping months (June to November).

Table 1. Soil physio-chemical property analysis before planting at Minjar and Chefedonsa in 2018-2020 years

Soil property	Locations					
	Minjar			Chefe Donsa		
Textural class	2018	2019	2020	2018	2019	2020
Clay (%)	54.4	50.2	52.3	57.4	56.2	55.3
Silt (%)	30.4	32.2	33.6	28.4	30.2	30.6
Sand (%)	15.2	17.6	14.1	14.2	13.6	14.1
pH (1: 2.5 H_2O)	6.23	6.58	6.78	5.34	5.87	5.97
CEC[Cmol(+)kg^{-1} soil]	36.0	45.0	50.0	28.0	31.0	27.0
Organic matter (%)	0.64	0.71	0.87	0.21	0.23	0.20
Total N (%)	0.07	0.06	0.05	0.02	0.03	0.01
Ava. P_2O_5 (mg/kg)	9.23	11.01	7.29	7.23	6.01	6.34.

Treatment Setups and Field Management

The treatments were arranged four nitrogen fertilizer rates (NR) (0 (not applied), 46, 92 and138 kg/ha) and four seeding rates (SR) (100, 125, 150 and 175 kg/ha). The experiment was arranged in Randomized Complete Block Design (RCBD) in

a factorial arrangement and each treatment was replicated three times. Spaced between the plots and blocks were 0.5 m and 1.0 m, respectively. The plots are 9.6 m^2 in size (3 m in width and 3.6 in length). Recently released durum wheat variety called *Utuba*, which is semi dwarf, was kindly availed from DZARC and used for this experiment. The seed was sown with hand drilling in a row method with 20 cm space on 27 July 2018, on 24 July 2019, and on 26 July 2020 at Minjar and on 02 August 2018, on 01 August 2019, and on 03 August 2020 at Chefe Donsa cropping season. Recommended fertilizer rate of 100 kg/ha of TSP equivalent of 46 kg/ha P_2O_5 was applied to all treatments at planting, whereas nitrogen in the forum of Urea was applied as a treatments specification in split form (one-fourth at sowing and half at tillering and one-fourth at heading). The crop management, all grass and broadleaf weeds were removed by manual weeding.

Agronomic and Grain Quality Traits Measurement

Traits measured for all plots were plant height (PH, cm), spike length (SL, cm), number productive tillers (NPT, number), number of kernels per spike (NKPS, number), biomass yield (BY, kg/ha), grain yield (GY, kg/ha) and harvest index (HI, %). Plant height was determined by measuring the distance between the base of the stem and the top of the spike without excluding awns. Spike length was determined by measuring the distance between the base of the spike and the top of the spike without excluding awns. Ten effective heads were taken randomly when the crop reached maturity and measured the length of PH and SL then the mean value was recorded. Number of productive tillers was determined at maturity by counting all head bearing and seed set headings tillers per plant. Number of kernels per spike was recorded from the average of 10 spikes. Ten effective heads were selected randomly and then spike had threshed, separated and cleaned the seed then counted the seed.

Biomass yield was obtained from the whole plant parts including leaves, stems and seed of the crop. First, samples were collected from 2 m row length and 2 m width in the net plot area of each plot. Then samples were dried until they reached a constant weight. Then dried samples were weighed by electronic balance and expressed in kg/ha. Grain yield was also determined from the collected samples. After biomass was recorded, the samples were threshed, cleaned and finally the grain was separate from the straw and weighed by electronic balance. The grain yield was expressed in kg/ha.

Harvest index was calculated by following formula Nichiporovich, (1967).

$$\text{Harvest index} = \frac{\text{Grain yield}}{\text{Biomass yield}} \text{ x } 100$$

Grain protein content (GPC) was described in the standard AACC Method 44-15A (AACC, 2000). Test weight (TW), it was determined for dockage-free grain

samples using Seed burro test weight mass device and an electronic balance. Agronomic use efficiency was calculated Ladha *et al.* (2005).

Agronomic use efficiency; AUE = $\frac{(Gn-Go)}{N}$

Where Gn stands for grain yield of the plot fertilized at 'n' fertilizer rate, Go for grain yield of unfertilized plot & 'N' is rate of applied fertilizer nutrient (Not applied at zero rate of fertilizer).

Data analysis

Statistical analysis was performed to test statistical differences in the seed rate and N levels. Data were tested for normality before doing the ANOVA following the procedure. Separate analyses across years for each location, because of heterogeneity of variance error of the locations, were performed using the R software 4.1.1 version. When significant treatment effects occurred, means were compared using LSD (0.05)**.**

Partial budget analysis

Partial budget analysis was done as described by CIMMYT (International Maize and Wheat Improvement Center) (1988)

Results and Discussion

Statistical analysis

The analysis of ANOVA for yield related, yield and grain quality traits revealed that the effects of year, location and nitrogen rate were highly significant (Table 2). Based on our two locations, the nitrogen by year interaction was significant for all traits except for NKSP, SL and HL. The nitrogen rate x location interaction was also significant for all agronomic and grain protein traits except NPT and Hl. Moreover, the location x year x nitrogen interaction had significant effects in most of tested traits but on the NKPS, SL and HL was nonsignificant. Regarding the effect of seed rate, seed rate x year, and seed rate x location, seed rate x year x location interaction was nonsignificant for all tested traits except seed rate x location on SL. The nitrogen rate x seed rate, nitrogen rate x seed rate x year, nitrogen rate x seed rate x location and nitrogen rate x seed rate x year x location interaction were nonsignificant except nitrogen rate x seed rate for NKP, nitrogen rate x seed rate x year for HI and nitrogen rate x seed rate x location for NKPS. Overall, the ANOVA result indicated that most of the variation was due to the main effects, year, location and nitrogen rate and the two-way, year x location and nitrogen rate x year, nitrogen rate x location and three-way interaction nitrogen rate x year x location. The main effect of N rate was highly significant differences were observed for agronomic and grain quality traits. On the other hand, at both locations, the main effect of seed rate was nonsignificant on most measured traits.

Table 2. F values of the combined analysis of variance effect of seed rate and N rate on durum wheat grown in Minjar and Chefe Donsa during 2018, 2019 and 2020 cropping seasons

Source	df	NPT	NKP	PH	SL	GY	BY	HI	PC	HL
Y	2	4.94**	6.57**	0.97	17.43**	7.51**	34.9**	24.07****	9.50	11.22**
LC	1	2.05*	3842**	703.74***	281.20**	423.07**	464.60***	9.50*	479.38**	3.84*
Y x LC	2	8.66	7.23**	0.18	11.25**	43.24**	60.2*	6.80**	128.67**	4.68*
N	3	8.82**	10.10**	9.15	28.42**	182.61***	163.51***	10.49**	17.16**	2.71*
N x Y	6	2.10*	2.69	3.75*	1.05	5.58**	2.29*	2.23*	7.83**	0.42
N x LC	3	0.78	4.93*	8.85**	5.06*	11.22**	4.24**	5.68**	31.45***	1.63
N x Y x LC	6	1.58*	2.37	7.82**	1.46	6.04**	7.44**	6.85**	5.21**	0.38
SR	3	2.32	1.34	1.24	1.32	1.30	0.90	0.50	0.85	0.54
SR X Y	6	0.81	0.66	0.50	0.58	0.13	0.20	1.77	0.86	1.44
SR X LC	3	0.48	2.27	0.30	3.60*	0.06	0.29	1.29	0.25	0.55
SR X Y X LC	6	0.68	1.13	0.84	1.19	0.42	0.61	1.10	0.76	1.19
N X SR	9	0.51	2.61**	0.36	0.75	0.95	0.99	1.90	1.40	0.68
N X SR X Y	18	0.82	0.45	0.87	0.48	1.57	1.38	2.02*	1.25	1.21
N X SR X LC	9	1.05	3.88*	0.90	1.22	1.89	1.67	0.90	0.72	0.66
N x SR X YX LC	18	1.37	0.86	0.40	0.34	1.12	1.24	1.02	0.14	1.12

Year and nitrogen fertilizer and seed rate effects on the growth traits

Table 3 and 4 reflects the effect of year, N rate and SR on the NPT, SL, NKPS and PH at Minjar and Chefe donsa, respectively. At Minjar, NPT, SL and PH differed significantly with each year. But at Chefe Donsa, only NPT differed with the year. Only NKSP at Minjar and SL, PH and NKSP at Chefe Donsa were a nonsignificant difference in all three study years (Table 2).

The highest value of NPT, SL, and PH in 2019 and only NPT in 2018 was recorded at Minjar and Chefe Donsa (Table 3 and 4), respectively. This significant influence of years on the NTP, SL and PH may be attributed to the effect of rainfall distribution, which 552.6 mm in 2019 at Minjar and Chefe Donsa, which can lead to better crop growth and development resulted increased growth traits (Garrido-Lestach *et al*., 2005).

The N rate was also significantly affected by NPT, SL, NKPS and PH, which increased as N rate increased both at Minjar and Chefe Donsa (Table 3& 4), respectively. The lowest results were recorded without N treated plots at both locations. On the other hand, the highest number of NPT, SL and PH was exhibited N application at a rate of 138 kg/ha but no significant differences were recorded between 92 and 138 kg N/ha) (Table 3 & 4), respectively. Thus, the response of these growth parameters is different by N rate, the reason behind, N has promoted greater vegetative development and growth, resulting in increased effective tiller numbers, plant height, and spike length. Moreover, optimum suppling of N nutrient in the soil may contribute to successfully completing of the cell development and cytokine synthesis, which is an important hormone for cell division and shoot growth, resulting increased the growth traits (Botella *et al.*, 1993; Muhammad *et al.*, 2016; Bizuwork and Yibekal, 2020).

Table 3. The effects of year, N rate and seed rate on the NPT, SL, NLPS and PH of durum wheat at Minjar from 2018 to 2020 cropping seasons

Treatments	Minjar			
	NPT	SL (cm)	NKPS	PH (cm)
Year				
2018	4.71b	5.81b	50.32	82.69b
2019	5.51a	6.29a	49.90	89.15a
2020	3.85c	5.37c	49.14	88.34a
Nitrogen (kg/ha)				
0	364.3b	5.49b	44.79c	82.69c
46	411.6ab	5.77ab	50.11b	85.67b
92	421.9ab	5.94a	52.99a	88.61a
138	431.2a	6.05a	51.43ab	89.87a
Seed rate (kg/ha)				
100	412.9	5.69	50.25	87.07
125	410.8	5.91	50.73	87.26
150	402.7	6.15	49.73	87.40
175	400.6	6.16	48.61	85.37
CV (%)	25.80	11.21	9.12	6.01

*PH= plant height; SL= spike length; NKPS= number of kernel per spike; NPT= number of productive tiller; Means with the same letter in columns are not significantly different at 5% level of significance; CV (%) = Coefficient of variation

Table 4. The effects of year, N rate and seed rate on the NPT SL, NLPS and PH of durum wheat at Chefe Donsa from 2018 to 2020 cropping seasons

Treatments	Chefe Donsa			
	NPT	SL (cm)	NKPS	PH (cm)
Year				
2018	5.00a	4.69	39.34	70.91
2019	4.29b	4.68	38.99	71.57
2020	4.29b	4.57	39.34	69.85
Nitrogen (kg/ ha)				
0	181.9b	4.03c	38.3b	65.59c
46	210.2ab	4.67b	36.9b	69.97b
92	227.3a	4.75b	42.0a	72.53ab
138	232.5a	5.13a	39.7ab	75.01a
Seed rate (kg/ha)				
100	281.4	4.82	40.18	72.13
125	265.2	4.75	40.12	71.07
150	218.0	4.62	38.44	69.81
175	212.1	4.39	38.16	70.08
CV (%)	29.42	8.04	17.62	9.82

*PH= plant height; SL= spike length; NKPS= number of kernel per spike; NPT= number of productive tiller; Means with the same letter in columns are not significantly different at 5% level of significance; CV (%) = Coefficient of variation

Year, nitrogen fertilizer and seed rate effects on grain yield

The response of GY differed significantly between the three study years in both Minjar and Chefe Donsa (Table 2). The highest GY was obtained in 2019 at Minjar and in 2018 at Chefe Donsa, (Figure 2), whereas the lowest GY was noted in 2018 at Minjar and in 2020 at Chefe Donsa in Figure 1 & 2, respectively. The differing influence of year on grain yield of durum wheat in the three study years may be attributed to year-to-year differences in the amount and distribution of rainfall pattern during the crop growing period. In 2019 at Minjar and 2018 at Chefe Donsa, the rainfall distribution was more balanced compared to the other two study years. On the other hand, low GY in 2018 at Minjar and in 2020 at Chefe Donsa could be the absence of optimum and excessive rainfall at Minjar and Chefe Donsa, respectively, during crop growing period, leading to poor establishment of crop and poor tillering due to low moisture at Minjar and waterlogging at Chefe Donsa causes, resulted low GY (Lopez-Bellido *et al*., 2005; Garrido-Lestach *et al*., 2005).

The N fertilize rate had also a highly significant effect on the GY of durum wheat at both locations (Figure 1 & 2). The lowest GY was noted from plots without nitrogen fertilizer plots. On the other hand, the highest GY was exhibited in plots treated with 138 kg N/ha. Application of 138 kg N/ha was also significantly different from 46 and 92 kg N/ha rates at Chefe Donsa, but the difference between 138 and 92 kg N/ha was not significant at Minjar (Figure 1& 2). However, compared to the previous recommendation, 69 kg N/ha for both locations, the current durum wheat N requirement was increased. This may be due to farmers growing considerably cereal to cereal year to year and variation in weather patterns. The current finding indicated that, the N response of durum wheat was more in Chefe Donsa than Minjar, this may, Chefe Donsa is more Vertisol, in this area, rainfall is higher and evaporate demands are lower, resulting increases the risks of nitrogen leaching losses and low nitrogen use efficiencies (Lopez-Bellido *et al*., 2005; Garrido-Lestache *et al*., 2005; Teklu *et al*., 2004). Consequently, increases the durum wheat nitrogen requirement budget.

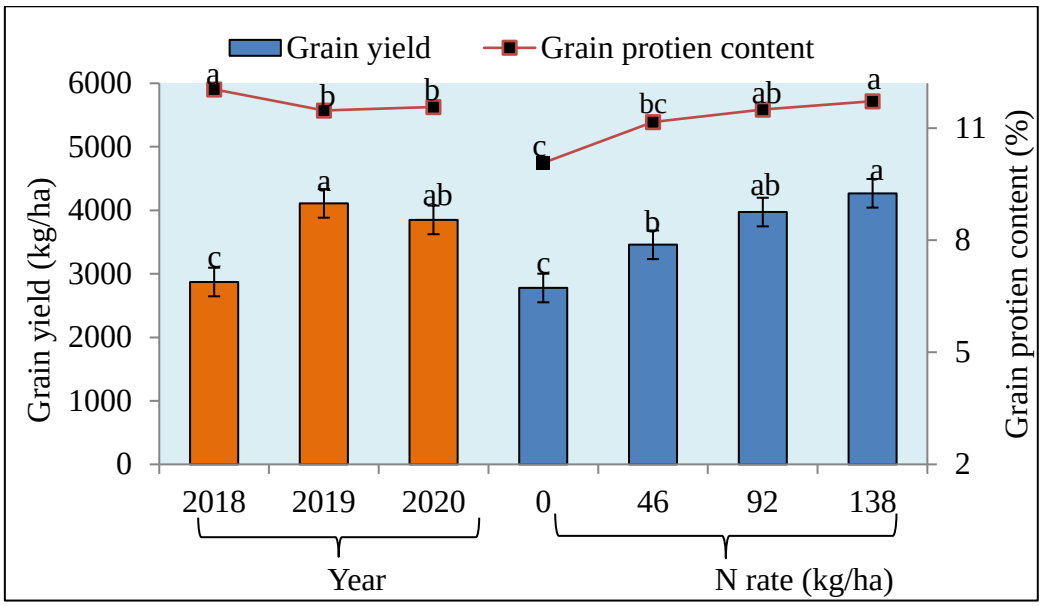

Figure1. Durum wheat grain yield and protein contents as affected by year and N rate at Minjar

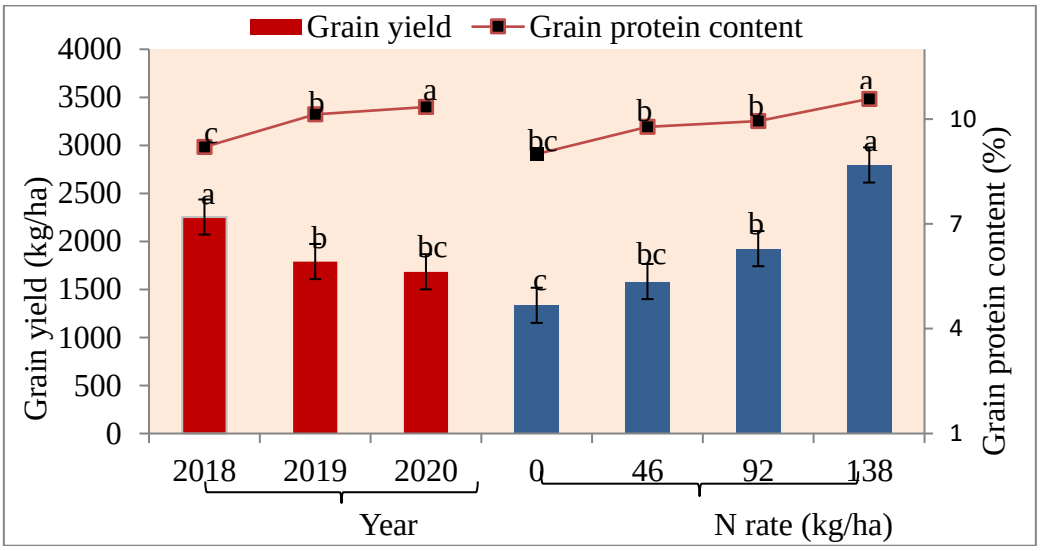

Figure 2. Durum wheat grain yield and protein contents affected by year, and N rate at Chefe Donsa

Year, nitrogen fertilizer and seed rates effects on biomass yield

The analysis of variance showed a significant effect of year for the BY (Table 2). Similarly, to the GY, the highest biomass yield was obtained in 2019 at Minjar and in 2018 at Chefe Donsa, whereas the lowest GY was noted in 2018 at Minjar and in 2020 at Chefe Donsa (Table 5). The low rainfall records in 2018 at Minjar and high rainfall in 2020 at Chefe Donsa during crop growing season, resulted in the crop exposed to low moisture and waterlogging stress, causing poor crop growth and development consequently low biomass accumulations.

Considering the N fertilizer treatment, N rate had also a significant effect on the BY (Table 5). At Minjar, the highest BY was produced from plants supplied with 138 kg N/ha, which was statistically similar to 92 kg/ha fertilization (Table 5). On the other hand, the lowest BY was obtained in treatment without nitrogen fertilizer application. Similarly, at Chefe Donsa the highest BY was noted from 138 kg/ha nitrogen fertilization but significantly lowest BY was recorded in treatment without nitrogen fertilizer application. Thus, BY recorded at 138 kg N fertilizer rates exceeded the lowest BY produced by 49.8 and 114.2%, at Minjar and Chefe Donsa, respectively. In each nitrogen fertilizer treatment, except without nitrogen fertilizer application, BY consistently increased at both locations. The increasing BY, with increased N fertilizers, probability due to nitrogen fertilization plots lead to plant growth rate, LAI, vigorous vegetative growth, and growth rate process, resulting in more BY produced. This result is in proximity to that of (Dawit *et al.*, 2015; Giuliani *et al*., 2011; Yasin *et al*., 2015) found that increasing nitrogen rate from 0 to 184 kg/ha increased the BY of wheat by about 70.1%.

Likewise, HI was highly significantly influenced by year both at Minjar and Chefe Donsa (Table 2). The maximum HI was obtained in 2019 at Minjar and 2018 at Chefe Donsa. The lowest HI was recorded in 2018 and in 2019 at Minjar and chefe Donsa, respectively (Table 5). As mentioned in the above paragraph, in all three study years, the balanced rainfall distribution was observed in 2019 and in 2018 cropping years at Minjar and Chefe Donsa, respectively. In fact, under good rainfall conduction, in these year high dry matter partitioning and grain yield resulting increases HI. Similar results have been also reported by (Giuliani *et al*., 2011).

Seed rate and N fertilizers levels effects on biomass yield, grain yield, harvest index and test weight of durum wheat at Minjar and Chefe Donsa in 2018-2020 cropping season.

Treatments	Minjar			Chefe Donsa		
	BY	HI	TW	BY	HI	TW
Year						
2018	7002c	0.36c	76.71b	5670.8a	9.20c	77.47b
2019	11448a	0.43a	81.92a	4891.2b	10.14b	81.38a
2020	9046b	0.41b	81.87a	3886.0c	10.35a	77.03b
Nitrogen (kg/ha)						
0	7088c	0.39	79.76b	7088c	0.39	75.28b
46	8782b	0.40	79.99b	8782b	0.40	79.71ab
92	10275a	0.39	80.33a	10275a	0.39	79.18ab
138	10621a	0.41	80.58a	10621a	0.41	80.34a
Seed rate (kg/ha)						
100	8783.7	0.41	80.13	8783.7	0.41	79.71
125	9201.5	0.39	80.18	9201.5	0.39	79.54
150	9261.3	0.39	80.06	9261.3	0.39	77.59
175	9520.5	0.40	80.28	9520.5	0.40	77.67
CV (%)	25.34	14.47	3.37	24.33	14.70	12.20

AGBY= Aboveground biomass yield; GY= grain yield; HI= harvest index; TW = tes weight; Means with the same letter in columns are not significantly different at 5% level of significance; LSD= least significant differences at 5%; CV (%) = Coefficient of variation.

Year, nitrogen fertilizer and seed rates effects on grain protein content

Protein content was significantly influenced by year and N rate (Table 2). In the three study years, the highest value of grain protein content was recorded in 2018 and 2020 at Minjar and Chefe Donsa (Figure 1 and 2), respectively. The lowest GPC was obtained in 2019 and 2018 at Minjar and Chefe Donsa, respectively. The year-to-year differences in GPC may be attributed to variation in rainfall and temperature. The higher rainfall in 2018 at Minjar and in 2020 at Chefe Donsa (waterlogging problem) may have promoted low GPC concentration due to the effect of high temperature on the protein synthesis during grain filling in durum wheat, reported (Garrido-Lestache *et al*., 2005; Mariani *et al*., 1995 and Stefanis *et al*., 2002), was not apparent in 2018 and in 2020 at Minjar and Chefe Donsa. Similarly, falling of high rainfall during the grain-filling stage negatively affected GPC in all cases, a finding also reported by (Rharrabti *et al*., 2003).

Considering nitrogen fertilization, N rate had a highly significant increase in grain protein concentration (GPC) both at Minjar and Chefe Donsa. The GPC increased with increasing nitrogen fertilization, by about 6% at Minjar and 7.5% at Chefe Donsa with an application rate of 138 kg N/ha. The lowest GPC was obtained without nitrogen fertilizer application both at Minjar and Chefe Donsa (Figure1 and 2), respectively. However, N rate from 92 to 138 kg/ha had resulted in an

approximately similar GPC at Minjar. Besides, the positive response of GPC to high N rate, availability of right amount nitrogen fertilizer might be greater synthesis and accumulation of storage proteins, leading to high GPC accumulation, were previously reported by (Foth and Ellis, 1997; Lopez-Bellido *et al*., 2005; Garrido *et al*., 2005; Gerba *et al*., 2013; Tilahun *et al.*, 2017; Bizuwork and Yibekal, 2020).

From the current result, N rate was a significant effect on the GPC, at Chefe Donsa, but the GPC has not been complemented for a minimum quality standard (11.0%) that set the processors. This might be due to high rainfall and poor soil fertility. According to Simmond, (1989) and Gooding and Davies, (1997) suggested that high soil moisture stress and low temperature increase grain carbohydrate accumulation rather than N accumulation this turns to low GPC. Thus, farmers and processors are well aware that GPC is affected more by the environment than by N fertilizer rate.

Year, nitrogen fertilizer and seed rates effects on test weight

Test weight was significantly influenced by the year (Table2). The highest test weight was recorded in 2019 in both locations (Table5). However, the lower mean test weights were obtained from the other two study years (2018 and 2020) (Figure). The season to season differences in the behavior of test weight may be attributed to variation in temperature, rainfall and soil conditions. Cool temperature would favor photosynthesis and subsequent starch deposition in the grain yield. Thus, would increase kernel weight and size, both of which are associated with high test weight (Giuliani *et al*., 2011; Moayedi, 2021).

Regarding the N rate, test weight was also significantly influenced by N rates (Table 2). The highest test weight was noted from plots treated with 92 kg N/ha, whereas the lowest test weight was recorded from without N treated plots. Test weight increased significantly with rising N rate only up to 92 kg N/ha, no significant differences were observed between 92 and 138 kg N/ha (Table 5). Although N is an essential component of the protein used to build cell materials and plant tissues, high levels of N are toxic to seed development (Mittler, 2002). This result was in line with that of Gerba *et al*. (2013) found that reduction in the hectoliter weight with increasing N rate beyond 92 kg N/ha. In contrast, Dawit *et al.* (2015) found that nitrogen fertilization had no significant effect on test weight.

Agronomic use efficiency

Agronomic use efficiency (AUE) was influenced by nitrogen fertilization at both locations (Figure 3). The highest AUE of 24.79 kg/kg at Minjar and 19.38 kg/kg at Chefe Donsa was obtained in low nitrogen fertilization treatment (46 kg N/ha) (Figure 3). However, the lowest AUE value (10.81 and 10.59 kg/kg) was noted in the highest nitrogen fertilization (138 kg/ha) application across both sites. Owing

to this finding, the AUE has higher at Minjar than compared to Chefe Donsa. This could be due to better uptake and utilization efficiency, cumulatively more N use efficiency at Minjar than Chefe Donsa. These could be due to dilution and leaching effects is more at Chefe Donsa because the area is received more rainfall and highly Vertisoil, resulting less responsive to nitrogen fertilization than Minjar. In cooler temperate areas, NO_3 losses sustained through leaching have approached 26 kg N under conventional tillage (Olson and Swallow, 1984). Moreover, according to Ortiz-Monasterio *et al.* (1997) found maximum uptake efficiency of nitrogen, in area where received optimum rain fall rather than in high rainfall N conditions.

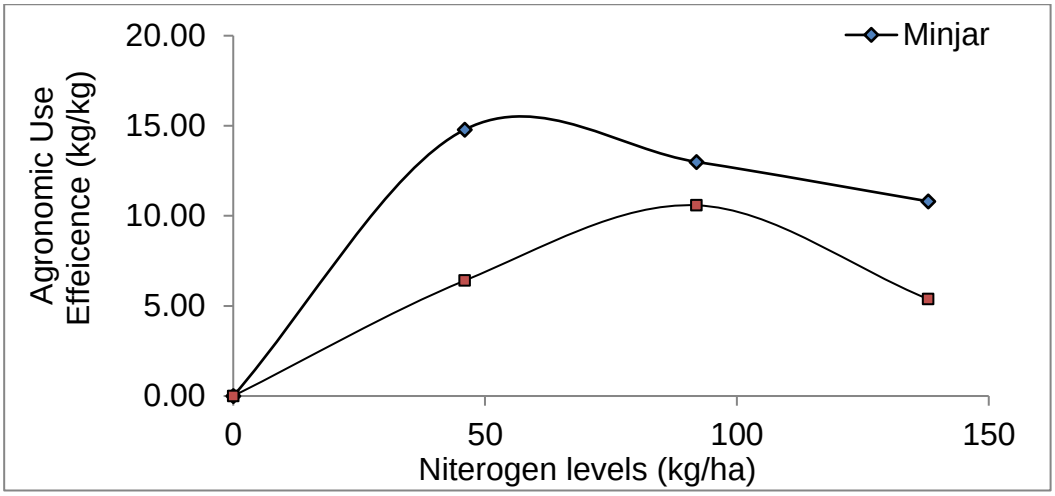

Figure 3. Nitrogen agronomic use efficiency on durum wheat at Minjar and Chefe Donsa in 2018-2020 cropping years

Partial Budget

The partial budget shows that the maximum mean net benefit (1564.9.22 USD/ha) with acceptable MRR (2016.9%) was achieved by 150 kg seed rate and 92 kg ha^{-1} nitrogen fertilizers at Minjar. At Chefe Donsa, the maximum mean net benefit (1202.6 USD/ha) and MRR (756.42%) was obtained from 150 kg seed rate and 138 kg N/ha fertilizers treatments. On the other hand, the lowest mean net benefit (1124.9 and 2560.81USD/ha) was obtained from plots treated without nitrogen fertilizer. Therefore, the use of 150 kg seed rate/ha combined with 92 kg/ha nitrogen fertilization would be economically best rewarding for production of durum wheat at Minjar but at Chefe Donsa 150 kg seed rate combined with maximum nitrogen fertilization (138 kg/ha) is more economical.

Conclusion and Recommendation

In conclusion, finding of the present study indicate that nitrogen fertilizers rate significantly enhanced the growth, yield components, yield, protein contents and test weight. The nitrogen rate of 138 kg/ha application effectively improved NPT, PH, NKPS, SL, BY, GY, PCT, and HLW in both environments. Based on the

economic ground 92 kg N/ha was satisfactory to provide sufficient yield and protein content to durum wheat production at Minjar location. However, at Chefe Donsa, high yield and protein content were achieved at the highest rate. Based on this fact, there is a need to improve N fertilizer use efficiency in Vertisol area to enhance grain yield and protein content. On the other hand, seed rate was not a significant effect in most accessed agronomic and grain quality traits of durum wheat. Even with a high seed rate of, there was not remarkable increased yield and protein content both at Minjar and Chefe Donsa. Moreover, the interaction effect of N rate and seed rate was also a nonsignificant effect in all measure traits.

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Implication of Nitrogen Fertilizer Application Levels on Productivity of Bread Wheat Varieties in Highlands of Arsi Zone, Southeastern Ethiopia

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Abstract

Studies on varieties with high N absorption and with low fertilizer requirements would be proper to develop varieties that absorb N more efficiently and that use it more effectually in the grain production process. Thus, the current work was carried out with the objective to investigate the interaction effects of N fertilizer rate and varieties on yield and yield related traits of bread wheat as well as to identify and recommend the optimum combination of N fertilizer rate with varieties which provided the best production and productivity specific to the study sites. The experiment was carried out in 2019 and 2020 main cropping seasons at Tiyo, Lemu-Bilbilo and Hasasa districts with factorial combinations of six bread wheat varieties (Daka, Honqolo, Wane, Kingbird, Ogolcho & Huluka), and four N levels (0, 46, 69 and 92 kg N ha-1). A randomized complete block design with three replications was used. The two seasons' results revealed that amongst agronomic parameters considered, grain yield and above ground biological yield were significantly influenced by the interaction effects of varieties and N fertilizer rate at all study areas. The maximum grain yields (5055, 5990 and 4754 kg ha-1) were gained from Daka, Honqolo and Wane bread varieties with the application of 92 kg ha-1, respectively at Tiyo, Hasasa and Lemu-Bilbilo experimental sites. Above ground biological yield was significantly increased for all varieties with increasing N rate at Tiyo and Hasasa experimental sites. Generally, based on grain yield and the other studied parameters, net benefit and economic feasibility; Wane and Daka varieties at 69 kg N ha-1 in Tiyo, Daka and Wane with N rate of 69 and 92 kg ha-1 at Lemu-Bilbilo as well as Honqolo and Daka varieties with 69 kg N ha-1 at Hasasa were economically viable for the production and productivity of bread wheat. However, for better recommendation this experiment should be validated across the study sites and the stakeholders' suggestions should be taken into account.

Keywords: Bread wheat, Grain yield, Harvest index, Net benefit, Nitrogen, thousand grain weight, Varieties

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important kinds of grain in Ethiopia in terms of area and production technology. It is primarily grown by subsistence farmers under rain-field conditions and ranks 4th in area coverage after

teff, maize and sorghum (Anteneh and Asrat, 2020). Most of the farming households are involved in the annual wheat production, which, however, cannot yet meet the country's annual domestic needs. Therefore, a large amount of wheat is imported every year to meet increasing domestic consumer demand.

Soil chemical degradation such as soil acidity, salinity and sodity, low fertilizer content, pests and moisture stress, are some of the main limiting factors of the crop production in Ethiopia (Berhane *et al*., 2011). Changes in soil fertility have long-term impacts on productivity, but it is essential to remember that variations in agriculture tend to be incremental rather than spectacular (Bain *et al*., 2013).

Wheat yield and end-use quality depend upon the environment, genotype, and their interactions. Low soil fertility, especially nitrogen deficiency, is one of the major constraints limiting wheat production in Ethiopian highlands (Kebede and Yamoah, 2009). Soil nitrogen is frequently deficient in continuous cereal cropping systems, and this is frequently encountered in soils on which crops are cultivated more than once annually (Bagayoko *et al*., 2000). Nitrogen plays crucial role in the biochemical processes of plants, including proteins, DNA, RNA, enzymes, and chlorophylls (Ohyama, 2010). The lack of this nutrient affects radiation use efficiency and biomass production, and also affects grain yield and its components (Xu *et al.*, 2012).

Expanding studies on cultivars with high N absorption and with low fertilizer requirements would be appropriate to develop cultivars that absorb N more efficiently and that use it more effectively in the grain production process. Therefore, the current experiment was undertaken with the objective to determine the interaction effects of N fertilizer rate and varieties on yield and yield related traits of bread wheat, so as to identify and recommend the optimum combination of N fertilizer rate with varieties which provided the best production and productivity specific to Tiyo, Lemu-Bilbilo and Hasasa districts of south-eastern Ethiopia.

Materials and Methods

Experimental setup

The trial was conducted under rain fed condition at Tiyo, Lemu-Bilbilo and Hasasa districts, southeastern Ethiopia in 2019 and 2020 main consecutive seasons. A factorial combination of six bread wheat varieties (Daka, Honqolo, Wane, Kingbird, Ogolcho & Huluka) and four N levels (0, 46, 69 and 92 kg N ha^{-1}) were laid in randomized complete block design with three replications. Following the history of preceding production season, farm lands which were covered with wheat or barley last year was selected. The gross plot size was 2.6m x 3 m (7. 8 m^2) with 20 cm row spacing and with net harvestable plot size of 2m x 3m (6 m^2). The distance between plots and replications was 0.5 m and 1.5 m,

respectively. The sources of nitrogen (N) and phosphorous (P) were urea and triple super phosphate (TSP), respectively. The TSP fertilizer was applied at planting. The N fertilizer was applied in triple form of application (1/3 at planting, 1/3 tillering and 1/3 stem elongations) as top dress as per the treatments. The seeds of all varieties were drilled by hand at optimum depth in rows using a manual row marker at the recommended seed rate of 125 kg ha^{-1}. The rest agronomic practices (weeding, harvesting and threshing) were done as per the suggestions for each site.

Data Collected

Agronomic parameters collected included, grain yield, above ground biological yield, harvest index and thousand kernels weight. After threshing, the harvested materials, grains were cleaned, weighed and adjusted to 12.5% moisture level. The total grain yields recorded on a plot basis were converted to kg ha^{-1} for statistical analysis. Finally, economic analysis was carried out at completion period of trial.

Economic analysis

The simple partial budget analysis was performed to study the economic viability of the treatments by using partial and marginal budget analysis. Gross yield benefit was obtained by multiplying the adjusted yield by the price of wheat grain at harvest in 2020 cropping season. Market price of bread wheat was estimated to be (15 Birr kg^{-1}) in all three experimental areas; means no grain cost variation across locations in 2020.Then net benefit was calculated by subtracting variable cost from gross yield. The price of urea was estimated to be 15 Birr kg^{-1}. Since, the cost of variety and the management cost were considered as uniform only the cost of nitrogen fertilizer was used as variable cost. The marginal rate of return (MRR) was calculated as the change in net benefit divided by the change in total variable cost of the successive net benefit and total variable cost levels (CIMMYT, 1988).

Results and Discussion

Grain yield

The homogeneity test of the error variances for locations showed that the error variance was heterogeneous and hence combined analysis of variance was not conducted. In all study areas, grain yield was significantly influenced by the main effect of varieties and N fertilizer rate as well as by the interaction effect of varieties by N fertilizer rate in both study years (Table 1). In the three study locations, the interaction between N rates and varieties showed that increasing N rate from unfertilized plots (control) to 92 kg N ha^{-1} significantly increased grain yield of all studied varieties, except for variety Ogolcho at which the highest grain yield was gained at 69 kg N ha^{-1} at Lemu-Bilbilo district. The grain yields

difference obtained from Huluqa and Wane varieties at Tiyo, Daka and Honqolo varieties at Lemu-Bilbilo and Daka, Honqolo, Huluqa, Ogolcho and Wane at Hasasa were significantly at par at N rate of 69 and 92 kg ha^{-1}, respectively (Table 1). With contrary to varieties, on average the maximum grain yields were recorded from Daka, Wane, Honqolo and Kingbird at Tiyo, Daka, Wane and Ogolcho at Lemu- Bilbilo, almost all studied varieties at Hasasa, respectively. On the other hand, the interaction effects of varieties and years significantly ($P<0.05$) affected grain yield at all study areas whereas the interaction effects of N rate and years affected grain yield ony at Tiyo experimental location(Figure 1,2,4 &7). The current findings also clearly indicated that all varieties showed better performance in 2019 cropping season in Tiyo, in 2020 at Lemu-Bilbilo whereas the fluctuation of performancy happened in both cropping years in Hasasa. Linear relationship of N rate and cropping seasons refelected at Tiyo experimental location (Figure 2). In both cropping years Daka, Honqolo and Wane gave good yields at Tiyo and Hasasa whereas Daka and Wane at Lemu-Bilbilo experimental location (Figure 1,4 &7).

Above ground biological yield

The mean difference of above ground biomass yield combined over two seasons significantly ($P<0.05$) affected by the main effect of N rate, Varieties and aso by their interactions (Table 2). The results revealed that above ground biomass yields of all varieties leanery inceased with inceasing N fertilizer application rate at Tiyo and Hasasa disticts whereas the icreaments were inconsistant at Lemu-Bilbilo district (Table 1). The maximum above ground biomass yields (12.2, 11.6 and 10.6 t ha^{-1}) were recorded from Honqolo, Wane and Huluqa varieties when tested with 92 kg N ha^{-1} at Hasasa, Tiyo and Lemu-Bilbilo districts, respectively (Table 1). However, the above ground biomass yield difference among Wane, Honqolo and Daka at Tiyo, Huluqa, Wane, Daka and Kingbird at Lemu-Bilbilo, Honqolo, Daka and Wane varieties at Hasasa were statisticaly similar. On the other hand, the above ground biomass yield gained at N rate of 69 and 92 kg N ha^{-1} showed significant difference for only Honqolo variety at Tiyo, Huluqa, Kingbird and Ogolcho varieties at Lemu-Bilbilo and Kingbird variety at Hasasa experimental sites.

Table 1. Interaction effect of nitrogen fertilizer rates and varieties on grain yield (kg ha^{-1}) of wheat at Tiyo, Lemu-Bilbilo and Hasasa districts combined over two years

Treatment	Tiyo				Lemu-Bilbilo				Hasasa			
	Nitrogen fertilizer rate (kg/ha)											
Varieties	0	46	69	92	0	46	69	92	0	46	69	92
Daka	2997^{ijk}	4064^{f}	4693^{cd}	5055^{ab}	3092^{hij}	4101^{def}	4652^{ab}	4693^{ab}	4273^{klm}	5054^{fg}	5696^{abcd}	5788^{abc}
Honqolo	2695^{k}	3367^{gh}	4195^{ef}	4755^{bcd}	1949^{m}	2844^{jk}	3655^{fg}	3735^{efg}	4980^{gh}	5388^{def}	5865^{ab}	5990^{a}
Huluqa	1936^{l}	2683^{k}	3180^{ghi}	3514^{g}	2429^{kl}	2977^{ij}	3636^{fg}	4327^{abcd}	4485^{ijkl}	4860^{ghi}	5133^{efg}	5401^{def}
Kingbird	2661^{k}	3912^{f}	3912f	4498de	2426^{klm}	3354^{ghi}	3494^{gh}	4609^{abc}	4018^{m}	4620^{hijk}	5040^{fg}	5531^{bcd}
Ogolcho	2057^{l}	2778^{jk}	2795^{jk}	3063^{hij}	2316^{lm}	2802^{jk}	4239^{bcd}	3656^{fg}	4179^{lm}	4474^{jkl}	4550^{jkl}	4765^{ghij}
Wane	3204^{ghi}	4144^{ef}	5310^{a}	4954^{abc}	2400^{klm}	3574^{g}	4175^{cde}	4754^{a}	4064^{m}	4981^{gh}	5483^{cde}	5649^{abcd}
LSD (5%)	360.0				476.0				376.0			
CV (%)	8.8				11.9				6.5			

Table 2. Interaction effect of nitrogen fertilizer rates and varieties on above ground biological yield (t ha-1) of wheat at Tiyo, Lemu-Bilbilo and Hasasa districts combined over two years

Treatment	Tiyo				Lemu-Bilbilo				Hasasa			
	Nitrogen fertilizer rate (t/ha)											
Varieties	0	46	69	92	0	46	69	92	0	46	69	92
Daka	8.0^{hi}	9.8^{de}	10.4^{bc}	10.8^{ab}	8.2^{fghij}	9.5^{abcd}	10.1^{abc}	10.1^{abc}	9.8^{klm}	10.9^{defg}	11.8^{abc}	11.9^{ab}
Honqolo	7.4^{ij}	8.6^{efgh}	9.8^{cd}	11.4^{a}	6.3^{m}	7.7^{hijk}	9.1^{cdefg}	8.7^{defgh}	10.7^{efgh}	11.3^{bcde}	12.0^{a}	12.2^{a}
Huluqa	6.2^{k}	8.0^{hi}	8.6^{efgh}	9.3^{def}	6.9^{klm}	8.1^{ghij}	9.3^{bcdef}	10.6^{a}	10.1^{ijkl}	10.6^{fghi}	10.8^{efg}	11.2^{cdef}
Kingbird	7.4^{ij}	8.2^{hi}	9.2^{defg}	10.1^{bcd}	6.4^{lm}	8.3^{efghi}	8.0^{ghijk}	9.9^{abc}	9.2^{m}	9.9^{jkl}	10.5^{fghij}	11.3^{cde}
Ogolcho	6.8^{jk}	8.4^{gh}	8.1^{hi}	8.4^{fgh}	6.4^{lm}	7.5^{ijkl}	10.3^{ab}	9.1^{cdefg}	9.7^{klm}	10.0^{ijkl}	10.1^{hijkl}	10.3^{ghijk}
Wane	8.1^{hi}	9.7^{cd}	11.7^{a}	11.6^{a}	7.1^{jklm}	8.4^{defghi}	9.3^{bcde}	10.2^{abc}	9.4^{lm}	10.9^{efg}	11.6^{abcd}	11.7^{abc}
LSD (5%)	898.1				1177.0				5.5			
CV (%)	8.7				12.0				679.7			

Harvest index

The main effects of N rate, varieties and year as well as the interaction effect of varieties and years had significantly ($P<0.05$) affected harvest index of bread wheat at all three experimental locations except the main effect of N fertilizer rate didn't show significant difference at Hasasa (Table 3& Figure 3,5,8). The harvest index results indicated it was increased with increasing N rate at all study sites and the mean difference of harvest index gained at 69 and 92 kg N ha^{-1} statistically similar at Tiyo and Lemu-Bilbilo experimental sites (Table 3). The highest harvest indexes (43.3 and 42.8%) were obtained from Daka variety at Lemu-Bilbilo and Tiyo experimental sites, respectively and didn't show significant difference with Wane variety whereas the maximum harvest index (47.9 %) was gained from Honqolo variety at Hasasa and revealed significant difference with the rest all varieties. According to the current findings, significantly the maximum harvest index was recorded in 2019 cropping season at Tiyo whereas in 2020 cropping season at Lemu-Bilbilo and Hasasa experimental fields (Table 3). In contrary, the better harvest index was gained at 2019 and 2020 cropping seasons from almost all tested varieties at Tiyo and Lemu-Bilbilo experimental fields, respectively; whereas the fluctuation of harvest indexes of all varieties occurred in two years at Hasasa experimental site. The present results also revealed that the maximum harvest index was recorded from Daka, Kingbird & Wane at Tiyo and Lemu-Bilbilo in two years cropping season whereas from Daka, Honqolo and Kingbird at Hasasa (Figure 3, 5 & 8).

Table 3. Main effect of year, nitrogen fertilizer rates and varieties on harvest index and thousand grains weight of wheat at Tiyo, Lemu Bilbilo and Hasasa districts

Treatment	Tiyo	Lemu-Bilbilo	Hasasa	Tiyo	Lemu-Bilbilo	Hasasa
	Harvest index (%)			Thousand kernels weight (g)		
Nitrogen fertilizer rate (kg/ha)						
0	35.2^{c}	34.9^{c}	44.1^{d}	33.2^{d}	40.6^{c}	40.7
46	38.4^{b}	39.0^{b}	46.2^{c}	36.1^{c}	41.6^{b}	40.7
69	41.1^{a}	42.2^{a}	47.4^{b}	38.1^{b}	41.6^{b}	40.6
92	41.7^{a}	43.7^{a}	48.2^{a}	40.1^{a}	42.7^{a}	40.5
LSD (5%)	1.4	1.5	0.5	1.4	0.8	NS
Varieties						
Daka	42.8^{a}	43.3^{a}	46.6bc	37.1^{ab}	45.4^{a}	42.0^{b}
Honqolo	40.2^{c}	37.4^{c}	47.9^{a}	38.4^{a}	40.1^{c}	43.4^{a}
Huluqa	34.6^{d}	37.7^{c}	46.5^{bc}	34.3^{c}	36.9^{d}	37.4^{d}
Kingbird	40.9^{bc}	41.3^{b}	46.9^{b}	36.1^{b}	39.6^{c}	39.4^{c}
Ogolcho	33.8^{d}	38.1^{c}	44.6^{d}	38.2^{a}	42.6^{b}	40.1^{c}
Wane	42.4^{ab}	41.9^{ab}	46.1^{c}	37.2^{ab}	45.0^{a}	41.6^{b}
LSD (%)	1.7	1.8	0.7	1.7	1.0	0.9
Year						
2019	40.7^{a}	37.2^{b}	46.2^{b}	37.6^{a}	39.6^{b}	41.3^{a}
2020	37.5^{b}	42.7^{a}	46.7^{a}	36.1^{b}	43.6^{a}	40.0^{b}
LSD (5%)	1.0	1.1	0.4	1.0	0.6	0.5
CV (%)	7.6	8.0	2.5	8.0	4.2	3.7

Thousand kernels weight

The main effects of N rate, varieties and year had significantly ($P<0.05$) affected thousand kernels weight of bread wheat at all three experimental locations except the main effect of N fertilizer rate didn't show significant difference at Hasasa whereas the interaction effect of varieties and years significantly affected thousand kernels weight at Lemu-Bilbilo district (Table 3& Figure 6). Significantly higher thousand kernels weights were recorded from all varieties in 2020 cropping season when compared to 2019 cropping year in Lemu-Bilbilo experimental location. The peak thousand kernels weights were gained from Daka, Ogolcho and Wane in both cropping years (Figure 6). Significantly higher thousand kernels weights (45.4, 43.4 and 38.4 g) were obtained from Daka at Lemu-Bilbilo and Honqolo at Hasasa and Tiyo, respectively though Daka variety was statistically similar with that of Wane variety at Lemu-Bilbilo and Honqolo with Daka, Ogolcho and Wane at Tiyo, but thousand kernels weight was consistently increased with increasing N fertilizer rate at Tiyo and Lemu-Bilbilo experimental sites (Table 3).Definitely, at Tiyo and Hasasa 2019 cropping season was the best season when the better thousand kernels weight was obtained and in 2020 at Lemu-Bilbilo location (Table 3).

Economic analysis

According to the economic analysis, the highest net benefit (69435 and 61106 Birr/ha) and MRR (4527 and 888%) were recorded from Wane and Daka varieties treated with the N rate of 69 kg ha^{-1} at Tiyo and the highest net benefit (61179 and 60552 Birr/ha) and MRR (1976 and 1840 %) were recorded from Wane and Daka at the N rate of 92 and 69 kg ha^{-1}, respectively at Lemu-Bilbilo; whereas the net benefit of (7628 and 74646 Birr/ha) and MRR (304 and 1187 %) were recorded from Honqolo and Daka varieties treated with the N rate of 69 kg ha^{-1} at Hasasa district (Figure 9, 10 & 11). Therefore, based on grain yield and studied traits, net benefit and MRR, production of Wane and Daka with N rate of 69 kg ha^{-1} at Tiyo, Daka and Wane with N rate of 69 and 92 kg ha^{-1} at Lemu-Bilbilo plus Honqolo and Daka varieties with 69 kg N ha^{-1} at Hasasa could be economically feasible technologies.

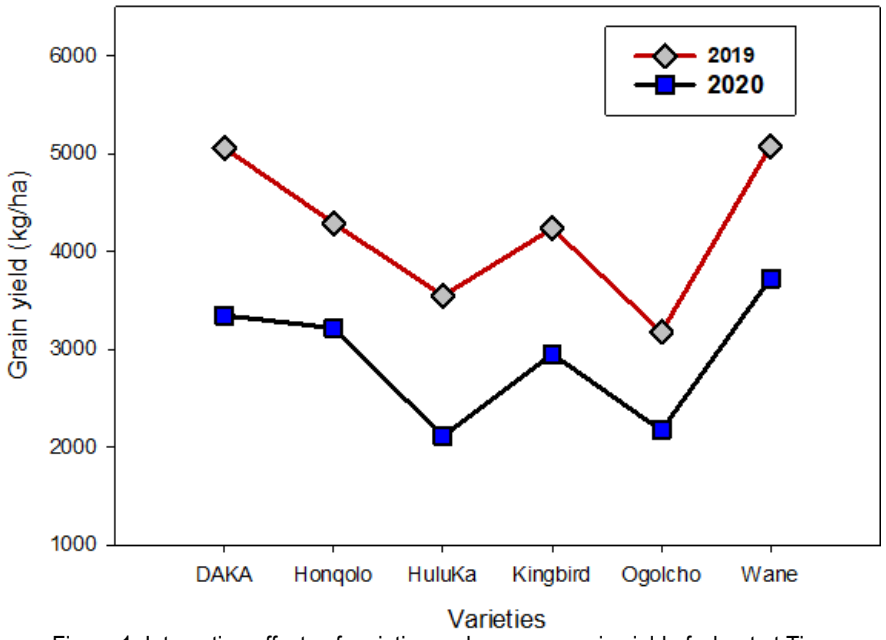

Figure 1: Interaction effects of varieties and years on grain yield of wheat at Tiyo.

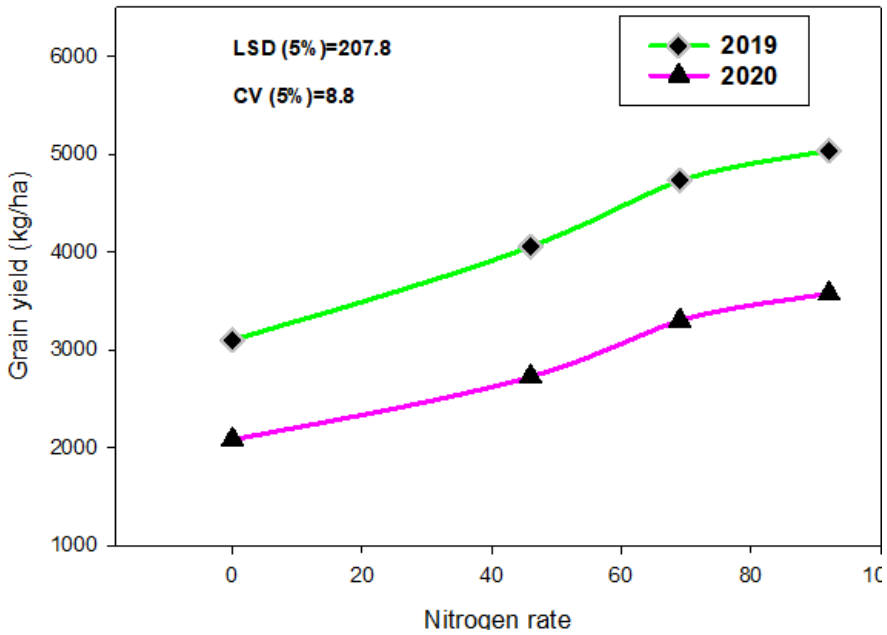

Figure 2: Interaction effects of nitrogen rate and years on grain yield of bread wheat at Tiyo

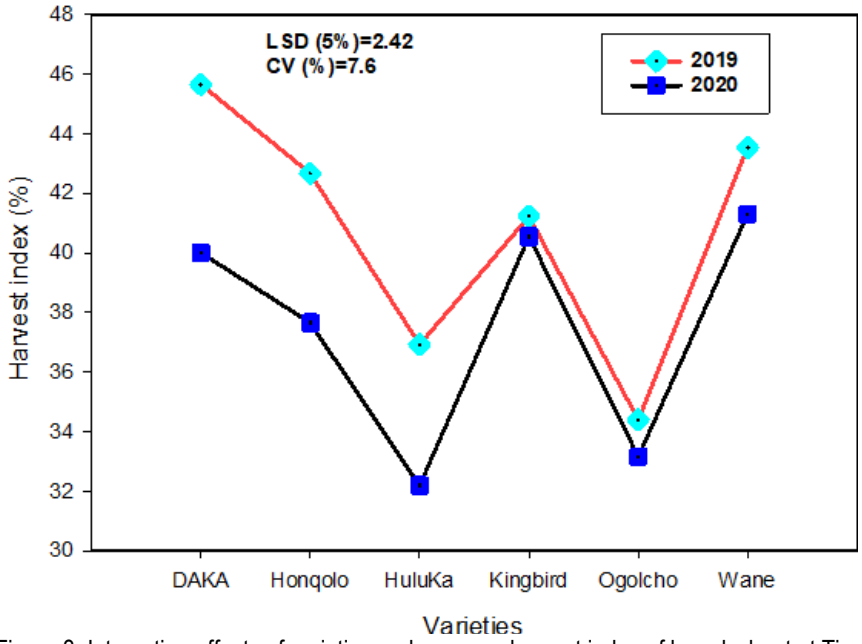

Figure 3: Interaction effects of varieties and years on harvest index of bread wheat at Tiyo.

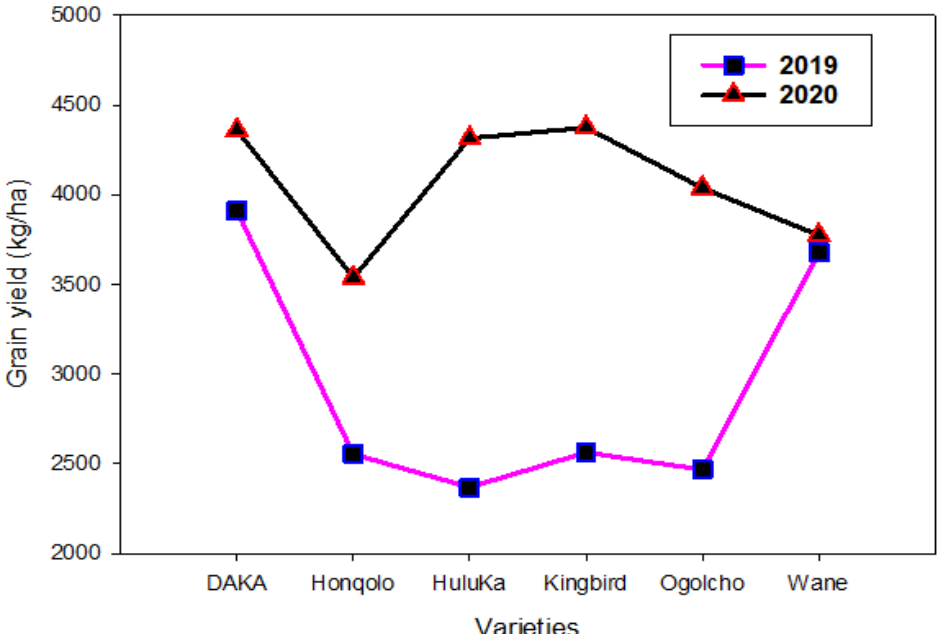

Figure 4: Interaction effects of varieties and years on grain yield of wheat at Lemu-Bilbilo.

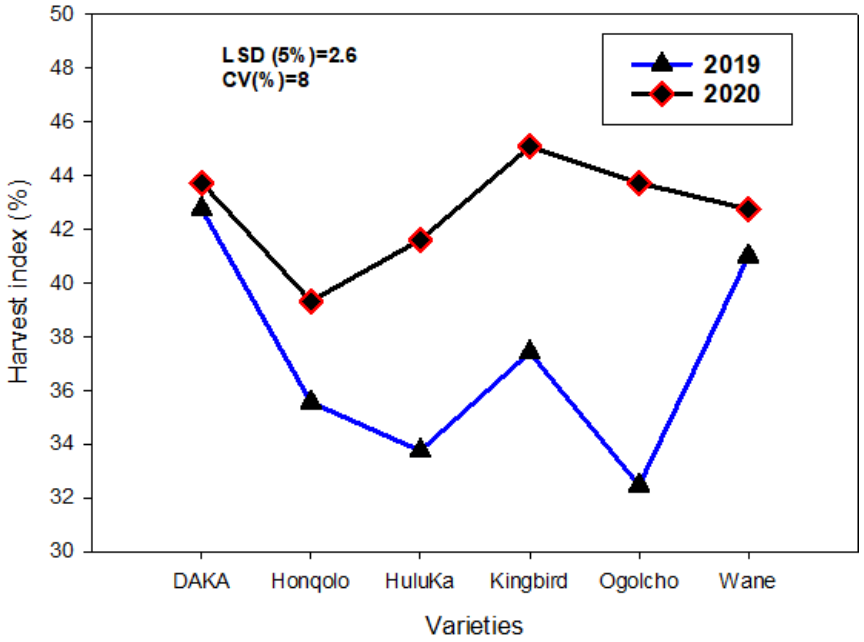

Figure 5: Interaction effects of varieties and years on harvest index of wheat at Lemu-Bilbilo.

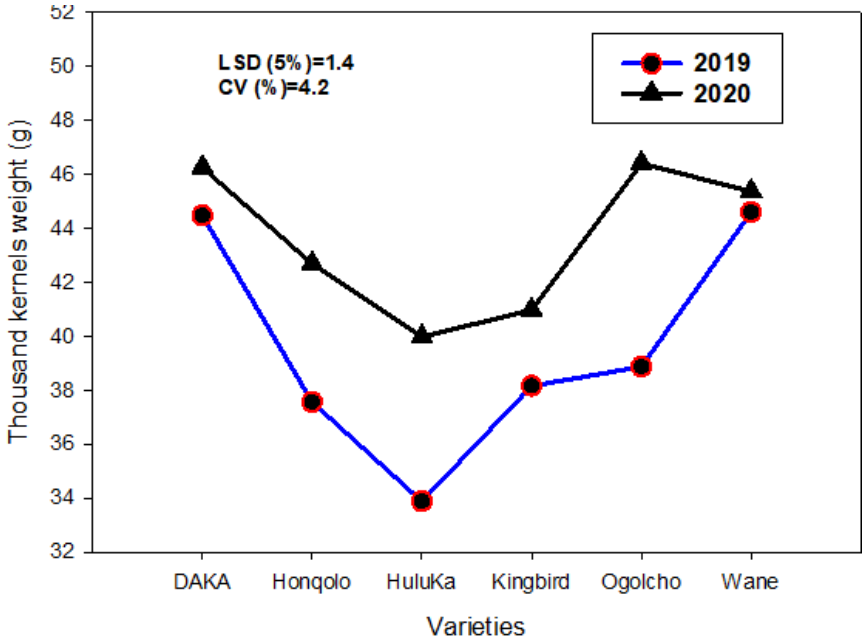

Figure 6: Interaction effects of varieties and years on thousand kernels weight of wheat at Lemu-Bilbilo.

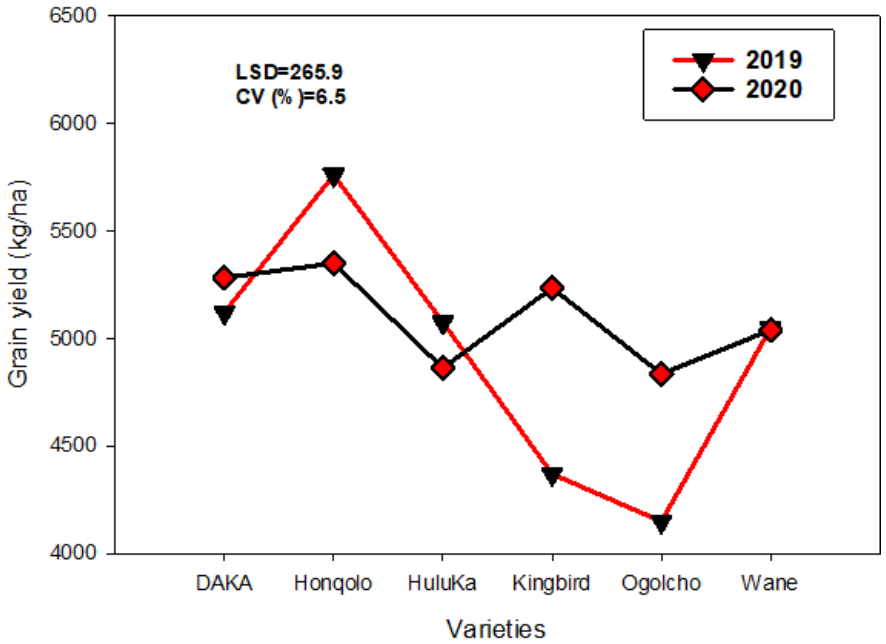

Figure 7: Interaction effects of varieties and years on grain yield of wheat at Hasasa.

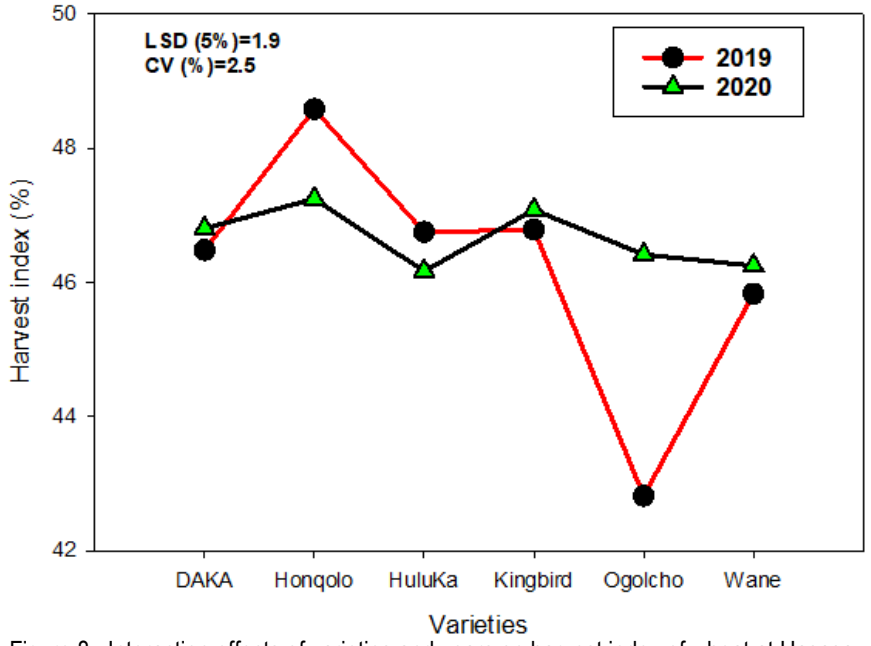

Figure 8: Interaction effects of varieties and years on harvest index of wheat at Hasasa.

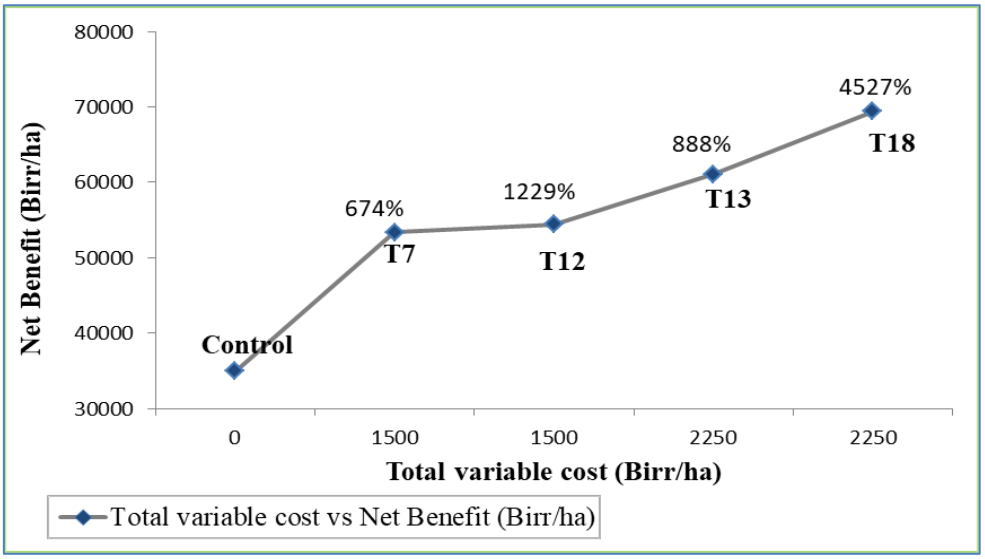

Figure 9: Partial budget analysis of bread wheat as affected by interaction effect of varieties and nitrogen fertilizer rate combined over two years at Tiyo district

T7= Daka at 46 N kg/ha, T12= Wane at 46 N kg/ha, T13= Daka at 69 N kg/ha, T18= Wane at 69 N kg/ha

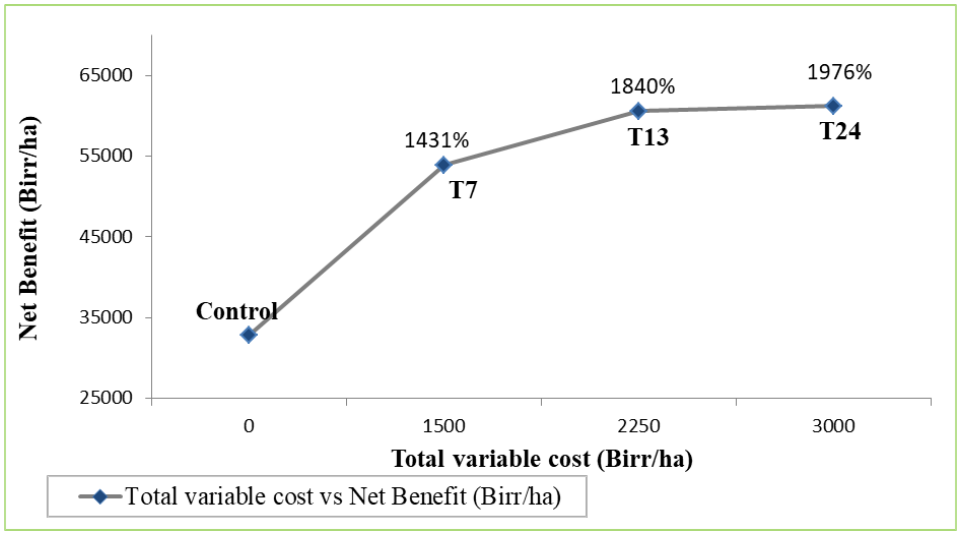

Figure 10: Partial budget analysis of bread wheat as affected by interaction effect of varieties and nitrogen fertilizer rate combined over two years at Lemu Bilbilo district

T7= Daka at 46 N kg/ha, T13= Daka at 69 N kg/ha, T24= Wane at 92 N kg/ha

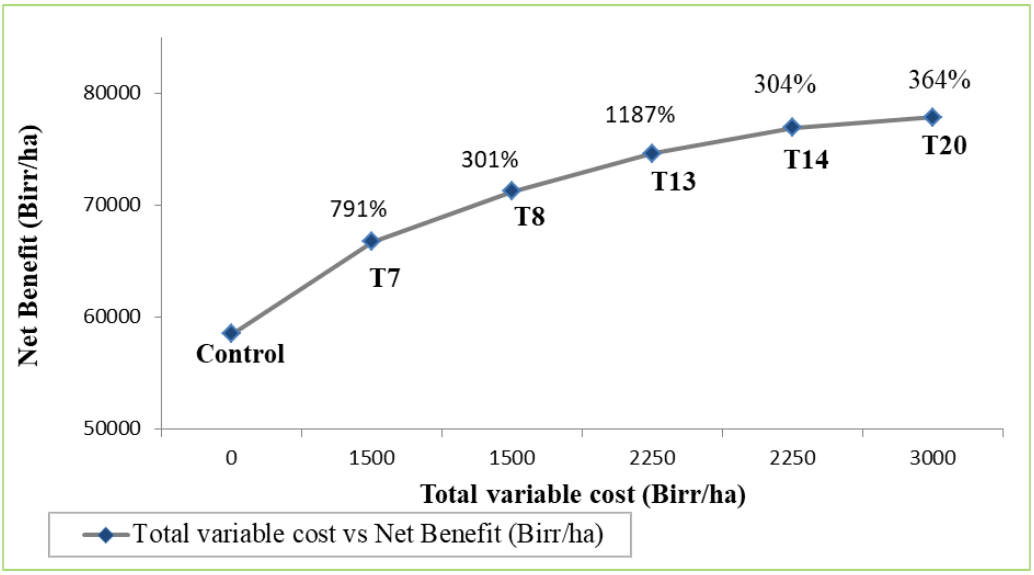

Figure 11: Partial budget analysis of bread wheat as affected by interaction effect of varieties and nitrogen fertilizer rate combined over two years at Hasasa district
T7= Daka at 46 N kg/ha, T8= Honqolo at 46 N kg/ha, T13= Daka at 69 N kg/ha, T14= Honqolo at 69 N kg/ha, T20= Honqolo at 92 N kg/ha

Conclusion and Recommendation

The two-year results revealed that among agronomic parameters considered, grain yield and above ground biological yield were significantly influenced by the interaction impacts of varieties versus N fertilizer rate at all study areas whereas the interaction impacts of varieties and years affected all the studied agronomic parameters in all three study sites. The maximum grain yields (5055, 5990 and 4754 kg ha^{-1}) were gained from Daka, Honqolo and Wane varieties with the application of 92 kg ha^{-1}, respectively at Tiyo, Hasasa and Lemu-Bilbilo experimental areas. However, the yield difference among Daka variety versus Hanqolo and Wane varieties at Tiyo, between Wane, Daka, Huluqa and Kingbird at Lemu-Bilbilo as well as among Honqolo, Daka and Wane at Hasasa showed non-significant at 69 and 92 kg N ha^{-1}. Above ground biological yield was significantly increased for all varieties with increasing N rate at Tiyo and Hasasa experimental locations. The current findings also revealed that varieties were more vulnerable to cropping seasons than N fertilizer rate. Generally, based on grain yield and studied parameters, net benefit and economic feasibility**;** Wane and Daka varieties with 69 kg N ha^{-1} at Tiyo, Daka and Wane with N rate of 69 and 92 kg ha^{-1} at Lemu-Bilbilo as well as Honqolo and Daka varieties with 69 kg N ha^{-1} at Hasasa were economically viable for the production of bread wheat.

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Plant Densities and Fertilizer Rates on Yield and Yield Components of High-Land Maize

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Abstract

Plant density and the application of nutrients in the soil are the leading factors affecting maize production. A field experiment was conducted from the 2019 to 2020 main cropping seasons at Holeta, in the Welmera wereda of West Shoa, central Ethiopia, to determine optimum planting density and fertilizer rates for maize production. Four different population densities (44,444, 53,333, 62,500, and 66,666 plants/hectare) and four fertilizer rates (150:200,150:250, 200:200 and 250:200 NPS and urea, respectively). Plant population and fertilizer rates were arranged factorially in the RCBD with three replications. The interaction effect of population density and fertilizer rates was not significant for any of the parameters measured. The main effect of population density significantly ($P < 0.05$) affected plant height, ear height, cob diameter, and grain yield, but not significantly affected cob length, number of cobs per plant, or thousand seed weight. The main effect of fertilizer rates significantly ($P < 0.05$) affected plant height and grain yield. As population density increased, maize grain yield also increased, and the highest grain yield (8894 kg/ha) was attained by the highest population density (66,666 plants/ha). The partial economic analysis indicated that the highest net benefit was obtained at the highest population density (66,666 plants/ha) and fertilizer rate of 250 NPS and 200 urea kg/ha.

Keywords: Highland maize, population density, fertilizer rate, yield, net benefit

Introduction

Maize (Zea mays L.) is one of the most important cereal grain crops used as the human diet, livestock feed, and raw material for various industries in large parts of the world (Khan *et al*., 2008). Maize is the second most widely cultivated crop in Ethiopia and is grown under diverse agro-ecologies and socioeconomic conditions, typically under rain-fed conditions (Abate *et al*., 2015). Maize is one of the top priority food crops selected to achieve food security, particularly in the major maize-producing regions in the western, northwestern, and southern parts of Ethiopia. It is used in household diets in different forms. Bread, muffins, boiled grain, enjera, local beer (tela), green cob, and porridge are the most common prepared forms for direct use (Golla, 2018).

Many factors, like declining soil fertility, poor agronomic practices, limited use of agricultural inputs, insufficient technology generation, and poor seed quality,

affect Ethiopian maize productivity (CIMMYT, 2004). There is a great possibility to enhance maize productivity through increasing planting density with an increasing N fertilizer rate (Vega *et al*., 2001). Nowadays, Ethiopian maize producers require more information about what combination of N-fertilizer level and plant density precisely increases maize yield. w The government is promoting intensive crop production, including maize, so as to enhance grain production in the country. Maize is commonly planted in rows of varying spaces to plant at optimum densities to maximize its productivity in different agro-ecologies of Ethiopia. Summaries of earlier results confirmed that at 5-7 plants/m2, medium to late maize maturity groups gave maximum yields in humid regions, while early maturity groups produced maximum yields at higher densities in both humid and moisture-stress areas (Tenaw *et al*., 2002). Maize is a popular C4 cereal crop, and plant population density has a significant impact on the growth and yield of the crop (Cox, 1996). Therefore, understanding how plants regulate their growth in response to plant population densities has profound importance, such as determining optimal planting density (Cox, 1996). Increased plant populations could lead to increased yields under optimal climatic and management conditions due to the greater number of smaller cobs per unit area (Bavec and Bavec, 2002). Plant population is the prime factor for getting maximum yield, which is decided by the inter- and intra-row spacing of crops. Decreasing the distance between neighboring rows in any particular plant population has several potential advantages, such as reducing competition among plants within rows for light, water, and nutrients due to a more equidistant plant arrangement (Olson and Sander, 1988). The more favorable planting pattern provided by closer rows enhances maize growth rate early in the season (Bullock *et al*., 1988), leading to better interception of sunlight and a higher radiation use efficiency, consequently resulting in a greater grain yield (Westgate *et al*., 1997). The current research was designed with the objectives of determining the appropriate population density and fertilizer rate to attain optimum yield by evaluating the interaction effect of population density and fertilizer rates on yield and yield components of high-land maize.

Materials and Methods

The experiment was conducted in the 2019 and 2020 main cropping seasons at Holeta, Welmera wereda, West Shoa zone, in central Ethiopia. The environment is seasonally humid, and the soil type is reddish-brown Eutric Nitisol (IUSS Working Group WRB, 2006). Holeta is located at 09° 03′ N latitude and 38° 30′ E longitude, at an altitude of about 2400 m above sea level. The long-term average annual rainfall is 1100 mm, about 85% of which is received from June to September, with the remaining rain received from January to May. The average minimum and maximum air temperatures are 6.2°C and 22.1°C, respectively. A factorial combination of four different population levels (44,444, 53,333, 62,500, and 66,666 plants/hectare) and four fertilizer rates (150:200,150:250, 200:200 and

250:200 NPS: urea kg/ha) was laid out in RCBD with three replications. Currently, a fertilizer rate of 100 kg NPS and 200 kg urea/ha with a population density of 53,333 plants/ha is used for maize production in the study area. The Highland maize variety 'Jibat' was used for the experiment.

Statistical analysis

The effect of treatments on various crop parameters was statistically analyzed using two-way analysis of variance (ANOVA) with Statistical Analysis System (SAS) software (SAS Institute, 2004). When the ANOVA showed significant differences among treatments for each parameter, the least significant difference (LSD) test at the 5% probability level was applied for means separation. A combined analysis of the data was made after evaluating the error variances as homogeneous using Bartlett's test, and the pooled residual error that is averaged over sites was used for the combined ANOVA (Gomez and Gomez, 1984).

Partial economic analysis

A partial economic analysis was conducted using a procedure provided by CIMMYT (1988). Total variable costs were estimated by considering the current prices of NPS and urea in 2020 at 1.62 Birr/ha each, the maize seed cost at 57 Birr/kg, and the grain at 12.5 Birr per kg.

Results and Discussion

According to the analysis result of the two-year data, the year effect did not significantly affect all the parameters tested except ear height and the number of cobs per plant. The main effect of population density significantly affected plant height, ear height, cob diameter, and grain yield. The highest grain yield was recorded at the highest population density (66,666 plants/ha) using a fertilizer rate of 250 NPS:200 urea kg/ha. However, the interaction of the main effects was non-significant for any of the tested parameters (Table 1).

Effects of planting density and fertilizer rates on maize growth parameters

Plant Height: Plant height was significantly ($P<0.01$) influenced by the main effects of planting densities and fertilizer rates (Table 1). The mean average plant height ranged from 222 to 237 cm (Table 1). Maize plant height increased significantly with the increase in planting density as well as fertilizer rates. The tallest plant height (i.e., 237 cm and 235 cm) was recorded at the highest plant density (66,666 plants/ha) and highest fertilizer rate (250 NPS and 200 urea kg/ha), whereas the shortest plant height was recorded at the lowest planting density and lowest fertilizer rate. These results agree with Rafiq *et al*. (2010), who reported that plant height increased significantly with plant density in hybrid

maize. Similarly, these results confirmed the findings of Sherifi *et al*. (2009) in hybrid maize.

Ear height: Ear height was significantly (P<0.01) affected by the main effects of planting densities (Table 1). It increased significantly with the increase in plant planting density. The mean average ear height ranged from 114 to 122 cm (Table 1). However, neither the main effect of fertilizer rates nor the interaction effect of the two factors influenced maize ear height. The main effect of planting density showed that ear height was more responsive to the change in planting density than fertilizer rates. The tallest ear height (125 cm) was recorded at the highest plant density (66,666 plants/ha), whereas the shortest ear height was recorded at the lowest planting density and lowest fertilizer rate. The current result agreed with Zeleke *et al*. (2018), who showed that ear height was more responsive to changes in planting density than fertilizer levels.

Cob length and diameter: cob length was neither affected by the main effects of planting densities nor fertilizer rates (Table 1). Only the main effect of population density significantly affected cob diameter, and generally, cob diameter decreased as population density increased.

Table 1. Main effects of population density and fertilizer rates on maize yield and yield components at Holeta during the main cropping seasons of 2019 and 2020.

Treatments	Plant height (cm)	Ear height (cm)	Cob length (cm)	Cob diameter (cm)	Number of cobs per plant	TSW (gm)	Grain yield (kg/ha)
Year							
2019	231.3	126.46a	16.45	13.94a	1.85a	347.21	7669.4
2020	228.3	113.16b	16.37	13.01b	1.21b	332.75	7633.7
Population density (No. plants/ha)							
44,444	224.90c	114.33c	16.22	13.63a	1.60	343.16	6617.3d
53,333	227.39bc	119.97b	16.8	13.7a	1.56	343.73	7034.0c
62,666	230.29b	119.97b	16.31	13.3b	1.46	347.71	8060.6b
66,666	236.76a	125.45a	16.3	13.29b	1.5	325.33	8894.2a
Fertilizer Rates (NPS: Urea kg/ha)							
150:200	222.42c	116.35	16.32	13.32	1.47	334.6	6717.1c
150:250	229.51b	119.29	16.61	13.63	1.51	340.88	7913.0ab
200:200	232.41ab	121.45	16.15	13.45	1.57	332.83	7748.9b
250:200	235.0a	122.16	16.56	13.5	1.56	351.62	8227.1a
CV (%)	**3.92**	**6.87**	**7.69**	**4.33**	**12.34**	**12.33**	**8.58**

Effects of planting density and fertilizer rates on maize yield and yield related parameters

Number of cobs per plant: The number of cobs per maize plant was not significantly affected by the main effects of population density and fertilizer rate (Table 1). Even if the difference was not significant, the trend of the data showed that the number of cobs per plant decreases as population density increases, but the number of cobs per plant increases as fertilizer rate increases.

Thousand seed weight: Neither the main effects of population density and fertilizer rate nor their interaction effects significantly alter maize thousand seed weight (Table 1). But even if the mean thousand seed weight difference was not significant, maize seed weight increased as fertilizer rate increased. But it decreased as the population density increased, and the lowest seed weight was recorded at the highest population density (Table 1). A similar report by Allessi and Power (2004) found that maize cob weight decreased with increased plant population.

Grain yield: Maize grain yield was significantly ($P<0.01$) influenced by the main effects of planting densities and fertilizer rates (Table 1). The mean average grain yield ranged from 6617 to 8894 kg/ha (Table 1). Maize grain yield increased significantly with increasing plant planting density and fertilizer rates. The highest grain yield (8894 kg/ha and 8227 kg/ha) was recorded from the highest plant density (66,666 plants/ha) and highest fertilizer rate (250 kg/ha NPS and 200 kg/ha urea). But the lowest grain yield was recorded with the lowest planting density and lowest fertilizer rate (Table 1). The increased maize grain yield under high plant density might be due to efficient utilization of available resources like nutrients, water, air, and solar radiation. These results conform to those of Bozorgi *et al*. (2011), who reported that the maximum maize grain yield was obtained from the combination of the highest planting density with the highest N fertilizer levels. According to Gözübenli (2010), maize hybrids can be grown up to 76,500 plants per hectare with no adverse effect on yield or grain quality. Muhidin (2019) also reported that maize grain yield increased with plant density, and the highest grain yield was recorded at the highest population density, which is 90,909 plants/ha.

Partial economic analysis

Based on the result of statistical data analysis, the interaction effect of the two main factors (population density and fertilizer rates) was not significant, and as a result, partial economic analysis was done separately for population density and fertilizer rates, as indicated in Table 2.

Table 2. Partial Economic Analysis for fertilizer rate and Plant density Holeta

Treatments	Adjusted GY (kg/ha)	TVC (Birr/ha)	Gross profit (Birr/ha)	Net benefit (Birr/ha)
Population density (No. plants/ha)				
44,444	6286.40	8856.14	78580.00	69723.85
53,333	6682.30	11027.14	83528.00	72500.85
62,666	7657.50	15203.84	95718.75	80514.90
66,666	8449.40	13282.50	105617.50	92335.00
Fertilizer Rates (NPS: Urea kg/ha)				
150:200	6381.20	5627.65	79765.00	74137.36
150:250	7517.35	6430.73	93966.87	87536.14
200:200	7361.45	6432.76	92018.12	85585.35
250:200	7815.74	7237.86	97696.75	90458.80

According to the partial economic analysis, out of the tested planting densities, a population density of 66,666 plants/ha yielded the highest net benefit, with fertilizer rates of 250 NPS and 200 urea/ha.

Conclusions and Recommendation

This research trial was designed to identify the optimum population density and fertilizer rates to get the highest maize grain yield in the study area. As the population density increased, maize grain yield also increased, and the highest grain yield (8894 kg/ha) was attained at the highest population density (66,666 plants/ha). This means that a population density of more than 66,666 plants /ha may be needed because the grain yield is still increasing. Regarding the fertilizer rates tested, the combined fertilizer rates of 250 NPS and 200 urea kg/ha showed the highest grain yield of 8227 kg/ha followed by 150 NPS and 250 urea kg/ha with a recorded grain yield of 7913 kg/ha. Besides the agronomic productivity, the partial economic analysis of the two-year data affirmed that a plant population density of 66,666 plants/ha and a fertilizer rate of 250 NPS and 200 urea kg/ha resulted in the highest grain yield and the highest net benefit.

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Screening Common Bean Varieties Compatibility to Intercropping with Maize in Different Agro-Ecologies

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Abstract

Maize is among the most important cereal crops in Ethiopia. Intercropping results in high overall system productivity on a given piece of land due to efficient use of the available plant growth resources. Field experiment was conducted to evaluate and select the cropping systems and best performing common bean varieties in intercropping with maize at different agro ecologies for higher productivity and profitability in southern parts of Ethiopia, at Wondo genet Agricultural Research Center at Sankura wereda, Jejebicho research station in 2019/20 cropping season. Three varieties of common bean (Deme, KAT-B1 and Awash-2) were intercropped with two maize varieties (Limu and Shone). The three common bean varieties and two maize varieties were included as a sole for comparison. Randomized complete block design in factorial arrangement with three replications was used. Aboveground biomass, days to tasseling, hundred kernel weight, grain yield and harvest index of maize were significantly affected by varieties of common bean, cropping system also significantly affected leaf area, leaf index, days to tasseling, days to physiological maturity and grain yield of maize but their interaction effect were non significantly affected. Days to tasseling of maize were delayed (81.50 days) and hastened (74.23 days) by variety Awash-2 and Deme, respectively as compared to KAT-B1. The wider leaf area (910.20cm2) was measured from intercropped maize than sole and the larger leaf area index (3.79) was also recorded from intercropped maize than sole one. Days to tasseling of maize were delayed (80.80 days) at sole cropped of maize. The longer days to physiological maturity (143.84 days) of maize was taken from sole cropping of maize. The highest grain yield (7.60 ton/ha) of maize was taken from Shone intercropped with Awash-2 as compared to other varieties. The longest plant (132.13cm) was measured from Deme intercropped with Limu. The highest (5.17) number of branches was counted at Deme intercropped with Limu. The highest number of pods per plant and number of seed per pod (10.92 and 4.63) was counted at Deme intercropped with Limu and Limu with Awash-2, respectively. The highest grain yield (22.38 ton/ha) was obtained when Shone intercropped with Deme. The highest partial land equivalent ratio (LER) of maize and common bean non significantly affected by varieties of both. Monitory advantage index was also non significantly affected. However, the highest value of monetary advantage index (105,359 ETB ha-1) was obtained at Shone intercropped with Deme. Therefore, any of the two (Limu or Shone) maize varieties could be recommended for intercropping with Deme of common bean variety.

Keywords: Common bean, cropping system, Deme, Grain yield, Limu and Shone.

Introduction

Intercropping is defined as the growing of more than one crop species more or less simultaneously in the same field during a growing season. Maize (*Zea mays*) is an important crop for feeding the increasing population of Ethiopia (Worku *et al*., 2002). It is one of the most prominent cultivation systems of smallholder farmers due to shortage of land, with individually owned pieces of land rarely exceeding 1.5 hectare (Lunze *et al.*,2012), and the practice ensures avoidance of risks associated with complete crop failure (Giller, 2001). Production of common bean is highest in the densely populated highlands of Eastern and Central Africa (Wortmann *et al.,* 1998). For example, on the area basis, common bean is partly sown as sole crop (22%) and in intercrops with maize (43%), bananas (15%), root and tuber crops (13%), and other crops (7%) (Wortmann *et al.,* 1998). The return from component crops when cultivated in an association is compared with the more valuable of the sole crops as the practice may result in yield reduction (Willey, 1979; Santalla *et al.,* 2001; Lithourgidis *et al.,* 2011; Bedoussac *et al.,* 2015; Kermah *et al.,* 2018) .

Maize (*Zea mays* L.) and common bean (*Phaseolus vulgaris* L.) are important food and cash crops cultivated for subsistence on smallholder farms in many parts of the world, including Sub-Saharan Africa (Baijukya *et al.,* 2016; Rurangwa *et al.,* 2018). It is originated in Central America and was introduced to Ethiopia during the 1600s to 1700s (Haffangel, 1961). In Ethiopia maize is one of the most important cereal crops grown in the country. It covers the total area of cereal crop production area in 2018/19 took 18.5% with the production of 9.5 million tons (CSA, 2018/19). In Ethiopia, maize ranks second in total production (30.3%) after Ethiopian teff from cereal crops (CSA, 2019). Its national mean yield is about 4 ton/ha (CSA, 2019). In 2018/19 Ethiopian *Meher* (rain fed) cropping season maize production was estimated with an area of 2,367,797.39 hectare and a total production of 9,492,770.834 tons (CSA, 2019). The *Meher* season production was estimated to be higher than the off season.

Common bean ranks third the most important food grain legume after soybean and peanut worldwide with nutritional and economic value to human and feed to livestock (Maingi *et al.,* 2001). Common bean also improves soil fertility through fixation of atmospheric N_2 in symbiosis with rhizobia (Manrique *et al.,* 1993; Tsai *et al.,* 1993; Bedoussac *et al.,* 2015; Latati *et al.,* 2016). It is thought that intercropping with maize and common bean would present an alternative to monoculture of maize and common bean as part of sustainable systems intensification on smallholder farms (Lunze *et al.,* 2007; Kermah *et al.,* 2018).
Intercropping results in high overall system productivity on a given piece of land due to efficient use of the available plant growth resources (Pretty and Bharucha, 2014; Brooker *et al.,* 2015). The overall productivity of intercrops is attributed to

the differences in acquisition and utilization of growth resources such as nutrients, moisture, and light interception (Giller, 2001; Yu *et al.,* 2016). The component crops also exhibit various mechanisms in resource acquisitions and utilizations such as complementarities, facilitation, and resource sharing (Dhima *et al.,* 2007; Bedoussac *et al.,* 2015; Brooker *et al.,* 2015; Kermah *et al.,* 2018). Most studies on intercrops have been run over a short period making it difficult to realize the long-term effect of the practice on crop productivity and sustainable soil fertility management from a legume crop (Ofori and Stern, 1987; Jensen, 1996). The mechanisms associated with increase in yield due to enhanced nitrogen nutrition of the cereal crop sown in association with a grain legume are widely reported (Danso *et al.,* 1993; Connolly *et al.,* 2001; Giller, 2001). The options for intensification of intercrops are manifold: substituting the improved to the local varieties of grain legumes, timing of introducing early and late-maturing crops, modification of the spacing between rows of the two crops and that of the same crop within rows and choosing compatible crops (Chu *et al.,* 2004; Prasad and Brook, 2005). According to Hillocks *et al.* (2006) intercropping of non-climbing bean varieties with maize enables more productive for maize.

The most common advantage of intercropping is the production of greater yield on a given piece of land by making more efficient use of the available growth resources using a mixture of crops of different rooting ability, canopy structure, height and nutrient requirements based on the complementary utilization of growth resources by the component crops (Lithourgidis *et al.,* 2011). Legume-cereal intercropping especially maize-bean intercropping is a common throughout developing world and can be the ideal ones for sustainable production and food security to resource poor farmers (Abera *et al.,* 2005). Many researchers have stressed the need of identification of suitable genotypes in intercropping that best cultivar for mono cropping might not be most suitable for mixed cropping due to change in micro climate within crop mixture (Muoneke *et al.,* 2012). The choice of compatible species and time of their establishment, therefore, seems relevant management options in improving the efficiency of this system. Aiming to maximize the yields of intercrop components through minimizing competition effects, selection of compatible genotypes and timing of intercropping, based on growth characteristics and requirements of the component species in question, are key agronomic issues in intercropping (Banik *et al.,* 2000). Therefore, varietal selection, understanding the physiology of the species to be grown together, their growth habits, canopy and root architecture, and water and nutrient use are important factors to be considered in intercropping (Vandermeer, 1989; Abera *et al.,* 2005). Similarly, complementarities in an intercropping situation can occur when the growth patterns of the component crops differ in time or when they make better use of resources in space. These factors affect the interaction between the component crops of intercropping and so affect their use of environmental resources and, as a result, the success of intercropping compared with sole cropping systems. However, farmers in Southern Ethiopia intercrop maize and

common bean without consideration of the compatibility of the component crops. The recently released common bean varieties are very productive but needs research to know the compatibility between common bean and maize varieties. There is need of information on appropriate variety of common bean for intercropping with maize for the recently released common bean varieties were developed under sole cropping. Intercropping did not give the best returns in terms of yield or cash if farmers do not necessarily select the most compatible varieties for intercropping. Therefore, the objectives of this study were to evaluate and select the cropping systems and best performing common bean varieties in intercropping with maize at different agro-ecologies for higher productivity and profitability.

Materials and Methods

The experiment was conducted at Sankura wereda Jejebicho research station of Wondo Genet Agricultural Research Center in Silte zone of South nation nationalities and people's regional state tested.

Description of the Experimental Materials

Improved maize varieties (Shone and Limu) were used as main crops and adapted to an altitude of 1000m to 1800m above sea level and matures at 144 days. The three common beans varieties namely Awash-2, KAT-B1 and Deme were used. The common bean varieties have different maturity date and potential yield and their seeds varying in its colour.

Treatments and Experimental Design

The experiment consisted of two factors, namely three common bean and two maize varieties. By combining these two factors we were having a total of eleven treatments including sole cropped of each. The intercropping was practiced as additive series between the two maize rows planted at the same time. Uniform populations of 44,444 plants ha^{-1} were maintained for maize in both intercropping and sole-cropped. The experiment was arranged in Randomized complete Block design with three replications in factorial arrangement of three common bean and two maize varieties totalling six intercropping treatments and there were five additional treatments (sole of two maize and sole of three common bean varieties) totalling eleven treatments. The spacing for sole and intercropped maize was 75cm x 30cm. The gross plot size was 15.75m2 (3.9m x 4.5m) and the net plot area was 6.75m^2 (3.6m x 3.75m). Each intercrop maize plot consisted of six rows of maize and ten rows of common bean. The spacing of sole common bean was 40cm x 10cm between rows plants, respectively and the gross plot size 10.4m^2(2.6m x 4m) and the net plot area was 9m^2 (2.5m x3.6m). Common bean was intercropped between two maize rows at 37.5cm away from maize row with

inter row and 10cm intra-row spacing. The data was taken from the central rows of common bean and harvested.

Experimental Procedures

The experimental field was ploughed and harrowed by a tractor to get a fine seedbed and leveled manually before the field layout was made. Maize was planted on April 28, 2019 and common bean varieties were planted on June 13, 2019. Two seeds per hill of both maize and common bean were planted and thinned to one plant per hill one week after emergence. At planting full dose of NPS at the rate of 150 kg ha^{-1} was applied uniformly into all plots. Half of N in the form of urea (46%N) at the rate of 250kgha^{-1} was applied into sole maize and maize/common bean intercropped plots at the time of planting and the remaining half N was applied at knee height growth stage of maize. Urea (N) was applied in to sole common bean by the rate of 50kg ha^{-1}. Hand hoeing and weeding were done as required. Both maize and common bean were harvested from the net plot after they attained their normal physiological maturity, i.e., when 75% of plants in a plot.

Data collection

Maize Data Collection:

Growth and Phenology data of maize

Phenological data: days to tasseling, days to physiological maturity of maize were recorded from the selected plants based on plot based.

Growth Parameters Leaf area (cm^2):- was determined from the same five plants used for plant height per plot randomly as leaf length (L) x maximum leaf width (W) x 0.733 as described by McKee (1964).

Leaf area index (cm2): - LAI were calculated as the ratio of total leaf area (cm^2) of the plant to the ground area coverage of maize.

Yield and Yield Components included aboveground biomass: were measured from five randomly sampled plants per plot at the end of harvest in each plot.

Hundred kernels weight (g): was measured from the collected data of the five selected plants at the end of harvest in each plot.

Grain Yield (kg/ha): Grain yield were measured from the net plot area and expressed as ton/ha. Grain yield was adjusted to 12.5% moisture content using a digital moisture tester.

Data of Common Bean varieties

Data on physiological maturity: - were recorded from five randomly taken plants as the number of days from emergence to the date on which physiologically matured of the plants in a plot matured.

Growth Parameters

Plant height (cm): Plant height was recorded as the height of plant grown from the ground level from five randomly sampled plants at the end of 50% flowering in each plot. Branch number: was also counted from the individual plants.

Yield and Yield Components

Number of pods per plant: - Number of pods was counted from the same ten randomly selected plants at the end of harvest in each plot. Number of seeds per pod: - Was taken from the same ten randomly selected pods at the end of harvest and each of seeds were counted manually in each plot. Above ground biomass, Harvest index (HI) and 100 kernel weights were recorded.

Grain Yield (ton/ha): Common bean yields were measured from the net plot area and expressed as kg/ha. Bean yield was adjusted to 12% moisture using a digital moisture tester.

System productivity

Land equivalent ratio (LER)

Partial land equivalent ratio: is the ration of intercropped and sole cropped yield of the individual crop. For instance, the partial land equivalent ratio of maize was calculated as,

Partial LER of maize =; where YMi= intercropped yield of maize and YMs = grain yield of sole cropped maize. Similar to maize the partial land equivalent ratio of common bean was also calculated as; partial land equivalent ratio of common bean= where YCi = intercropped yield of common bean and YMs = sole cropped of common bean. The LER was calculated using the formula LER= Σ (Ypi/Ymi) (where Ypi is the yield of each crop in the intercrop, and Yms is the yield of each crop in the sole crop. So, in this study the LER was calculated as, LER =YMi+ YCi YMs, YCs (from the sole crop the actual yield was used from the three varieties)

Where,

YMi = Yield per unit area of maize intercrop (net plot area of intercropped maize)
YMs = Yield per unit area of Maize sole (net plot area of sole maize)
YCi = Yield per unit area of common bean in intercropping (net plot area of intercropped common bean)

YCs = Yield per unit area of common bean sole (net plot area of sole C)

Monetary Advantage Index (MAI)

First the Gross monetary value (GMV) was calculated as; Yield of component crops × respective market price; i.e., (yield of maize x price of maize + yield of common bean x price of common bean) (Willey (1979). In order to access the economic advantage of intercropping as compared to sole cropping of maize and common bean varieties, the gross monetary value (GMV) and the Monetary Advantage index (MAI) were calculated from the yield of maize and common (kg ha^{-1}). Gross monetary value and monetary advantages were calculated to measure the productivity and profitability of the intercropping as compared to sole cropping of the component crops.

Monetary Advantage Index (MAI): The most important part of recommending a cropping pattern was the cost: benefit ratio more specifically total profit, because farmers are mostly interested in the monetary value of return. The yield of all the crops in different intercropping systems and also in sole cropping system and their economic return in terms of monetary value were evaluated to find out whether maize grain yield and additional common bean grain yield were profitable or not. This is calculated with monetary advantage index (MAI) which indicates more profitability of the cropping system with the higher the index value (Mahapatra, 2011).

It was expressed as MAI= (Pab+Pba) *(LER-1)/LER Where, Pab = Pa ×Yab; Pba =Pb ×Yba; Pa = Price of maize and Pb = Price of common. In this research we used the price of common and maize was 12.5 and 11 Ethiopian birr per kilo gram of grain yield, respectively. We have taken the current the average price of common bean varieties from local market, the price of maize was also just taken from the local grain market of Shashemene. The price of both common bean and maize was fluctuated and seasonal but we used the average of maximum and minimum price of maize and common bean grain (ETB 12 kg^{-1}) at the time of harvet collection from Shashemene local market.

Statistical Data Analysis

All data were subjected to the analysis of variance (ANOVA) appropriate to the randomized complete block design using SAS (Version, 9.4). Least significant difference (LSD) test at 5% level of probability was also used for mean separation as procedure described by Gomez and Gomez, (1984).

Results and Discussion

The analysis of variances showed that days to tasseling of maize showed highly significance difference due to the varieties of common bean (Appendix Table 1). The longest (81.50) day of tasseling was taken when Limu intercropped with

Awash-2 and shortest day of tasseling was taken due to Limu intercropped with KAT-B1.

This may due to inter-specific competition between Limu and Awash-2 was low as compared to Limu and KAT-B1 intercropping, when the inter-specific competition is high, so it hastens the physiological maturity of maize to tassel. This study was disagreed with the experimental results of Jibril *et al*. (2015), Demessew (2002); Yesuf (2003) and Dechasa (2005) reported that days to 50% emergence, days to tasseling and days to 50% maturity of maize/common bean and sorghum/common bean are not affected by component planting density.

Cropping system showed a significant (P>0.05) effect on leaf area and leaf area index (Appendix Table 1). The maximum (910.20 cm^2) and minimum (811.91cm^2) leaf area was measured from intercropped and sole cropped of maize with common bean varieties respectively (Table 1). This may due to the presence of common bean varieties, which enables to fix atmospheric nitrogen. The reduction in leaf area of sole cropping maize may also be due to the absence of common bean varieties and presence of interspecific competition for sun light interception during the latter growth stages. This study was in contrast with the experimental result of Jibril *et al*. (2015) which revealed that the maximum leaf area was measured from sole cropping of maize than the intercropped. The highest (3.79) and lowest (3.02) leaf area index was measured from intercropping and sole cropping system of maize varieties (Table 1). The experimental result of Rana *et al.* (2001) showed that stature of plant moreover leaf area index (LAI) of maize crop was maximum in legumes-maize based intercropping systems compare to sole maize. This may due to the presence of common bean varieties which enables improve soil nitrogen and has a role for more photosynthesis rate. However, Rashid *et al.* (2006) reported the viability of inter-cropped legumes with sorghum and discussed that intercropping of legumes effect on leaf area index of intercropped sorghum is lower than the alone growing of sorghum, this leaf area index will be more less in case of intercropping of sorghum with cluster beans.

Table 1. Mean effects of varieties of maize and common bean, cropping system and their interaction on plant height, leaf area (cm2), leaf area index and days to tasseling of maize.

Treatments	PH	LA	LAI	DT
Shone+KAT-B1	248.93	914.05	3.81	75.10b
Shone+Awash-2	260.73	923.78	3.85	81.43a
Shone+Deme	261.60	907.65	3.78	74.33b
Limu+KAT-B1	253.27	908.72	3.79	74.23b
Limu+Awash-2	250.27	873.30	3.64	81.50a
Limu+Deme	253.80	933.70	3.89	75.50b
LSD	NS	NS	NS	3.00
CV (%)	2.82	6.46	6.46	2.14
Cropping system				
Intercropped	254.77	910.20a	3.79a	77.02b
Sole	250.00	811.91b	3.02b	80.80a
LSD	NS	45.20	0.20	3.67
CV (%)	2.89	5.20	5.52	4.39

Where PH=plant height, LA=leaf area, LAI=leaf area index, DT=days to tasseling, NS= not significant Means in a column followed by the same letters are not significantly different at p≤5% level of significance

The analysis of variance revealed that aboveground biomass, hundred kernel weight, grain yield and harvesting index of maize varieties were significantly affected by common bean varieties (Appendix Table 1). The highest hundred kernel weight (52.12g) of maize was obtained when Limu intercropped with Awash-2, this statistically at par with Shone intercropped with Aash-2. This might be the interspecific competition Awash-2 was the most positive as compared to other common bean varieties.

The analysis of variances showed that day to physiological maturity and grain yield of maize was significantly affected by cropping system in common-maize varieties intercropping (Appendix Table 1). The longer (143.84 days) and shorter (142.92 days) of physiological maturity of maize was taken from sole and intercropped respectively (Table 2). Similarly supported by the experimental result of Alemayehu *et al.* (2018) revealed that simultaneous intercropping of common bean variety with maize resulted longer days to flowering and maturity compared of sole maize. This may due to intra-specific competition in sole cropping of maize whereas the longer days due to inter-specific competition and absence of intra-specific competition intercropped of maize.

The highest (29.60 ton/ha) and lowest (21.24 ton/ha) aboveground biomass was obtained from Shone intercropped with Awash-2 and Limu intercropped with KAT-B1 intercropping respectively (Table 2). This may due to the genetic nature of both maize and common bean varieties. Variety KAT-B1 is a non-bushy and climbing variety, which enable more competent with Limu than Awash-2 and it may also due to a non-climbing and bushy type. The highest (51.53g) and lowest

(42.59g) hundred kernel weights were obtained from Shone+Awash-2 and Shone+KAT-B1 intercropping respectively (Table 2). Cropping system non significantly affected hundred kernel weights of maize. Similar with this result, Saban *et al.* (2007) reported that hundred kernel weights of maize not significantly affected by common bean intercropping. It was also supported by the experimental results of Alemayehu *et al. (*2018) who revealed that hundred kernel weights of maize not significantly affected by common bean intercropping. The highest (7.60 ton/ha) and lowest (6.69 ton/ha) grain yield of maize was obtained when Shone intercropped with Awash-2 and Limu intercropped with KAT-B1, respectively (Table 2). This may due to the presence of KAT-B1 in both Shone and Limu for hundred kernel weight and grain yield. The experimental result of (Alemayehu *et al.*, 2018) is disagreed with this study which revealed that varieties of common bean did not significantly affect grain yield of maize. This experimental result is not supported by Lulie *et al*. (2016) who revealed that the maximum grain yield was obtained from sole cropping system of maize while the lower grain yield was maintained for intercropped maize. The amount of yield increment over sole crop was 19.66% (Table 2). This suggests lower intra-specific competition of intercropped maize for natural resources (light, water and nutrients) compared to maize intercropped with haricot bean and also revealed effective utilization of applied nitrogen and phosphorus fertilizer by intercropped maize.

Table 2. Mean effects of varieties of maize and common bean, cropping system and their interaction on days to physiological maturity, above ground biomass (ton/ha), hundred kernel weight (g), grain yield (ton/ha) and harvest index of maize.

Treatments	DPM	AGB	HKW	GY	HI
Shone+KAT-B1	141.71	22.22bc	42.59c	6.77b	0.31
Shone+Awash-2	144.70	29.60a	51.53a	7.60a	0.26
Shone+Deme	141.34	24.05bc	45.07b	7.23ab	0.30
Limu+KAT-B1	141.27	21.24c	42.64c	6.69b	0.32
Limu+Awash-2	146.15	26.25ab	52.12a	7.35ab	0.28
Limu+Deme	142.34	26.17ab	44.34b	7.10ab	0.27
LSD	5.52	4.93	1.59	0.81	0.06
CV (%)	2.12	10.87	1.90	6.22	10.51
Cropping system					
Intercropped	142.92b	24.92	0.289	7.12a	0.289
Sole	143.84a	21.48	0.293	5.95b	0.293
LSD	3.08	NS	NS	0.44	NS
CV (%)	2.18	17.56	8.47	6.61	16.20

Where DPM= days to physiological maturity, AGB=above ground biomass, HKW=Hundred kernel weight, GY=grain yield, HI=harvest index, NS= not significant Means in a column followed by the same letters are not significantly different at p≤5% level of significance.

Response of Common Bean Varieties

The analysis of variance showed that branch number per plant, number of seed per pod and days to physiological maturity of common bean varieties were significantly affected by maize varieties (Appendix Table 2). However, plant height, number of pods per plant, hundred kernel weight, grain yield and harvest index were very highly significantly affected due to intercropped with maize varieties (Appendix Table 2). The tallest (132.13cm) and shortest (48.50cm) plants were measured from Deme intercropped with Limu and KAT-B1 with Shone (Table 3). This may due to the highest inter-specific competition for light and other soil resources in between Shone and KAT-B1 intercropping, it may also due to the presence of shading effect by Shone on KAT-B1. This may also due to the climbing nature of this variety as compared to others. The maximum (5.17) and minimum (2.58) branch number per plant was counted from the association between Deme and Limu and between KAT-B1 and Limu cropping system (Table 3). The reason may be similar with that of plant height may be the presence of competition for light, soil resources and shading effects in between the component crops. The highest and lowest number of pods per plant was counted from the intercropping of Deme with Limu and KAT-B1 with Shone, respectively (Table 3). The highest (4.63) and lowest (3.63) number of seed per pod was counted from the association Awash-2+Limu and KAT-B1+Limu, respectively (Table 3). The longest (112.67) and shortest (95.33) days of physiological maturity was recorded from the intercropping of Limu with Deme and Shone with that of Awash-2, respectively (Table 3). This finding agreed with that of Adipala and Ocaya, (2002) and Saban *et al*. (2007) who reported that intercropping of legumes in already established maize stand, significantly affected the number of pods per plant and number of seeds per pod of common bean.

The analysis of variance showed that cropping system significantly affected branch number of common bean (Appendix Table 2). The highest (6.33) and lowest (3.58) number of branches were counted from sole and intercropped of common bean respectively (Table 3). This may due to the presence of inter-specific competition in intercropped cropping system i.e., less photo assimilation rate, shading effect for light resources and scarcity of available soil moisture and nutrients, finally less biomass (branch number) was produced. This finding is in agreement with Demesew (2002); Wogayehu (2005) on maize/common bean intercropping reported that, number of branches per plant was significantly affected by maize varieties and cropping system. Adem (2006) on sorghum-cowpea found a significant difference on branch number due to interspecific competition between the component crops. Turk *et al*. (2003) confirmed that branch and pod number per plant was negatively related to plant density.

The analysis of variance showed that maize and common bean varieties intercropping had a very highly significance effect on Aboveground biomass

(ton/ha), Hundred grain weight (g), Grain yield (ton/ha) and Harvest index of common bean (Appendix Table 2). The highest (28.02 ton/ha) and lowest (14.49 ton/ha) aboveground biomass was obtained from Deme intercropped with Limu and Awash-2 intercropped with Limu, respectively (Table 4). The maximum (64.90g) and minimum (21.99g) hundred kernel weights were recorded from Deme intercropped with Limu and Awash-2 intercropped with Limu, respectively (Table 4). The highest (22.38ton/ha, 0.86) and lowest (8.02 ton/ha, 0.59) grain yield and harvest index were obtained due to Deme intercropped with Shone and Awash-2 intercropped with Limu for both grain yield and harvest index respectively (Table 4). Consistent with this result, Jibril *et al*. (2015) reported a significant difference in hundred seed weight of common bean in maize-bean intercropping due to varietal difference hundred grain weight of common bean was significantly affected by varieties of common bean. The difference in hundred seed weight might be because of inherent characteristics of the variety. The highest Harvest index recorded for variety Deme intercropped with Shone this might be due to the high grain yield to biomass obtained by the variety as a result of high partitioning of dry matter to the grain**.** This may also due to a non-shading effect of maize varieties of on grain yield reduction of common bean varieties. On the other hand, Deme best competent with maize for limited resources and best compatible for intercropping with maize.

Table 3. Mean effects of varieties of maize and common bean, cropping system and their interaction on plant height (cm), Branch number, number of pods per plant, number of seed per pod and days to physiological maturity of common bean.

Treatments	PH	BN	NPP	NSP	DPM
Shone+KAT-B1	48.50d	2.79b	3.29b	3.92bc	98.00b
Shone+Awash-2	63.58c	3.46b	4.25b	4.46ab	95.33b
Shone+Deme	100.54b	4.04ab	8.83a	4.49a	104.67ab
Limu+KAT-B1	53.50cd	2.58b	3.50b	3.63c	98.33b
Limu+Awash-2	63.13c	3.42b	4.04b	4.63a	96.67b
Limu+Deme	132.13a	5.17a	10.92a	4.56a	112.67a
LSD	12.09	1.50	2.65	0.56	10.12
CV (%)	8.64	22.99	25.12	7.61	5.51
Cropping system					
Intercropped	76.90	3.58b	5.80	4.28	100.94
Sole	83.39	6.33a	7.35	4.51	99.22
LSD	26.02	0.93	NS	NS	NS
CV (%)	28.67	24.59	30.77	12.52	7.96

DPM= days to physiological maturity, NPP=Number of pods per plant, NSP=Number of seed per pod, means represented by the letter showed a non-significance effect.

The analysis of variance showed that cropping system significantly affected aboveground biomass and grain yield of common bean (Appendix Table 2). The highest (24.03 ton/ha, 20.08 ton/ha) and lowest (20.29 ton/ha, 14.38 ton/ha) above

ground biomass and grain yield of common bean were obtained from sole and intercropped cropping system respectively (Table 4). Correspondingly, cropping system significantly influenced the grain yield of common bean. Because of additive intercropping of maize and common bean, the yield of intercropped common bean was reduced by 28.39% as compared to sole cropped common bean. Higher grain yield (20.08-ton ha^{-1}) was obtained from sole cropped common bean than the intercropped common bean (14.38-ton ha^{-1}) (Table 4). Lower grain yield of intercropped common bean might be due to increase inter-specific competition and the depressive effect of the cereals on common bean in intercropping. This might be also due to the absence of inter-specific competition like shading and dominance of maize varieties to common bean varieties. This results in less branch number and performance as compared to sole cropping of common bean varieties. The shading effect of the maize drastically reduced the light transmission that might have significantly reduced photosynthetic assimilates. The high population of the bean and maize component crops per unit area of land might cause greater inter-specific competition for growth resources like nutrient and light that leads to decreased yield of the component crops. Furthermore, yield reduction of common bean in an intercropping could be due to a more extensive root system; particularly a larger mass of fine roots of maize which compete more for soil nutrients. Lulie *et al*. (2016) and Kheroar and Patra (2013), in line with this finding, reported that yield of intercrops was reduced by intercropping with maize that was caused due to receipt of lower amount of solar radiation. In agreement with the current, Rezaei-Chianeh *et al*. (2011) showed reduction in the yield of faba bean under intercropping system. This experimental result is supported by Gutu *et al.* (2015) who reported that the maximum grain yield was obtained from sole cropping of soybean than intercropping in maize-soybean intercropping. Mean grain yield of common bean in the intercrop systems was significantly lower than the sole crop yield of common bean. The yield of intercropped common bean was reduced by 28.39% as compared to sole common bean. Lower grain yield of intercropped common bean might be due to increase inter-specific competition in intercropping than sole cropping. In consistence with this result Alemayehu *et al.* (2018) and Muoneke *et al.* (2007) reported similar yield reduction in common bean and soybean inter cropped with maize and sorghum and attributed the yield depression to inter specific competition and the depressive effect of the cereals.

Table 4. Mean effects of varieties of maize and common bean, cropping system and their interaction on above ground biomass (ton/ha), hundred kernel weight (g), grain yield (ton/ha) and harvest index of common bean varieties.

Treatments	AGB	HGW	GY	HI
Shone+KAT-B1	20.34b	44.65b	13.15b	0.65b
Shone+Awash-2	16.12bc	23.83c	9.25b	0.59b
Shone+Deme	25.58a	56.94ab	22.38a	0.86a
Limu+KAT-B1	17.22bc	44.07b	11.80b	0.68ab
Limu+Awash-2	14.49c	21.99c	8.02b	0.59b
Limu+Deme	28.02a	64.90a	21.68a	0.77ab
LSD	5.24	13.75	6.26	0.20
CV (%)	14.28	17.69	23.91	16.12
Cropping system				
Intercropped	20.29b	42.73	14.38b	0.69
Sole	24.03a	51.32	20.08a	0.71
LSD	3.24	NS	5.10	NS
CV (%)	22.86	20.22	23.30	27.43

Where AGB=above ground biomass, HGW=Hundred Grain weight, GY=grain yield, HI=harvest index, NS= not significant Means in a column followed by the same letters are not significantly different at p≤5% level of significance

The analysis of variance showed that partial LER of both maize and common bean varieties were non significantly (P>0.05) affected by maize common bean varieties intercropping (Appendix Table 3). However, the highest partial LER (0.96) of maize was due to, Limu intercropped with Awash-2 and Deme, Shone intercropped with Awash-2 but no significant in all treatments (Table.5). This may due to common bean varieties had no significant effect on yield reduction of maize and economical in intercropping system. The maximum (0.96) partial land equivalent ratio of maize was similarly obtained from Shone intercropped with Awash-2, Limu with Deme, and Limu with Awash-2, but the minimum (0.88) partial land equivalent ratio of maize was Shone intercropped with KAT-B1 respectively (Table 5). The maximum (0.85) and minimum (0.64) partial land equivalent ratio of common bean was due to Shone intercropped with Deme and Limu intercropped with Awash-2 respectively (Table 5). Even though a non-significance difference showed by maize common bean varieties intercropping on total land equivalent ratio. The highest and lowest value of total land equivalent ratio was due to Limu intercropped with Deme, and Limu intercropped with KAT-B1 respectively (Table 5).

Regarding the Monitary Advantage Index (MAI), maize–common bean varieties intercropping and their interaction effect did not show significant (P>0.05) variation on MAI (Appendix Table 3). Even though maize-common bean varieties non significantly affected, the maximum (105,359 ETB) MAI value was obtained from Shone intercropped with Deme and the minimum (87,853 ETB) MAI was

obtained from Limu intercropped with KAT-B1 (Table 5). Therefore, both Limu and Shone intercropped with Awash-2, Deme and KAT-B1 common bean varieties is more economical and advantageous for farmers.

Table 5. Mean effects of varieties of maize and common bean, on partial land equivalent ratio of maize and common bean, total land equivalent ratio and monitory advantage index of maize-common bean intercropping

Treatments	PLERM	PLERC	TLER	MAI
Shone+KAT-B1	0.88	0.76	1.64	90,948
Shone+Awash-2	0.96	0.75	1.71	103,093
Shone+Deme	0.91	0.85	1.76	105,359
Limu+KAT-B1	0.87	0.67	1.54	87,853
Limu+Awash-2	0.96	0.64	1.59	89,637
Limu+Deme	0.96	0.82	1.78	99,037
LSD	NS	NS	NS	NS
CV (%)	5.70	23.12	12.37	10.35

Where ns=non significance difference, PLERM=Partial land equivalent ratio of maize, PLERC=Partial land equivalent ratio of Common bean, MAI=Monitory Advantage index

Conclusion and Recommendation

The experiment was a one-year experiment at Sankura wereda Jejebicho research station and conducted in 2019/2020 cropping season. All necessary data were collected of the component crops from field experiment and analysed.

The highest (7.60 ton/ha) and lowest (6.69 ton/ha) grain yield of maize was obtained from Shone+Awash-2 and Limu+KAT-B1, respectively. This may due to the presence of KAT-B1 in both Shone and Limu for hundred kernel weight and grain yield. Whereas the highest grain yields common bean (22.38to/ha, grain yield was obtained from Deme intercropped. Even though the land equivalent ratio (LER) and monitory advantage (MAI) of maize-common bean intercropping the highest (1.78, 105,359 ETB) value of both LER and MAI from Limu intercropped with Deme and Shone intercropped with Deme respectively.

Farmers can achieve greater benefit from their land by growing the main crop (maize like Limu and Shone) in association with a common bean variety Deme. Hence, maize/common bean intercropping could increase incomes obtained by smallholder farmers at Sankura area of Southern Ethiopia, through enhancing efficient utilization of land. Therefore, any of the two (Limu or Shone) maize varieties could be recommended for intercropping with Deme of common bean variety.

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Appendices

Appendix Table 1. Mean square values of ANOVA on the agronomic and yield components of Maize (Zea mays L.) under intercropping with common bean varieties

SOV.	DF	PH	LA	LAI	AGB	DT	DPM	HKW	GY	HI
Replication	2	65.31	315.91	0.0055	1.86	7.24	2.00	0.41	0.089	0.00026
Treatment	5	83.85	1273.04	0.022	28.07*	36.32**	12.39	56.22*	0.36*	0.00128*
Error	10	51.70	3457.41	0.06	7.33	2.72	9.20	0.76	0.196	0.00093
CV (%)		2.82	6.46	6.46	10.87	2.14	2.12	1.88	6.22	10.52
Cropping system										
Rep	2	39.26	533.23	0.024	4.36	6.53	2.23	0.0001	0.041	0.0004
CS	1	102.25	43471.51*	2.71*	53.25	64.43*	3.80*	157.00	6.21*	0.0001
Error	2	53.55	2112.66	0.040	17.84	11.72	9.78	17.57	0.20	0.002
CV (%)		2.88	5.19	5.52	17.55	4.39	2.18	9.00	6.61	16.21

*, **, Significant at p≤0.05 and p≤0.01 probability levels respectively; Rep=Replication;
SOV. = Sources of Variation; CS=cropping system;

Appendix Table 2. Mean square values of ANOVA on the Agronomic and Yield components of Common bean under intercropping with maize varieties

SOV.	DF	PH	BN	NPP	NSP	DPM	HGW	AGB	GY	HI
Replication	2	174.62	0.82	2.65	0.045	32.89	88.59	48.00	13.57	0.0364
Treatment	5	3197.96**	2.63*	31.47	0.50*	129.92*	891.84**	88.90	115.29**	0.0363*
Error	10	44.14	0.68	25.13	0.09	30.95	57.14	8.28	11.82	0.012
CV		8.64	22.97	25.12	7.16	5.51	17.69	14.18	23.91	16.11
Cropping system										
Rep	2	13.94	0.70	1.15	0.07	17.93	60.38	23.58	16.80	0.0264
CS	1	252.96**	45.60*	14.26	0.33	17.80	329.40	9.61*	10.14*	0.001
Error	2	949.40	1.22	14.75	0.30	63.94	297.74	29.71	36.46	0.019
CV (%)		28.67	24.59	30.77	7.32	7.97	22.85	27.42	23.30	20.21

*, **, significant at P≤0.05 and p≤0.01 probability levels respectively; Rep=Replication;
SOV.=Sources of Variation; CS=cropping system.

Appendix Table 3. Mean square values of ANOVA on the agronomic and yield components of common bean under intercropping with maize varieties

Sources of variation.	DF	PLERM	PLERC	TLER	MAI
Replication	2	0.00128	0.01	0.014	15176394.4
Treatment	5	0.0026	0.02	0.027	167706764.5
Error	10	0.0028	0.03	0.043	98758901
CV (%)		5.70	23.12	12.37	10.35

Where, PLERM= partial land equivalent ratio of maize, PLERC= partial land equivalent ratio of common bean, TLER=total land equivalent ratio and MAI= monitory advantage index

Critical Leaf Color Chart Level and N Determination for Rice Production in Fogera Plain

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Abstract

Assessment of the nitrogen status of standing crops and its application according to crop needs is the best approach to reducing the loss. The Leaf Color Chart (LCC) is one of the best methods for monitoring leaf N status. A field experiment was conducted at Fogera Plain for two years in the 2019 and 2020 main cropping seasons to determine the critical LCC value of the X-Jigna rice variety and the level of appropriate N rate to be applied at the critical LCC. The treatments included four levels of LCC cv. (LCC cv. 1, 2, 3, and 4) with different rates of N application (20, 25, 30, and 35 kg ha-1 at a time) along with two checks (control {(0 kg N ha-1), recommended N (276 kg N ha-1 in two splits with 1/3 at planting and the remaining 2/3 at maximum tillering)}. The statistical analysis indicated that all of the rice growth parameters, as well as dry biomass and grain yields, were significantly affected by the N management treatments. With the reduction of 101 kg (36.6%) N, the LC4+35 kg ha-1 treatment was found to give statistically equivalent grain and biomass yields compared to the previous recommended rate of 276 kg ha-1 N. The economic analysis indicated that the highest net benefit (Birr 64,975.46/ha) with an acceptable level of marginal rate of return (652.155%) was observed at the LCC4 combined to 35 kg ha-1 N. The application of nitrogen to rice at a rate of 35 kg ha-1 N whenever the leaf color of the rice plant matches the value of LCC4 could be recommended for rainfed lowland rice production in Fogera Plain using the X-Jigna variety.

Keywords*:* Lowland Rice, N loss, leaf N, Leaf Color Chart.

Introduction

Rice (Oryza sativa L.) is one of the major staple foods for half of the world's population (Mohidem *et al*., 2022). Nitrogen is an essential nutrient for rice production, sustaining high yields (Subedi and Panta, 2018). The nutrient is required for chlorophyll formation, which gives the leaves their green color and enables the plants to gain energy for nutrient uptake and growth (Subedi and Panta, 2018). Rice crops usually use half of the applied nitrogen for grain yield and above-ground biomass. The other half of the N is lost via ammonium volatilization, denitrification, runoff, and leaching and dissipated in the water and environment, causing a number of ecological problems (Houshmandfar and Anthony, 2011; Nacjimuthu *et al*., 2007). The applied nitrogen is lost due to a lack of synchronization between nitrogen demand and nitrogen supply (Sen *et al*.,

2011). Conversely, inadequate N utilization results in reduced yield and profit. Fixed-time recommended N split applications at specified growth stages are the most common practice followed by farmers (Houshmandfar and Anthony, 2011). However, application of nitrogen in splits may produce optimum yields but cannot help increase N use efficiency beyond a limit as the nutrient is not synchronized with crop demand as well as the use of nitrogen in excess of the requirement (Subedi and Panta, 2018; Reena *et al*., 2017). Therefore, there is a need to rethink our traditional method of fertilizer recommendation.

Different techniques are available in nutrient nitrogen management to tailor the supply of the nutrient for the target yield while also enhancing fertilizer use efficiency (Chittapur *et al*., 2015). Real-time (also called need-based) nitrogen management requires periodic assessment of nitrogen status in standing crops and its application according to crop need and the time of fertilizer application (Subedi and Panta, 2018; Reena *et al*., 2017). As leaf N content is closely related to photosynthetic rate and biomass production, it is a sensitive indicator of the dynamic changes in crop N demand during a growing season (Houshmandfar and Anthony, 2011). The direct measurement of leaf N concentration by laboratory procedure is laborious, time-consuming, and costly (Houshmandfar and Anthony, 2011). Such procedures have limited use as a diagnostic tool for optimizing N top dressing because of the extensive time delay between sampling and obtaining results (Houshmandfar and Anthony, 2011). Two simple, quick, and non-destructive tools available for in situ monitoring of leaf N status in rice and other crops are the chlorophyll meter, also known as the SPAD (soil plant analysis development) meter, and the Leaf Color Chart (LCC) (Houshmandfar and Anthony, 2011). SPAD is a chlorophyll metering device that can provide a quick estimate of the leaf N status, but it is relatively expensive (Houshmandfar and Anthony, 2011). The Leaf Color Chart (LCC), on the other hand, is cheap, simple, and an easy-to-use alternative to monitor the relative greenness of the rice leaf as an indicator of crop N status (Houshmandfar and Anthony, 2011). The concept is based on results that show a close link between leaf chlorophyll content and leaf N content.

The first LCC was developed in Japan (Islam *et al*., 2007). Chinese researchers developed a modified LCC and calibrated it for indica, japonica, and hybrid rice (Islam *et al*., 2007). The commonly used LCC was developed from a Japanese prototype by the Crop and Resource Management Network (CREMNET) at IRRI and the Philippine Rice Research Institute, Philippines (Philrice) (Islam *et al*., 2007; Nacjimuthu *et al*., 2007). The Leaf Color Chart has been tested for real-time N management in farmers' fields in several countries (Sudhalakshmi *et al*., 2008). The Leaf Color Chart has been tested for real-time N management in farmers' fields in several countries (Sudhalakshmi *et al*., 2008). LCC has been successfully used for rice and wheat (Houshmandfar and Anthony, 2011). Several experimenters reported LCC as the best way of real-time N management

considering higher grain yield and N savings in rice (Budhar, 2005; Balaji and Jawahar, 2007; and Sathiya and Ramesh, 2009). The LCCs used in Asia are typically a durable plastic strip about 7 cm wide and 13 to 20 cm long, containing shades of green from yellowish green (No. 1) to dark green (No. 7), and calibrated with the SPAD meter (Chittapur *et al*., 2015; Houshmandfar and Anthony, 2011). With a real-time approach to N management, farmers monitor the color of rice leaves at seven- to ten-day intervals and apply N fertilizer whenever leaves become more yellowish green than the critical color on the LCC (Houshmandfar and Anthony, 2011).

The critical or threshold value of the LCC is defined as the intensity of green color that must be maintained in the uppermost fully opened leaf of the crop plant (Chittapur *et al*., 2015). At a critical or predetermined stage of the crop, a calibrated dose of fertilizer N needs to be replenished whenever leaf greenness is below the critical LCC threshold (Chittapur *et al*., 2015). Thus, maintaining the leaf greenness just above the LCC critical value ensures high yields with need-based N applications, thereby leading to high fertilizer N use efficiency (Chittapur *et al*., 2015). Farmers will benefit hugely if they can adjust N application through LCC as an indicator of actual crop condition and nutrient requirement (Chittapur *et al*., 2015). Nacjimuthu *et al*. (2007) reported a nitrogen fertilizer savings of 50% by using LCC compared to the conventional N application method. The LCC could be adopted to save 20–50 kg N/ha particularly in crops with greater N demand or in crops grown in environments prone to N loss (Chittapur *et al*., 2015; Houshmandfar and Anthony, 2011). Nitrogen management based on LCC cv. 4 helped to avoid excess application of nitrogen to rice and reduced the nitrogen requirement from 12.5 to 25% without causing yield reduction (Subedi and Panta, 2018). Chittapur *et al*. (2015) indicated that LCC, originally developed for rice, was found handy in other cereals/grasses such as maize, wheat, sugarcane, and others (Figure 1). Reena *et al*. (2017) reported that application of nitrogen at a lower rate of 105 kg /ha based on LCC values (4 and 5) resulted in statistically similar growth and yield of wheat compared with recommended practice (150 kg/ha) with a nitrogen saving of 30 percent or 45 kg /ha.

Figure 1. Leaf Color Chart as used for different crops

The topmost fully expanded leaf is chosen for leaf color measurement as it is highly correlated to the N status of rice plants. The color of a single leaf is measured by holding the LCC vertically and placing the middle part of the leaf in front of a color strip for comparison (Sudhalakshmi *et al*., 2008). The leaf should neither be detached nor destroyed. The leaf on which the reading is recorded be shielded from our body, as the leaf color chart reading is affected by the sun's angle and sunlight intensity (Sudhalakshmi *et al*., 2008). The reading should be taken on a clear, sunny day between 0900 and 1100 or 1400 and 1600, with the sun at your back to shade the leaf being measured. Readings should not be taken very early in the morning since dew drops can make reading difficult (Sudhalakshmi, *et al*., 2008). LCC readings are taken once a week, starting 14 days after transplanting for transplanted rice and 21 days after seeding for direct-seeded rice (Sudhalakshmi *et al*., 2008). The critical leaf color reading for N top dressing may normally range from 3 to 5 depending upon the cultivar groups, and 4 is the best optimum for most (Sudhalakshmi *et al*., 2008). If more than 5 leaves show readings below the critical value, nitrogenous fertilizer has to be applied (Sudhalakshmi *et al*., 2008). If the color falls between two grades, the mean of the two values is taken for LCC readings (Sudhalakshmi *et al*., 2008).

The use of LCC for scheduling N application may not be uniformly applicable to all varieties that differ in inherent leaf color and regions that differ in climate, thereby necessitating individual or group standardization in different cultivated areas (Houshmandfar and Anthony, 2011). Identification of the correct threshold values of the LCC is essential, as they differ according to location, season, variety, and rice ecosystem (Ahmad *et al*., 2016). Critical LCC values vary considerably among different rice genotypes with different genetic backgrounds and leaf colors (Sen *et al*., 2011). The critical LCC value should be determined for distinctively varying rice varieties (Sen *et al*., 2011). After assessing LCC values for different rice varieties, Sen *et al*. (2011) reported higher grain yield along with correspondingly higher agronomic and recovery efficiency and other parameters: LCC < 5 for NDR 359, Sarju 52 and ≤ 4 for HUBR 2-1 rice varieties. Based on their experiment in Iran, Houshmandfar and Anthony (2011) reported that, though the two rice varieties they consider have an equal critical LCC value of 4, one variety, named Tarom-Hashemi needs 25 kg N ha^{-1} while the other variety, called GRH-1, needs 35 kg N ha^{-1}. The present experiment is therefore initiated to determine the critical LCC value of the X-Jigna variety and the level of appropriate N at the critical LCC.

Materials and Methods

The field experiment was conducted at Fogera Plain in two cropping seasons of the years 2019 and 2020 cropping seasons at two sites in each year. The experimental site is located between Latitude 11°49'55 North and Longitude 37°

37′ 40 East at an altitude of 1815 meters above sea level. The study site receives average mean annual rainfall and minimum and maximum temperatures of 1219 mm, 12.75°C and 27.37°C, respectively. The long-term rainfall data (1986–2017) years indicated that much of the rainfall appeared in July and August (Figure 2).

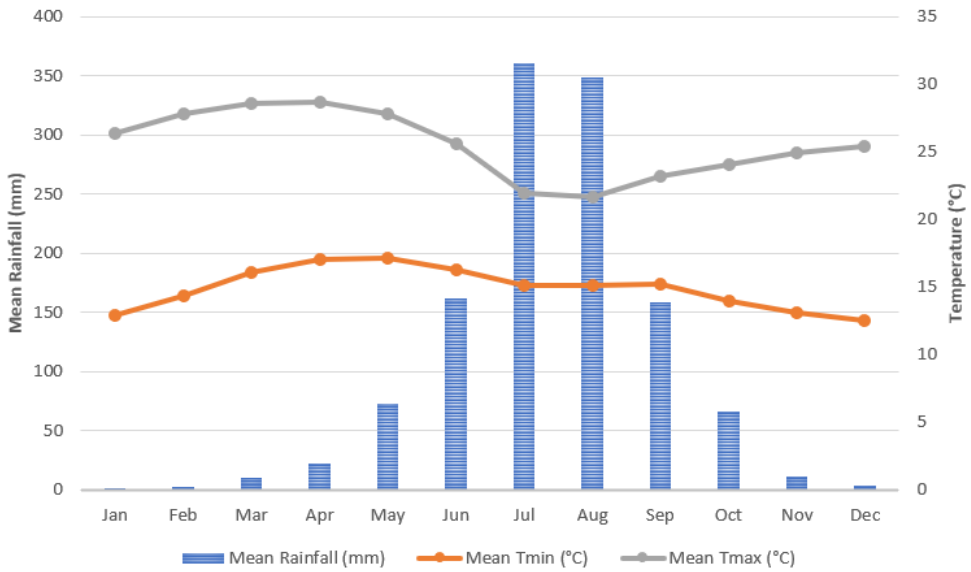

Figure 2. The Rainfall and Temperature condition of Fogera Plain for the period 1981-2017

The soil of the experimental sites was found to be heavy clay with a pH range of 5.87–6.63, which is slightly acidic and a preferred range for most crops (Table 1). Total nitrogen content (%) was in the range of 0.09–0.16, within the low range for tropical soils. The organic matter content of the soil was between 2.13 and 3.09%, which is within a range of medium (2-4%) for Ethiopian soils (Murphy, 1968). The available P content of the soil was 11.4–25.13 ppm, which lies in a range of moderate to low or deficient (< 20–40 mg/kg) for most crops (Landon, 1991).

Table 1. Relevant soil physicochemical properties of the experimental rice field before planting in Fogera Plain of Ethiopia

Soil properties	Units	Minimum Value	Maximum value
Textural class		Heavy clay	Heavy clay
Chemical properties			
pH (H_2O) 1:2.5 g soil	-	5.87	6.63
Total nitrogen (TN)	%	0.09	0.16
Organic carbon (OC)	%	1.24	1.93
Available Phosphorus	Ppm	11.4	25.13

Treatments were arranged in a factorial randomized block design with three replications. The treatments included four levels of LCC cv. (LCC cv. 1, 2, 3, and 4) with different rates of N application (20, 25, 30, and 35 kg ha^{-1} at a time) along with two checks {(control (0kg N ha^{-1}), recommended N (276 kg N ha^{-1} in two splits with 1/3 at planting and the remaining 2/3 at maximum tillering). All the plots received an equal amount of phosphorous at a rate of 69 kg ha^{-1} P_2O_5. The widely grown, locally adapted variety, X-Jigna, was used.

Table 2. Total N applied to the respective treatments during the experiment

N Management	N application frequency	Total N (kg/ha)
LC1-N20	4	80
LC2-N20	5	100
LC3-N20	5	100
LC4-N20	5	100
LC1-N25	3	75
LC2-N25	4	100
LC3-N25	5	125
LC4-N25	5	125
LC1-N30	2	60
LC2-N30	3	90
LC3-N30	4	120
LC4-N30	5	150
LC1-N35	2	75
LC2-N35	3	105
LC3-N35	4	140
LC4-N35	5	175
C1(0-0NP)	0	0
C2(N-276+P69)	2	276

Leaf color chart (LCC) measurement was conducted following the recommended steps. LCC, consisting of four green shades from yellowish green to dark green, showing increasing greenness with increasing number (1=Yellowish, …. 4=Deep green), were used in the study. LCC readings were measured every week from 21 Days After Sowing (DAS) to heading. Ten disease-free rice plants were randomly

selected in the plot, and the colors of the youngest fully expanded leaves of the selected plants were compared by placing their middle part on top of the color strip in the chart. If 6 or more leaves read equal to or below the treatment critical value (LCC of the respective treatments), a dose of N kg ha-1 (depending on the N treatments) was applied for each plot.

Agronomic data on plant height, number of effective tillers, grain yield, straw yield, thousand seed weight, and harvest index were collected depending on the specific crop character. Statistical analysis was performed using the statistical analysis system (SAS) software version 9.2 (SAS-Institute 2008). Whenever the F-test showed a significant difference among treatments for a parameter in question, the mean separation of treatments was performed using the least significant difference (LSD) method.

To assess the profitability of the treatments, cost-benefit analysis was carried out by following the CIMMYT partial budget analysis method (CIMMYT 1988). The prevailing cost of inputs and outputs in 2020 was considered for the analysis. The respective prices of rice grain (16 Birr per kg) and straw (2.0 Birr per kg), and the cost of urea and NPS fertilizers for the stated period at Fogera were 13.1 and 14.3 Birr per kg, respectively.

Results and Discussion

Growth, yield and yield components

The total N applied during the experimental period was added, keeping records of N applications based on observations of the corresponding LCC values for each treatment (Table 2). The most frequent (five times) and highest total N application (175 kg ha-1) was done for the LC4 value and the 35 kg ha-1 N application rate. However, the total N applied for the LC4+35 kg ha-1 treatment was much lower than the previous recommended rate of 276 kg N ha-1, with a reduction of 101 kg N (36.6%).

The statistical analysis indicated that all of the rice growth parameters, namely plant height, panicle length, number of fertile grains per panicle, number of effective tillers, dry biomass yield, grain yield, thousand seed weight, and harvest index, were significantly ($P < 0.05$) affected by the N management treatments (Table 3). The comparison of plant height among the treatments showed that the highest plant height (83.47 cm) was recoded from the control treatment of 276 kg N ha-1 application, which is statistically at par with the treatment of combined application of LCC4 with 35 kg ha-1 N and many other treatments (Table 4). The lowest plant height of 73.22 cm was observed at the no-N fertilizer application, which is found to be statistically equivalent with many of the treatments related to the LCC2 and LCC1 values.

Table 3. Analysis of variance (ANOVA) for Yield and yield components of rice

Source of variation	Df	Mean Square							
		PH (cm)	PL (cm)	NFGPP	ET/m2	DBY (t ha^{-1})	GY (t ha^{-1})	TSW (g)	HI (%)
Treatment (T)	17	83.46*	2.42*	331.03*	0.024691**	49.45**	7.86**	14.90**	99.40**
Location (L)	3	1760.22**	31.12**	38654.35**	100.23**	12.28**	0.81**	182.4**	33.60NS
L x T	51	14.57NS	1.40NS	124.29NS	33.16NS	4.27NS	0.35NS	1.92NS	34.99NS
CV		5.23	6.77	19.65	13.59	20.89	12.14	6.85	16.81

PH=Plant Height, PL= Panicle length, NFGPP=Number of Fertile Grains Per Panicle, ET= Number of Effective Tillers per 1m row, DBY=Dry Biomass Yield, GY= Grain Yield, TSW= Thousand Seeds Weight, HI= Harvest index

Regarding the number of effective tillers, the highest values were recorded for the LCC4 values at the N rates of 30 and 35 kg ha-1, which were not significantly different from the 276 kg N ha-1 of the control treatment and most others having the highest LCC and N rates (Table 4). Similarly, for the case of fertile grains per panicle, the highest number (81.8) was exhibited at the treatment of the combined application of LCC4 with 35 kg N ha-1, which was statistically similar to the control treatment of 276 kg N ha-1 application and with many of the others related to LCC4 and LCC3 values as well as higher N rates (Table 4). In a similar fashion to the other growth parameters, a statistically higher panicle length of 18.35 cm was associated with the LCC4 combined with 35 kg ha-1 N and was at par with the lengths of the N-276 kg ha-1 N applied control treatment and the other treatments with higher LCCs combined with higher N rates (Table 4).

In agreement with the current finding, Sathiya and Ramesh (2009) reported that growth parameters like plant height, number of tillers, and number of filled grains per panicle of rice were positively influenced by different nitrogen management practices and higher values were obtained with nitrogen application based on an LCC value of 4 as compared to an LCC value of 3. Satpute *et al*. (2015), Chaudhary *et al*. (2018), and Subedi *et al*. (2017) also reported significant responses in rice growth parameters due to N management by LCC compared to conventional nitrogen application methods.

The statistical analysis for the dry biomass and grain yields, thousand seed weight, and harvest index showed that there was a significant ($P<0.05$) response to the treatments (Table 3). The highest and statistically at par dry biomass yields of 12.86 and 12.04 t ha-1 were exhibited at the 276 kg N ha-1 and the LCC4 combined to 35 kg ha-1 N treatments, respectively (Table 5). Like the biomass, the stated treatments showed the highest grain yields of 5.14 and 5.09 t ha-1, respectively (Table 5). The lowest grain (2.03 t ha-1) and biomass yields (5.47 t ha-1) were associated with the no N fertilizer application. A tendency toward

lower grain and biomass yields was observed with the lowest LCC and N values. The LCC4 combined with 35 kg N ha-1 gave statistically equivalent grain and biomass yields to the 276 kg N ha-1 control treatment. In line with this finding, Nacjimuthu *et al*. (2007) reported a nitrogen fertilizer savings of 50% by using LCC compared to conventional N application and the control treatment of 276 kg N ha-1. Subedi and Panta (2018) also stated that nitrogen management based on LCC cv. 4 helped avoid excess nitrogen application to rice and reduced the nitrogen requirement from 12.5 to 25% with no yield reduction.

Table 4. Effects of N management using LCC on rice growth components

N Management	Plant height (cm)	Number of Effective Tillers per 1m row	Panicle length (cm)	Number of Fertile Grains Per Panicle
LC1-N20	75.50^{cd}	41.5^{d}	16.90^{c}	60.67^{b}
LC2-N20	78.98^{abcd}	48.0^{abc}	17.03^{bc}	62.47^{ab}
LC3-N20	75.65^{cd}	49.33^{ab}	17.03^{bc}	62.07^{b}
LC4-N20	80.02^{abc}	49.5^{abc}	17.50^{abc}	65.00^{ab}
LC1-N25	79.43^{abc}	49.0^{abc}	17.35^{abc}	61.57^{b}
LC2-N25	77.53^{abcd}	44.33^{dc}	17.68^{abc}	62.27^{ab}
LC3-N25	79.40^{abc}	45.50^{bcd}	17.53^{abc}	63.10^{ab}
LC4-N25	80.93^{abc}	50.0^{abc}	17.18^{bc}	67.13^{ab}
LC1-N30	77.75^{abcd}	47.167^{abcd}	17.53^{abc}	68.37^{ab}
LC2-N30	80.87^{abc}	48.33^{abc}	17.43^{abc}	65.63^{ab}
LC3-N30	81.70^{abc}	47.33^{abcd}	17.33^{abc}	67.40^{ab}
LC4-N30	80.87^{abc}	47.83^{abc}	17.78^{abc}	70.10^{ab}
LC1-N35	76.57^{bcd}	49.66^{abc}	18.0^{abc}	67.30^{ab}
LC2-N35	75.87^{cd}	51.3^{ab}	18.10^{ab}	64.67^{ab}
LC3-N35	80.37^{abc}	53.0^{a}	18.01^{abc}	70.03^{ab}
LC4-N35	82.17^{ab}	53.0^{a}	18.35^{a}	81.80^{a}
C1(0 + 69P)	73.22^{d}	46.667^{abcd}	16.85^{c}	58.10^{b}
C2(N-276+P69)	83.47^{a}	50.83^{ab}	18.12^{ab}	74.40^{ab}
CV (%)	5.23	13.59	6.77	19.65

Working on wheat, Reena *et al*. (2017) similarly reported that the application of nitrogen at a lower rate of 105 kg /ha based on LCC values (4 and 5) resulted in statistically similar growth and yield of wheat compared with recommended practice (150 kg/ha) with the N saving of 30% or 45 kg/ha nitrogen. A comparison of the treatments concerning the thousand seed weight showed that the highest weight (29.25 g) was recorded from the LCC3 combined with 35 kg ha-1 N (Table 5). Most of the treatments exhibited statistically equivalent thousand seed weights compared to the best-scoring treatment except the lowest scoring (25.47 g) treatment of no N fertilizer application, which of course, also had other statistically equivalent treatments that were either at the lower values of LCC or N or both combined. The harvest index is a parameter of growth analysis that

compares the most economic factor (the grain yield) to the total above-ground biomass yield. The analysis of variance indicated that the treatments of LCC3 combined with 20 kg ha-1 N and LCC3 combined with 25 kg ha-1 N resulted in the highest harvest indices. Few treatments were statistically at par, but most exhibited statistically lower harvest indices compared to the best-scoring ones (Table 5).

Table 5. Effects of N management using LCC on rice yield dry biomass, grain yield, thousand seeds weight and harvest index

N Management	Dry Biomass Yield (tha^{-1})	Grain Yield (t ha^{-1})	Thousand Seeds Weight (g)	Harvest Index (%)
LC1-N20	7.24^{cdef}	2.51^{gh}	28.57^{abc}	34.7^{dc}
LC2-N20	8.60^{bcde}	2.92^{def}	27.95^{abcd}	33.9^{d}
LC3-N20	8.01^{bcdef}	3.56^{bcd}	28.38^{abc}	44.4^{a}
LC4-N20	8.88^{bcde}	3.60^{bcd}	28.95^{ab}	40.5^{abcd}
LC1-N25	6.32^{ef}	2.66^{fg}	28.62^{abc}	42.1^{ab}
LC2-N25	8.54^{bcde}	2.96^{def}	28.27^{abc}	35.0^{dc}
LC3-N25	9.17^{bcd}	3.99^{b}	28.35^{abc}	44.0^{a}
LC4-N25	10.73^{b}	4.01^{b}	29.25^{ab}	37.4^{bcd}
LC1-N30	6.99^{def}	2.70^{gf}	26.72^{bcd}	39.0^{abcd}
LC2-N30	9.64^{bcd}	3.46^{bcde}	27.93^{abcd}	36.0^{bcd}
LC3-N30	10.12^{b}	3.91^{bc}	29.70^{a}	38.6^{abcd}
LC4-N30	10.14^{b}	3.96^{b}	27.87^{abcd}	39.0^{abcd}
LC1-N35	7.59^{bcdef}	3.23^{def}	25.87^{cd}	37.1^{bcd}
LC2-N35	9.63^{bcd}	3.57^{bcd}	27.60^{abcd}	41.18^{abc}
LC3-N35	9.97^{cb}	3.64^{bcd}	29.25^{ab}	36.5^{bcd}
LC4-N35	12.04^{a}	5.09^{a}	28.85^{ab}	42.30^{ab}
C1(0 + 69P)	5.47^{f}	2.03^{h}	25.47^{d}	37.1^{bcd}
C2(N-276+P69)	12.86^{a}	5.14^{a}	27.13^{abcd}	39.97^{abc}
CV (%)	20.89	12.14	6.85	16.81

As of the present observation, Sathiya and Ramesh (2009) claimed that nitrogen management treatments significantly influenced the productivity of rice for grain and straw yield and harvest index. They found higher grain and straw yields with nitrogen application based on an LCC value of 4 compared to an LCC value of 3. According to Satpute *et al.* (2015) and Subedi *et al.* (2017), the test weight and harvest index of rice showed significant responses at various levels of LCC values.

The improvement in the yield attributes of rice might be due to the adequate supply of photosynthates that sink under higher nitrogen levels (Chaudhary *et al.*, 2018). The availability of a sufficient quantity of nitrogen during critical stages of plant growth might have resulted in better growth characteristics and yield components at various phenological stages and, finally, in the yield of aerobic rice

(Sathiya and Ramesh, 2009). The leaf nitrogen status of rice is closely related to photosynthetic rate and biomass production, and it is a sensitive indicator of changes in crop nitrogen demand within a growing season. Application of fertilizer nitrogen based on leaf color charts was effective in maintaining optimal leaf nitrogen, resulting in better crop growth and high rice grain yield (Sathiya and Ramesh, 2009).

Economic analysis

Following the CIMYYT (1988) partial budget analysis method, grain and straw yield adjustments, calculations of total variable costs (TVC), gross benefits (GB), and net benefits (NB) were performed (Table 6). Dominance analysis was carried out after arranging the treatments in their order of TVC. Treatment will be dominant if it has a higher TVC but a lower NB than a previous treatment with a lower TVC and a higher NB (Table 7). Non-dominated treatments were taken out, and the marginal rate of return (MRR) was computed (Table 8). According to the CIMYYT (1988) partial budget analysis methodology, treatments exhibiting MRR of more than 100% will be considered to compare their NB. The highest NB (Birr 64,975.46/ha) with an acceptable level of MRR (652.155%) was observed at the LCC4 combined with 35 kg N ha-1 (Table 8). Consistent with the current result, Iqbal *et al*. (2016) reported that the net income (Rs.153,063 ha-1) using the LCC technique was higher than the farmers' practice (Rs.141,050 ha-1). The authors concluded that LCC is an easy technique and a cost-effective apparatus for monitoring chlorophyll in leaves and improving nitrogen fertilizer management in rice. The application of nitrogen to rice at a rate of 35 kg N ha-1, whenever the leaf color of the rice plant matches the value of LCC4, is to be recommended for rainfed lowland rice production in Fogera Plain using the X-Jigna variety.

Table 6. Grain and straw yield adjustments, total variable cost, gross and net benefit analysis

N Management	Adjusted Grain Yield (kg/ha)	Adjusted Straw Yield (kg/ha)	Total N applied (kg/ha)	Total Urea (Kg/ha)	TVC (Birr/ha)	GB (Birr/ha)	NB (Birr/ha)
LC1-N20	2259	4257	80	173.9	2857.4	36882.0	34024.6
LC2-N20	2628	5112	100	217.4	3571.7	43146.0	39574.3
LC3-N20	3204	4005	100	217.4	3571.7	49261.5	45689.8
LC4-N20	3240	4752	100	217.4	3571.7	50868.0	47296.3
LC1-N25	2394	3294	75	163.0	2678.8	37260.0	34581.2
LC2-N25	2664	5022	100	217.4	3571.7	43497.0	39925.3
LC3-N25	3591	4662	125	271.7	4464.7	55471.5	51006.8
LC4-N25	3609	6048	125	271.7	4464.7	57793.5	53328.8
LC1-N30	2430	3861	60	130.4	2143.0	38596.5	36453.5
LC2-N30	3114	5562	90	195.6	3214.6	50382.0	47167.4
LC3-N30	3519	5589	120	260.9	4286.1	55890	51603.9
LC4-N30	3564	5562	150	326.1	5357.6	56457.0	51099.4
LC1-N35	2907	3924	75	163.0	2678.8	45130.5	42451.7
LC2-N35	3213	5454	105	228.3	3750.3	51556.5	47806.2
LC3-N35	3276	5697	140	304.3	5000.4	52771.5	47771.1
LC4-N35	4581	6255	175	380.4	6250.5	71226.0	64975.5
C1(0-0NP)	1827	3096	0	0	0	29308.5	29308.5
C2(N-276+P69)	4626	6948	276	600.0	9858	72873.0	63015.0

Table 7. Dominance Analysis

N Management	TVC (Birr/ha)	NB (Birr/ha)	
C1(0-0NP)	0	29,308.5	
LC1-N30	2143.0	36,453.5	
LC1-N25	2678.8	34,581.2	D
LC1-N35	2678.8	42,451.7	
LC1-N20	2857.4	34,024.6	D
LC2-N30	3214.6	47,167.4	
LC2-N20	3571.7	39,574.3	D
LC3-N20	3571.7	45,689.8	D
LC4-N20	3571.7	47,296.3	
LC2-N25	3571.7	39,925.3	D
LC2-N35	3750.3	47,806.2	
LC3-N30	4286.1	51,603.9	
LC3-N25	4464.7	51,006.8	D
LC4-N25	4464.7	53,328.8	
LC3-N35	5000.4	47,771.1	D
LC4-N30	5357.6	51,099.4	D
LC4-N35	6250.5	64,975.5	
C2(N-276+P69)	9858.0	63,015.0	D
D= Dominated treatment			

Table 8. Marginal Rate of Return (MRR) Analysis

N Management	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
C1(0-0NP)	0	29,308.50	
LC1-N30	2143.043	36,453.46	333.40
LC1-N35	2678.804	42,451.70	1,119.57
C2-N30	3214.565	47,167.43	880.19
LC4-N20	3571.739	47,296.26	36.07
LC2-N35	3750.326	47,806.17	285.53
LC3-N30	4286.087	51,603.91	708.85
LC4-N25	4464.674	53,328.83	965.87
LC4-N35	6250.543	64,975.46	652.15

Conclusion and Recommendatuion

Monitoring rice plant N status is a valid approach for balancing crop N demand and supply from soil and applied fertilizer. In many field situations, more than

50% of applied nitrogen is lost due to the lack of synchrony between plant nitrogen demand and supply. The LCC is a simple tool that can assist farmers in avoiding nitrogen over- and under-application in rice plants. The LCC-based nitrogen nutrient management in rice can save nutrients without reducing yield. Thus, there is considerable opportunity to increase rice yield and economic advantage through improved N management with the LCC. The critical LCC value of 4 with 35 kg N ha-1 for the X-Jigna variety was found to be the best N management option for guiding N application to achieve equivalent grain yield with a significant (36.6%) reduction of N application (101 kg ha-1) than the previous fixed-time split N recommendation and a better economic advantage for the rainfed lowland rice production in Fogera Plain.

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Effects of Different Rice Based Double and Relay Cropping-Systems on Productivity and Sustainability of Rice Production in Fogera Plain

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Abstract

Relay and double cropping options could assist in increasing the profitability and sustainability of the rice-based cropping system. An experiment was conducted at Fogera Plain in five cropping seasons of 2016-2020 at a fixed field in the main research station of Fogera National Rice Research and Training Center. Seven relay and double cropping treatments following the main season rice were tested in RCBD with three replications. The treatments were: -T1- only rice in the main seasons, T2= planting onion in the off seasons, T3= planting tomato in the off seasons, T4= planting onion and tomato in the off seasons rotating them across years, T5= relay intercropping of grass pea with rice, T6= planting chickpea in the off seasons, and T7= planting mung bean in the off-season. The statistical analysis indicated that the preceding off-season double and relay cropping treatments were having significant (P <0.05) effect on the succeeding rice number of effective tillers, grain yield, straw yield, and thousand seeds weight. The 7th treatment, whereby mung bean was double-cropped in the offseason, resulted in the highest effective tillers, grain, and straw yields. The treatment had a grain yield advantage of 42.7% compared to the 1st treatment (only rice). The highest NB (Birr 1,397,876.55 /ha/5yrs) with an acceptable level of MRR (5832.2%) was observed from the same treatment. It is thus recommended that mung bean is a better double cropping option for better economic advantage and sustainability of the rainfed lowland rice production in Fogera plain.

Keywords: Agricultural intensification, Diversification, Sustainability, Profitability, Double cropping, Relay cropping, Rice.

Introduction

In rain-fed rice fields in Fogera Plain, only a single rice crop is commonly planted in the rainy season. There is a declining trend in rice yield due to monocropping (Tegegne and Becker, 2019; Afework Hagos and Lemma Zemedu, 2014). It is a well-established fact that the yield of cultivated crops is higher in crop rotation compared to monoculture under identical conditions (Shah *et al*., 2021). Rotation breaks soil pathogen and pest cycles, reduces pesticide use, declines soil erosion, facilitates weed control, enhances crop yield and productivity, and restores fertility if legumes are included (Han-ming *et al*., 2019). However, crop rotation is quite difficult in the rainfed lowland rice production ecosystem due to the water logging in the main season, which crops except rice cannot tolerate and survive.

Cropping intensification in rainfed rice-based farming systems through multiple cropping after the rice harvest using residual soil moisture and supplemental irrigation offers a way to increase agricultural productivity and boost rural incomes (Promkhambut and Arunee, 2017). Crop diversification, which reduces fallow and decreases inputs, is being promoted to improve economic and environmental sustainability (Peterson *et al*. 1993). Many farmers in Fogera Plain produce vegetable crops like onions and tomatoes in the offseason using available irrigation sources. This rice production in the main season and vegetables in the off-season could all contribute to the decline of soil fertility and production. The farmers also have the habit of rice-grass pea relay cropping, which widely exists in the area (Yayeh and Fekremariam, 2014). However, the relay-cropped grass pea faces problems associated with pests, requiring the producers to apply chemicals frequently (Akalu *et al*., 2009). In the case of Fogera Plain, it is quite a time to look for other crop diversity options for ensuring the sustainability of rice production in the area. The experiment was conducted to study the effects of different relay and double cropping options on the sustainability and profitability of rice production in Fogera Plain.

Materials and Methods

The experiment was conducted at Fogera Plain in five cropping seasons of the 2016–2020 cropping seasons at a fixed field in the main research station of Fogera National Rice Research and Training Center. The experimental site is located at latitude 11°49′55 North and longitude 37°37′40 East at an altitude of 1815 meters above sea level. The study site receives average mean annual rainfall and minimum and maximum temperatures of 1219 mm, 12.75 °C, and 27.37°C, respectively. The long-term rainfall data (1986–2017) indicated that much rainfall occurred in July and August (Figure 1).

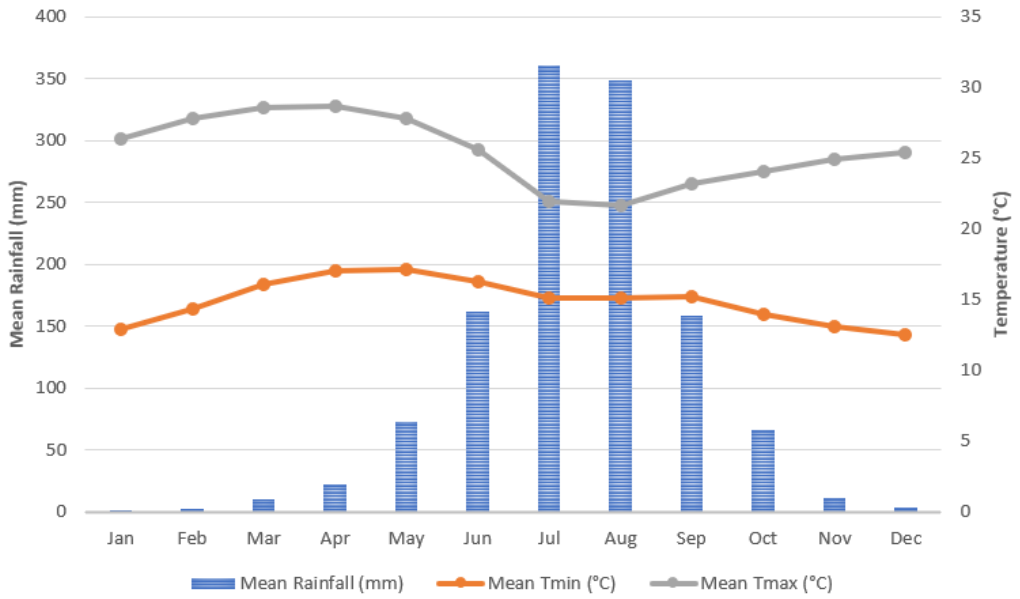

Figure 1. Rainfall and Temperature condition of Fogera Plain for the period 1981-2017

The soil analysis conducted for the sample collected just before executing the experiment in 2016 indicates that the soil at the experimental site was found to be heavy clay with a pH of 5.81, which is slightly acidic and is a preferred range for most crops (Table 1). The electrical conductivity (EC) of the soil was 0.525 ds/m and the cation exchange capacity (CEC) was 33.8 cml(+)/kg. Total nitrogen content (%) was 0.19, which is within the range of low levels (0.02-0.5%) for tropical soils. The available P content of the experimental site soil was 8.0 ppm, which lies in a range of deficiency (< 20–40 mg/kg) for most crops (Landon, 1991). The organic carbon content of the soil was 1.9%, which is within a range of medium (2-4%) for Ethiopian soils as per criteria developed by Murphy (1968).

Table 2. Relevant soil physicochemical properties of the experimental rice field just before beginning the experiment (2016)

Soil properties	Units	Minimum Value
Textural class		Heavy clay
Chemical properties		
pH (H_2O)	-	5.81
EC	ds/m	0.525
CEC	Cml(+)/kg	33.8
Total nitrogen (TN)	%	0.19
Organic carbon (OC)	%	1.9
Available Phosphorus	Ppm	8.0

Treatments

Seven treatments of relay and double cropping following the main season rice were tested in RCBD with three replications. The treatments are presented in Table 2 below.

Table 2. The whole set up of Treatments (TRTs) across the five years

TRTs	1st year	2nd year	3rd year	4th year	5th year
1	Rice	Rice	Rice	Rice	Rice
2	Rice + Onion Double crop	Rice + Onion Double crop	Rice + Onion Double crop	Rice + Onion Double crop	Rice + Onion Double crop
3	Rice + Tomato Double crop	Rice + Tomato Double crop	Rice + Tomato Double crop	Rice + Tomato Double crop	Rice + Tomato Double crop
4	Rice + Onion Double crop	Rice + Tomato Double crop	Rice + Onion Double crop	Rice + Tomato Double crop	Rice + Onion Double crop
5	Rice + Grass pea relay	Rice + Grass pea relay	Rice + Grass pea relay	Rice + Grass pea relay	Rice + Grass pea relay
6	Rice + Chick pea Double cropping	Rice + Chick pea Double cropping	Rice + Chick pea Double cropping	Rice + Chick pea Double cropping	Rice + Chick pea Double cropping
7	Rice + Mung Bean Double cropping	Rice + Mung Bean Double cropping	Rice + Mung Bean Double cropping	Rice+ Mung Bean Double cropping	Rice + Mung Bean Double cropping

Experimental Materials, data collection and analysis

Rice (Oryza sativa) variety X-jigna, tomato (Solanum lycopersicum) variety "Cochoro", mung bean (Vigna radiata L. Wilczek) variety N-26 /Rasa/, Onion (Solanum esculentum) variety Bombay Red, Grass pea local variety, chickpea variety Arerti, were used with their respective agronomic recommendations. Agronomic data were collected on plant height, the number of effective tillers, grain yield, straw yield, thousand seeds weight, and harvest index depending on the specific crop character. Statistical analysis was performed using the statistical analysis system (SAS) software version 9.2 (SAS-Institute 2008). Whenever the F-test showed a significant difference among treatments for a parameter in question, the mean separation of treatments was performed using the least significant difference (LSD) method. For the profitability of the treatments, a cost-benefit analysis was carried out by following the CIMMYT partial budget analysis method (CIMMYT 1988). Respective prices of rice grain (Birr 16 per kg) and straw (Birr 2.0 per kg), check pea grain (Birr 50 per kg), chickpea straw (Birr 2.5 per kg), mung bean grain (Birr 50 per kg), mung bean straw (Birr 2.5 per kg), grass pea grain (Birr 43.6 per kg), grass pea straw (Birr 2.5 per kg) tomato (Birr 12.4 per kg), onion (Birr 21 per kg), were taken. Moreover, the variable costs

related to each treatment, like seed, fertilizer, pest management, and irrigation, were considered.

Results and Discussion

The statistical analysis indicated that the preceding off-season double and relay cropping treatments were having significant ($P < 0.05$) effect on the succeeding rice number of effective tillers, grain yield, straw yield and thousand seeds weight (Table 3).

Table 3. Analysis of variance (ANOVA) for with mean square values for yield components and yield of rice

Source	Df	Mean Square					
		Plant Height (cm)	Effective Tillers (per 1 m)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Thousand Seeds Weight (g)	Harvest Index (%)
Treatment	6	25.396NS	25.396**	5.704**	55.450**	7.801NS	12.322NS
Year	3	3349.181**	3349.181**	10.733**	18.634**	101.756**	89.262**
Year x TRT	18	26.7604NS	26.760**	0.426NS	2.445NS	4.590NS	7.631NS
CV (%)		10.34	12.69	12.77	14.73	10.45	12.6

The 7th treatment, whereby mung bean was double-cropped in the offseason, resulted in the highest number of effective tillers (327.8 m-2), grain (5.11 t ha-1), and straw yields (13.54 t ha-1) (Table 4). The 6th treatment, whereby the chickpea was double-cropped in the offseason, resulted in statistically equivalent tiller count, grain, and straw yields to those of the 7th treatment. However, the rest of the five treatments had significantly lower values of the stated parameters than the 7th and 6th treatments, but there was no statistical difference among them (Table 4). A significant difference between the two groups might be associated with the nitrogen fixation of the mung bean and chickpea crops. The 7th treatment had a grain yield advantage of 42.7% and the 6th advantage of 40.5%, compared to the 1st treatment, single rice cultivation in the main season without off-season crop production.

Table 4. Effects of offseason double and relay crops on rice yield components succeeding rice crop

Treatment	Number of Effective Tillers per 1m row	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
1	167.7^{b}	3.58^{b}	8.84^{b}
2	182.2^{b}	3.73^{b}	9.46^{b}
3	176.5^{b}	3.62^{b}	9.41^{b}
4	178.3^{b}	3.59^{b}	8.32^{b}
5	180.6^{b}	3.82^{b}	9.13^{b}
6	316.9^{a}	5.03^{a}	13.18^{a}
7	327.8^{a}	5.11^{a}	13.54^{a}
CV (%)	12.69	12.77	14.73

Similarly, Muhammad *et al*. (2010) reported the residual effect of mung bean on the subsequent wheat crop. The authors further elaborated that, averaged across pre-season mung bean production, the wheat grain yield increased by 21%.

Economic analysis to compare the treatments for their profitability was done following the CIMYYT (1988) partial budget analysis method. Grain and straw yield adjustments to 90%, calculations of total variable costs (TVC), gross benefits (GB), and net benefits (NB) were performed (Tables 5 and 6).

Table 5. Mean grain and straw yields of rice and companion crops averaged as per a year

Treatment	Rice Grain Yield (t ha-1)	Rice Straw Yield (t ha-1)	Onion yield (qt ha-1)	Tomato yield (qt ha-1)	Chickpea Grain Yield (t ha-1)	Chickpea straw Yield (t ha-1)	Mung bean Grain Yield (t ha-1)	Mung bean straw Yield (t ha-1)
1	4.17	9.31	0	0	0	0	0	0
2	4.83	11.55	50	0	0	0	0	0
3	4.37	10.64	0	41.7	0	0	0	0
4	4.80	10.72	50	41.7	0	0	0	0
5	4.91	10.95						
6	4.95	11.91			3.3	4.8		
7	4.94	11.42					4.49	6.1

Table 6. Five years cumulative gross benefit, total variable cost and net benefit analysis

Treatment	Total Gross Benefit (Birr/ha/5yrs)	Total Variable Cost (Birr/ha/5yrs)	Total Net Benefit (Birr/ha/5yrs)
1	337320.0	132751.0	204569.1
2	826200.0	306584.3	519615.7
3	578016.0	265870.0	312146.0
4	709934.4	290298.6	419635.8
5	678825.0	155778.4	523046.6
6	1277280.0	184528.4	1092751.6
7	1568655.0	170778.5	1397876.5

Dominance analysis was carried out after arranging the treatments in their order of TVC. A treatment was considered dominant if it had a higher TVC but a lower NB than a previous treatment with a lower TVC and a higher NB (Table 7). Non-dominated treatments were selected, and the marginal rate of return (MRR) was computed (Table 8). According to the CIMYYT (1988) partial budget analysis methodology, treatments exhibiting the minimum MRR of >100% are considered to compare their NB. The highest NB (Birr 399,958.5 /ha/5 yrs) with an acceptable MRR (140.82) was observed from the 7th treatment, whereby mung bean is planted as an off-season crop following the main season rice cultivation.

Table 7. Dominance Analysis

Treatment	Total Variable Cost (Birr/ha/5yrs)	Total Net Benefit (Birr/ha/5yrs)	
1	132,751.0	204,569.1	
5	155,778.4	523,046.6	
7	170,778.5	1,397,876.5	
6	184,528.4	1,092,751.6	D
3	265,870.0	312,146.0	D
4	290,298.6	419,635.8	D
2	306,584.3	519,615.71	D
D= Dominated treatment			

Table 8. Marginal Rate of Return (MRR) Analysis

Treatment	Total Variable Cost (Birr/ha/5yrs)	Total Net Benefit (Birr/ha/5yrs)	MRR (%)
1	132,750.95	204,569.05	
5	155,778.45	523,046.55	1383.0
7	170,778.45	1,397,876.55	5832.2

In line with the current finding, Promkhambut and Arunee (2017) stated that farmers usually get a higher return per unit of land from crops grown after rice than from mono-cropping rice. Availability of markets and institutional support were the most critical factors contributing to multiple crops (Promkhambut and Arunee, 2017). The fact that growing vegetable crops provide the lowest returns may explain the problems that Fogera Plain farmers are facing with the lowest seasonal market prices of onions and tomatoes, which need policy interventions in the marketing of particular high-value commodities that they widely produce (Dawit and Tirhas, 2021). In recent years, most smallholder rice farmers have yet to be able to benefit well from their onion and tomato productions. For rice farmers engaged in rice production, the prevailing farmgate price of most vegetables has been reported to be far lower than the cost of production (Dawit and Tirhas, 2021). Previous studies showed that the cost of onion production in

the Fogera district was, on average, 3.42 ETB/kg; however, farmers have faced an increase in the cost of production, and the farmgate unit price of onion in 2021 (March–June) was lower than the cost incurred, which was in the range of 1-2 ETB/kg. As a result, farmers engaged in onion production experienced substantial economic losses. To minimize the extent of additional losses due to the costs of onion harvesting in 2021, rice farmers ploughed their onion fields without harvesting the onions so that the fields would be ready for rice production. Production of other alternative off-season crops is vital in the current Fogera Plain situation. Farmers are nowadays engaged in the off-season production of tef and emmer wheat other than vegetable crops. However, planting cereal crops could negatively impact the sustainability of rice production due to the possible over-depletion of soil fertility. Mung bean could be another good option for crop diversity and the sustainability of rice production. Jayaram *et al*. (1993) reported mung bean's advantages as an option to diversify the rice-based cropping system. Muhammad *et al*. (2010) also reported the economic and ecological advantages of mung bean inclusion during the post-rice fallow period in the rice cropping system.

Conclusion and Recommendation

After long years of continuous monocropping, a decline in rice yield is becoming common in Fogera Plain. Besides using fertilizers to increase production, considering crop rotation, relay, and double cropping options could assist in increasing the profitability and sustainability of the rice-based cropping system. The experiment conducted for five years on rice double and relay cropping indicated that the double cropping of mung bean planted in the off-season after the main season rice had a positive impact on the succeeding main season rice. The system profitability was also found to be higher. Thus, mung bean is recommended as a double cropping option for better economic advantage and sustainability of the rainfed lowland rice production in Fogera Plain.

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Response of Rain-Fed Lowland Transplanted Rice to Different Nitrogen and Phosphorus Fertilizer Rates in Fogera Plain, Northwest Ethiopia

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Abstract

An experiment was conducted at Fogera Plain during the rainy seasons of 2018/19 and 2019/20 to determine, economically optimum rates of Nitrogen and Phosphorus fertilizer on yield of transplanted rice in Fogera plain, Northwest Ethiopia. Five levels of N rates (0, 92, 184,276 & 368 kgha-1) and four levels of P2O5 rates (0, 23, 46 & 92 kgha-1) were combined factorially and laid in RCB Design with three replications. The combined analysis of the two years result showed that very highly (P<0.001) significant effect on plant height, number of total tillers/m2 per m2 and number of fertile panicles per m2, grain yield, straw yield and harvest index. Whereas highly (P<0.01) significantly affected panicle length. The highest grain yield (4.56 t ha-1) was obtained at 368-46 N- P2O5 kg ha-1. The economic analysis has exhibited that the combined application of 184-46 N- P2O5 kg ha-1 is the most profitable treatment with mean net benefit of 63928.2 Birr ha-1. Therefore, it can be concluded that application of nitrogen and phosphorous fertilizers at rates of 184-46 N - P2O5 kg ha-1 is the best recommended for rainfed lowland transplanted rice production in Fogera plain

Keywords: Transplanted; Low land rice; rain fed, grain yield, N, P, net benefit

Introduction

Rice (*Oryza sativa* L.) is one of the most popular field crops among other cereals in the world, being cultivated in different agro-ecosystems. Rice serves as the staple food for world's half population (FAO 2004: 87-91). Rice is a source of energy for major portion of world's population and ranks second after maize with respect to production (Manjappa and Shailaja, 2014). Therefore, sustainable rice production is necessary to overcome food scarcity throughout the globe. Besides various abiotic stresses causing extensive losses to sustainable rice production, imbalanced nutrient, also leads to decreased grain yields, with marginal net returns (Zafar *et al.* 2018: 65-9; Wattoo *et al.*, 2018).

The world average paddy rice productivity is about 4.6 tons ha^{-1} (FAOSTAT, 2018). The national average productivity of rice in Ethiopia is still however low about 2.8 t ha^{-1} (CSA, 2018). Weeds, pests, soil nutrient deficiencies and terminal moisture stress are the major causes of low rice productivity in Ethiopia (MoARD,

2010; Gebey *et al*., 2012). There are a number of agronomic managements constrains with this crop. Rice is becoming a high potential crop and there is a lack of appropriate agronomic management recommendations that could help to maximize the productivity of the cultivation techniques in the study area.

Poor soil fertility is among the major factors limiting rice production in Ethiopia. Nitrogen, phosphorus, and potassium are applied as fertilizers in large quantities to rice fields, and a deficiency of either of the nutrient leads to yield losses (Subedi *et al.*, 2019). Nitrogen and phosphorus are often cited as the most limiting nutrients in agricultural soils of Ethiopia (Molla and Sofonyas, 2018). Appropriate fertilizer application is an important management practice to improve soil fertility and rice production. Availability of plant nutrients, particularly nitrogen at various plant growth stages is of crucial importance in rice production (ShaRada *et al*., 2018; Daquiado, 2019). Area specific recommendation of nitrogen and phosphorous fertilizer rate is vital for rice production in the study area. This research was therefore conducted to determine economically optimum Nitrogen and Phosphorus fertilizer rate for transplanted rice production in Fogera plains.

Material and Methods

Description of the study area

The field experiments were conducted on transplanted rice in Fogera plain, South Gondar Zone of Amhara Regional State in 2018/19 and 2019/20 main cropping seasons. The experimental site is located between Latitude 11°49'55" North and Longitude 37° 37' 40" East at an altitude of 1815 meters above sea level. The study site receives average mean annual rainfall, minimum and maximum temperature of 1219 mm, 12.75°C and 27.37°C, respectively. The experimental site soil was found to be heavy clay with a pH of 6.19, which is slightly acidic and is a preferred range for most crops (Table 1). Total nitrogen content (%) was 0.15, which is within the range of low levels (0.02–0.5%) for tropical soils. The organic matter content of the soil was 2.76%, which is within a range of medium (2–4%) for Ethiopian soils as per criteria developed by Murphy (1968). The available P content of the experimental sites soil was 6.5 ppm, which lies in a range of deficiency (< 20-40mg/kg) for most crops (Landon, 1991). The CEC of the soil was 55.4 cmol kg^{-1} soils.

Table 1. Soil physicochemical properties of the experimental rice field before planting in Fogera Plain of Ethiopia

Sand (%)	Silt (%)	Clay (%)	Textural class	PH (1:2.5)	EC (ds/m)	CEC (cmole kg^{1})	Organic matter (%)	Organic carbon (%)	Total nitrogen (%)	Available phosphorus (ppm)
22	14	64	Clay	6.07	0.450	55.4	2.76	1.6	0.15	6.5

EC=Electron conductivity; CEC= Cation exchange capacity; ppm=parts per million; $cmolekg^{-1}$; =cent mol per kilogram; ds/m=deci Siemens per meter

Treatments and Experimental Design

The experimental treatments were comprised of factorial combinations of five levels of N rates (0, 92, 184,276 & 368 kg ha^{-1}) and four levels of P_2O_5 rates (0, 23, 46 & 92 kg ha^{-1}) in randomized complete block design (RCBD) replicated three times. The gross and net plot sizes were 4 m x 3 m (12 m^2) and 3 m x 2 m (6 m^2), with 1 m spacing between plots and blocks, respectively. For field planting, seedlings were transplanted at the spacing of 25 cm between rows and 20 cm between plants. Three seedlings per hill were planted for each plot (Tilahun *et al.*, 2013). To control mixing of treatments, experimental plots were bunded manually. The variety X-Jigna was used for this experiment.

Data Collection

Data were collected from a net plot size of 3 m x 2 m avoiding two rows from the left and two rows from the right as border rows and 50 cm from each of the top and bottom sides of the plots. Data collected include plant height, panicle length, number of total tillers/m^2, and number of fertile panicle/m^2, number of filled grain/panicle, thousand seeds weight, grain yield, straw yield and harvest index. The plant height was taken at physiological maturity of the crop by selecting five random plants. Number of tillers was counted just before harvesting by using quadrant. The total sundried biomass of the harvested rice was recorded before threshing. The rice grain yield and thousand seeds weight were adjusted at 14% standard moisture content. The harvest index was calculated as the ratio of grain yield to biological yield following the equation:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} * 100.$$

Statistical Analysis

All collected data were subjected to analysis of variance (ANOVA) using SAS software version 9.2 (SAS Institute, 2008). Since the test of homogeneity of variances for each parameter was non-significant, combined analysis of variance was done over the years to determine the effects of N and P application rates by year interaction. Wherever treatment differences are found significant, mean separation of treatments would be calculated based on results of F-test and probability levels of 0.01 and 0.05 depending on the results of the ANOVA. The prevailing cost of inputs and out puts in year 2020 considered for the analysis. The cost of Urea and NPS fertilizers for the stated period at Fogera were Birr 13.1 and 14.3, respectively while the price of rice grain and straw were Birr 13.5 and 1.2, respectively.

Results and Discussion

Plant Height

The analysis of variance indicated that plant height of transplanted rice was highly significantly ($P < 0.001$) affected by the main effects of nitrogen rates, but not by phosphorous rates and their interaction (Table 2). The highest plant height (108.3 cm) was recorded at the highest nitrogen rate of 368 kg ha^{-1}, while the lowest plant height (85.7 cm) was recorded at the control without N application (Table 2). The result indicated that plant height increased significantly by increasing the amount of fertilizer. In line with the present findings, Sah *et al.*, (2019) had reported that different level of N caused significant difference in plant height, the height of plant found to increase from 60 kg^{-1} N to 120 kg N ha^{-1}.The increase in plant height of rice in response to the increase of N fertilizer rates was probably due to enhanced availability of N, which enhanced further cell division and more leaf area that in turn resulted in higher photo assimilates and thereby resulted in more dry matter accumulation (Shiferaw *et al.* 2012).

Panicle Length

The analysis of variance indicated that panicle length of transplanted rice was highly significantly ($P < 0.01$) affected by the main effects of nitrogen rates, but not by phosphorous rates and their interaction (Table 2). The highest panicle length (22.5 cm) exhibited at the rate of 368 kg ha^{-1} N, followed by 276 and 184 kg ha^{-1} N which was statistically similar (Table 2) whereas, the lowest panicle length (20.0 cm) was observed at the control without N fertilizer application. This result might be due to nitrogen takes part in panicle formation as well as panicle elongation and for this reason, panicle length increased with the increase of N fertilization. The findings of many authors had confirmed for the significant effect of nitrogen levels on panicle length (Fageria and Baligar, 2001; Gewaily *et al*., 2018; Sah *et al.*, 2019). Sah *et al.*, (2019) recorded highest panicle length with 180 kg N application while Fageria and Baligar, (2001) stated nitrogen application of 210 kg ha^{-1} exhibited larger panicle length. Riste *et al.* (2017) stated that the highest and most significant panicle length (27.06 cm) was recorded with the application of fertilizer dose at 60 kg Nha^{-1}compared to the control without N fertilizer. On the other hand, Molla and Sofonyas (2018) reported longest panicles of 20.19 cm at the rate of 46 kg N ha^{-1}, while they noted the shortest panicles in the control plots.

Number of Tillers per m^2

The analysis of variance for number of total tillers and number of fertile panicles showed that the main effects of nitrogen and phosphorous on both yield components were highly significantly ($P<0.01$) and significantly ($P<0.05$), respectively. The interaction of N and P significantly ($P<0.05$) affected the number of tillers, but not the number of fertile panicles (Table 2). The highest

number of total tillers and fertile panicles was recorded at the highest rate of 138 kg ha^{-1} N while their lowest number was observed at the control without N fertilizer application (Table 2). Similarly, the highest number of total tillers and fertile panicles were exhibited at the rate of 92 kg ha^{-1} P2O5, which were statistically at par at the rate of 46. The interaction of N and P significantly ($P<0.05$) affected the number of tillers, but not the number of fertile panicles (Table 2). The highest number of total tillers and fertile panicles was recorded at the highest rate of 138 kg ha^{-1} N while their lowest number was observed at the control without N fertilizer application (Table 2). Similarly, the highest number of total tillers and fertile panicles were exhibited at the rate of 92 kg ha^{-1} P2O5, which were statistically at par at the rate of 46 kg ha^{-1} P2O5. Number of total tillers was significantly responding to the interaction of nitrogen and phosphorous fertilizer applications. The highest number of total tillers was observed at the interaction of 138 kg ha^{-1} N and 92 kg ha^{-1} P2O5, while the lowest number of total tillers was recorded at the interaction of the controls without application of both N and P fertilizers (Table 2). In conformity with the results of the present experiment, Kumar *et al*. (2017) had reported maximum number of total and effective tillers m-2 with application of 150 kg N and75 kg P2O5 ha^{-1}. On the other hand, Riste *et al*. (2017) reported maximum number of tillers and panicles per m^2at the rate of 120 kg N and 90 kg P2O5 ha^{-1}.

Number of Fertile Panicles per m^{-2}

The maximum number of fertile panicles per m^2 (332) were recorded at the rate of 368 kg ha^{-1} N respectively, which were statistically similar. While the lowest number of fertile panicles per m^2 (152) was observed from the control treatment (without N fertilizer application) (Table 2). This result might be due to application of sufficient amount of nitrogen and phosphorus fertilizer enhanced for the formation of different organs in the rice plant and facilitates other physiological processes. In line with the present results, among the yield attributes, the number of productive tillers is an important agronomic trait, which finally determines the number of fertile panicles and grain yield per unit land area (Ginigaddara and Ranamukhaarachchi, 2011). Application of NP fertilizers at optimum rates might result in superior growth and development that eventually reflected with significantly superior yield attributes (Kumar *et al*., 2017; Riste *et al*., 2017). Inferior crop growth in the controls without NP applications might be closely associated with insufficient availability of NP below their optimal requirements (Riste *et al*., 2017).

Table 2. Combined analysis of N and P fertilizer rates on yield and yield components of transplanted rice in Fogera plain

N level	PH (cm)	PL (cm)	NT/m^2	Nfp/m^2	Nfg/p	Tgw(g)	Agy (t/ha)	Sy (t/ha)	Hi (%)
0	85.7d	20.0c	168e	152e	108	30.5	1.86c	4.9d	37.3ba
92	97.8c	21.3b	229d	213d	113	29.6	3.00b	8.1c	37.6ba
184	102.7bc	21.8ba	283c	264c	118	29.6	4.29a	11.3b	37.9a
276	103.8ba	22.1ba	326b	300b	109	30.0	4.29a	12.0b	35.8b
368	108.3a	22.5a	363a	332a	106	29.9	4.56a	13.6a	33.9c
LSD (5%)	***	**	***	***	NS	NS	***	***	***
P levels									
0	100.3	21.7	263b	242b	117	30.0	3.38b	9.5b	36.1
23	100.8	21.6	277ba	260ba	111	29.8	3.57b	9.8b	36.7
46	99.8	21.5	289a	263a	107	30.2	3.85a	10.6a	36.8
92	97.9	21.3	266ba	244ba	107	29.7	3.61ba	10.0ba	36.5
LSD (5%)	NS	NS	NS	NS	NS	NS	**	*	NS
N*P	NS	NS	***	***	NS	NS	NS	NS	NS
CV (%)	9.17	9.55	16.1	17.7	16.09	11.3	13.9	14.4	8.95

PH = plant height (cm), PL = panicle length (cm), NFP = number of fertile panicles/m^2, NFG/P= number of filled grain per panicle, Agy = grain yield (t ha^{-1}), SY = straw yield (t ha^{-1}), TGW=thousand grain weight (g), HI = harvest index (%), *** = very highly significant at P<0.001, highly significant at P<0.01 * = significant at P<0.05, ns = not significant at P≥0.05

Grain Yield

The grain yield of transplanted rice exhibited highly significant ($p< 0.001$) response to the main effect of nitrogen rates and was highly significantly affected by phosphorous rates but not their interaction. On the contrary, thousand seeds weight was not affected by the main and interaction effect of nitrogen and phosphorous rates. The highest grain yield (4.56 ton/ha) was obtained at the highest nitrogen rate of 368 kg ha-^{1} N followed by nitrogen rates of 276 and 184 kg ha-^{1} N (4.29 and 4.29 ton /ha) respectively, which was statistically similar. (Table 2) While the lowest grain yield (1.86 t/ha) was recorded at the control without N application (Table 2). The result indicated that the highest grain yield obtained might be attributed to the highest number of total tillers per m^2 and a greater number of fertile panicles per m^2 that cumulatively increased the grain yield. Nitrogen and Phosphorus are fundamental to crop development because they form the basic component of many organic molecules, nucleic acids and proteins (Vinod and Sigrid, 2012). The increase in the grain yield in response to Nitrogen and phosphorus fertilizer could be attributed to the production of more productive tiller and fertile panicle numbers (Azhiri *et al*., 2004). The results agree with the finding of Amanullah *et al*., (2016) The higher grain yield may be attributed to better growth with higher nutrient availability, a higher photosynthetic rate of the plants, and more photosynthetic partitioning into the reproductive parts. Different authors reported that nitrogen application increased grain yield, with the highest values recorded at the nitrogen application treatment of 209–220 kg N ha–1 (Fageria and Baligar, 2001; Dong *et al*., 2016; Gewaily *et*

al., 2018). A bit differently, Liu *et al*, (2019) reported the highest mean grain yield of 10.5 t ha^{-1} at 300 kg ha^{-1} N treatment, elaborating that as the N rates increased to 360 kg ha^{-1}; mean grain yield decreased to 9.4 t ha^{-1}. The optimum fertilizer level plays an important role in achieving crops potential yield. Among the fertilizers, N is most important for the proper growth and development of rice (Sah *et al.*, 2019). The increase in grain yield might be due to nitrogen application enhancing dry matter production, improving rice growth rate, promoting elongation of internodes, and the activity of growth hormones like gibberellins (Gewaily *et al*., 2018).

Straw Yield

The rice straw yield was highly significantly ($P<0.001$) affected by the main effect of nitrogen rates but significantly ($P<0.05$) affected by phosphorus rates, not by the interaction of the two rates (Table 2). Significantly higher straw yield (13.6 ton /ha) was obtained from maximum nitrogen rate of (368 kg/ha N) followed by 276 and 184 kg/ha N (12.0 and 11.3 ton/ha) respectively which was statistically similar. The lowest straw yield (4.9 ton/ha) were recorded from Zero N application (Table 2). This might be due to the application of nitrogen fertilizer rate according to crop requirements increased the nitrogen absorption, and consequently, better utilization of applied nitrogen leads to higher yield attributes and finally resulted in higher grain and straw yields. Moreover, the tall plant height, the higher number of total tillers per m^2 and longer panicle length might have contributed to an increase in straw yield. This is in agreement with Maragatham, *et al.* (2010) who stated that better straw yield could be explained a higher capability of rice to utilize more N through the expression of better growth by accumulating more plant dry biomass. The better grain and straw yields at the higher rates of N and P nutrients may be attributed to the fact that the application of fertilizer may have resulted in optimum levels of nutrients for crop uptake and translocation to the sink thereby expressing superior crop growth and development (Riste *et al*., 2017). In support of the present finding, Kumar *et al.* (2017) stated that the grain and straw yields of rice increased up to an application of 150:75 N-P_2O_5 kg ha^{-1}. Masni and Wasli (2019) also reported that the grain and straw yields of upland rice were significantly affected and best at 60N and 35 kg P kg ha^{-1}.

Harvest index

Nitrogen showed a highly significant negative effect on harvest index of rice crop (Table 2). As revealed in the analysis of variance, the harvest index responded highly significantly ($P<0.001$) by the main effect of nitrogen and phosphorous fertilizer rates but not by their interaction (Table 2). As indicated in Table 2, harvest index decreased with increasing levels of N and P fertilizer at the maximum rate of 368 and 276 kg of N P_2O_5 ha^{-1} (Table 2). The highest harvest index among the nitrogen rates was recorded at 184 kg ha^{-1} N. The lowest harvest

index was recorded at 368 kg ha^{-1} N followed by 276 kg ha^{-1} N (Table 2). Results of a number of similar studies Kumar and Rao, (1992); Patra *et al.*, (1992) and Hari *et al.*, (1997) have also revealed decreasing trends of harvest index with increased rates of applied N fertilizer. They also stated that harvest index in rice is closely related to the percentage of productive tillers, which generally decreases with the increase of N fertilizer. Mulugeta Seyoum and Heluf Gebrekidan (2006) also reported that harvest index consistently declined with increasing levels of applied N up to the highest level 150 kg of N ha^{-1}. On the other hand, application of 13.2 kg P ha^{-1} significantly increased harvest index of rice. Generally, increasing the levels of N fertilizer from 0 to 150 kg ha^{-1} decreased the harvest index of rice from 44.93 to 37.22%

Partial budget analysis

Based on the principles of economic analysis as per CIMMYT (1988), the minimum acceptable marginal rate of return (MRR %) should be 100%. The economic analysis was done on the basis of the prevailing prices of variable costs using the Ethiopian currency (Birr). The price of NPS and Urea fertilizer was 1430.00 and 1310.00 Birr per 100 kg, respectively. Moreover, the price of rice straw valued at Birr 120.00 per 100 kg. In addition to this, the prices of seed for planting material during the cropping season were 1350.00 Birr per 100 kg. Grain and straw yield adjustments, calculations of total variable costs (TVC), gross benefits (GB) and net benefits (NB) were performed (Table 3). Dominance analysis was performed after arranging the treatments in their order of TVC (Table 3). Treatments are considered as dominated if it has higher TVC but lower NB than a previous treatment with lower TVC and higher NB (Table 3). Non dominated treatments were taken out and marginal rate of return (MRR) was computed (Table 3). The economic analysis of the result of this experiment revealed that the highest NB (Birr 63928.2 ha-^{1}) with an acceptable level of MRR (1677.59) was observed at 184-46 N-P2O5 kg/ha (Table 3). In agreement to the present finding Irfan *et al*., (2016) reported that rice genotypes performed efficiently at 120 kg N + 90 kg P2O5 ha-^{1} where the highest paddy yield, net production value, and profit were obtained.

Table 3 Effects of N and P fertilizer rates on economic benefit of Transplanted rice in Fogera plain

N kg/ha	P2O5 kg/ha	GY (t/ha)	SY (t/ha)	AGY (t/ha)	ASY(t/ha)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	Dominance	MRR %
0	0	1.74	4.73	1.56	4.26	26228.5	0	26228.5		-
0	23	1.78	4.81	1.60	4.33	26773.6	715	26058.6	D	-
0	46	2.15	5.68	1.94	5.11	32309.3	1430	30879.3		325.23
0	92	1.72	4.53	1.54	4.08	38740.9	2620	36120.9		440.47
92	0	2.57	6.93	2.32	6.23	25747.2	2860	22887.2	D	-
92	23	3.21	8.51	2.89	7.66	48230.2	3158.03	45072.2		1663.73
92	46	3.23	8.47	2.90	7.62	48330.7	3696.05	44634.6	D	-
92	92	3.14	8.36	2.82	7.53	47159.9	4772.11	42387.8	D	-
184	0	3.84	10.35	3.46	9.32	57836.5	5240	52596.5		361.40
184	23	4.05	10.68	3.64	9.61	60680.3	5778.03	54902.3		428.56
184	46	4.71	12.07	4.24	10.86	70244.2	6316.05	63928.2		1677.59
184	92	4.48	11.94	4.03	10.75	67277	7392.11	59884.9	D	-
276	0	4.26	11.71	3.83	10.54	64381.6	7860	56521.6	D	-
276	23	4.03	11.94	3.63	10.75	61845.6	8398.03	53447.6	D	-
276	46	4.57	12.79	4.12	11.51	69380.8	8936.05	60444.8	D	-
276	92	4.26	11.60	3.83	10.44	64279.3	10012.1	54267.2	D	-
368	0	4.47	13.81	4.02	12.43	69187.5	10480	58707.5	D	-
368	23	4.81	13.24	4.33	11.92	72771	11018	61753	D	-
368	46	4.48	14.13	4.03	12.72	69688.1	11556.1	58132	D	-
368	92	4.44	13.39	4.00	12.05	68416.3	12632.1	55784.2	D	-

Nitrogen (kg ha-1); P2O5= Phosphorous rate (kg ha-1); TVC= Total variable cost (Birr ha-1) GY, grain yield (t ha-1) AGY= Adjusted grain yield (ton ha-1); SY= straw yield (ton ha-1) ASY= Adjusted straw yield (ton ha-1); GB= Gross benefit (Birr ha-1); NB = Net benefit (Birr ha-1) ; D=Dominance analysis and MRR(%) marginal rate of return

Conclusion and Recommendation

Basically, there are two methods of rice plant establishment namely; transplanting and direct seeding. Direct seeding is the major method of rice planting being used in Fogera plain. On the other hand, transplanting is the practice of raising seedlings in a nursery and moving them into the main field and it is the major means of rice planting used in other parts of the world. The growth, yield components and yield of X-Jigna rice variety responded more to nitrogen than phosphorus fertilizer. In this study, number of fertile panicles per m^2, and number of productive tillers as well as panicle length were the most important yield forming attributes causing significant variation in grain yield of rice. From the findings of the present experiment, highest mean net benefit of (Birr 63928.2. ha^{-1}) was obtained from nitrogen and phosphorous fertilizers at rates of 184-46 N-P_2O_5 kg ha^{1} The results of two years experiment indicated that combined application of 184-46 N-P_2O_5 kg ha^{-1} is the best treatment giving higher productivity and economic profitability. It is thus concluded that application of nitrogen and phosphorous fertilizers at rates of 184-46 N P_2O_5 kg ha^{1} is the best recommended for rainfed lowland transplanted rice production in Fogera plain and other similar agroecologies.

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Effect of Different Plant Population Density Study on Sorghum at Omonada, Jimma Zone

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Abstract

Field experiments were carried out at Omonada district, Jimma Zone, for two consecutive years 2019 and 2020 main cropping season at farmer's fields. The 14 selected treatments laid down in a randomized complete block design (RCBD) with three replications. Across season data analysis showed that most of all parameters of sorghum like stem diameter, above ground biomass, harvest index and grain yield were significantly affected by different densities except plant height. The stem diameter (1.71 t ha-1) recorded from the lower density (53333), harvest index (45.81%) recorded from the lowest density (44444), above ground biomass yield (11.65 tha-1) recorded from the highest density (363636) and grain yield (3.01 t ha-1) recorded from the highest density (181818) plants per hectare. While the lowest grain yield (1.26 t ha-1) and above ground biomass yield (2.7 t ha-1) recorded from the higher density (53333) recorded from the lower density (44444) respectively. In general, grain and above ground biomass yield were showed a linear relation with plant population densities due to morphological growth nature of the variety accommodates more plants per unit area. In conclusion, partial budget analysis based on the field prices of inputs and sorghum grain yield showed that, (166667) followed by (181818) ha-1 plant population density gave the highest net benefit of (69105.19 ETB ha-1) and (83327.77 ETB ha-1) with acceptable MMR (301.69%) and (1027.90 ETB), respectively. Therefore, from current on-farm input availability and economic feasibility sorghum Abamelko variety (166667) and (181818) ha-1 plant population recommended to the study area.

Keywords: Grain yield, net income*;* above ground biomass, plant population density

Introduction

Plant population is the prime factor for getting maximum yield which is decided by inter and intra row spacing of crops. Decreasing the distance between neighbor rows at any particular plant population has several potential advantages. First, it reduces competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement (Olson and Sander, 1988; Porter *et al*., 1997). Secondly, the maximization of light interception from early canopy closure also reduces transmittance to bottom leaves canopies. The smaller amount of sunlight striking the ground decreases the potential for weed interference, especially for shade intolerant species (Gunsolus JL, 1990). Thirdly the quicker shading of soil water being lost by evaporation (Karlen and Camp, 985).

Furthermore, earlier crop cover provided by narrower row width is instrumental to enhance soil protection diminishing water runoff and soil erosion. The nutrient use efficiency can be improved with the use of optimum plant population (Srikanth *et al*., 2009).

Sorghum can be planted in a wide range of row spacing generally ranging from 6 to 40-inch rows. The grain sorghum likely to be planted using the same equipment as planting soybean, corn or cotton and row spacing will be dependent upon the equipment the producer is currently utilizing. Grain sorghum can also be planted using a grain drill which would allow for narrow row spacing, down to 15 cm. Research from other states has indicated that yields were maximized when using rows as narrow as 25, especially when the crop was irrigated or when conditions were favorable for high yields. Though, optimal plant densities for grain sorghum differ from region to another especially those have different in soil condition. It was reported that crop row spacing's of less than 76 cm would increase grain yield in areas with high yield potential with little risk of reduced yield in areas with lower yield potential (Staggenborg, 1999). Row spacing and plant populations are variables that can have a significant impact on the net returns of sorghum producers. Grain sorghum cultivated in Omonada area was 75*25 cm and has no definite spacing especially between plants.

The more favorable planting pattern provided by closer rows enhances growth rate early in the season, leading to a better interception of sun light, higher radiation use efficiency and a greater grain yield (Westgate *et al*., 1997) and this Abamelko sorghum variety has the ability of high tillering capacity that leads to un uniform in maturity and so that, was targeted to discourage tillering, increasing plant population and resulting uniform maturity to increase yield. But according to (Duncan WG., 1985) plant population above critical density has a negative effect on yield per plant due to the effects of interplant competition for light, water, nutrient and other potential environmental factors. So, the research is initiated to determine optimal plant densities for grain sorghum study area since they differ from region to region due to different factors.

Materials and Methods

Description of the Study Area

The field experiments were conducted for two consecutive main cropping seasons in Omonada district, Jimma Zone on farmers' fields. The sites were located at 7º46' N and 36º 00'E and laid at an altitude of 1753 m.a.s.l. with soil type of the area is Upland: Chromic Nitosol and Combisol. The average maximum and minimum temperature are 9ºC and 28ºC, respectively, and reliably receive 1561 mm of rain per annum cropping season**.**

Description of the experimental materials

Plant material for the study was sorghum varieties (Abamelko) use. It is the most promising variety released by mma Agricultural Research Centre at 2001 and which adapted well to the agro-ecologies of the area and popularized.

Experimental treatment and procedures

The experimental field was ploughed and prepared following ~~the~~ conventional tillage practices before planting at all experimental locations. The land was leveled using manual power before the field layout was made. The seeds were drilled in furrows and then thinning was done after the good establishment of seedlings based on the treatments per row and plot. Fourteen plant population densities were selected, including control (Table 1) below. The randomized complete block design (RCBD) with three replications and plot size 22.5 m^2 (4.5 m x 5 m) for each treatment was used. Each factor within a replication was chosen randomly and each plot accommodates different numbers of rows based on intra-row spacing. Nitrogen fertilizer rates were applied in a split: half during planting and half at the growth stage to increase nitrogen use efficiency. All other agronomic practices were applied uniformly to all experimental plots as per their respective recommendations for maize in the study area, like hand weeding three times. The season's rainfall pattern and other weather variables were suitable for sorghum growth and development, except for shoot fly occurrence, which was controlled by chemicals.

Table 1. Treatments; 14 treatment combinations of spacing and plant population.

S.No.	Spacing (cm)	Plant population /Hectare	S.No.	Spacing (cm)	Plant population /Hectare
1	55*5	363636	8	70*5	285714
2	55*10	181818	9	75*5	266667
3	60*5	333333	10	75*10	133333
4	60*10	166667	11	75*15	88889
5	60*15	111111	12	75*20	666667
6	65*5	307692	13	75*25	53333(control)
7	65*15	102564	14	75*30	44444

Data Collection and Measurement

Plant height: plant height (cm) was recorded on five random plants at maturity by measuring the height from the ground to the tip of the panicle.

Stem diameter (girth): Stem diameter was measured and the average value of 5 randomly taken plants stem 5 cm above ground.

Biomass yield: five pre-tagged, randomly selected plants were considered for determination of above ground dry biomass weight by drying in sunlight for ten days till a constant dry weight was attained.

Grain yield: grain yield (q ha^{-1}) was recorded after harvesting from the harvestable rows. Seed yield was adjusted to 12.5% moisture using a moisture tester (Dickey-John) and converted to quintal ha^{-1} for statistical analysis. Adjusted yield=Actual yield × 100-M/100-D; where M is the measured moisture content in grain and D is the designated moisture content (12.5%).

Harvest index: was calculated as the ratio of grain yield to total above-ground dry biomass yield multiplied by 100 at harvest from the respective treatments (Donald and Hamblin, 1976). Harvest Index = Grain yield/ above-ground dry biomass yield × 100.

Partial budget analysis

To assess the costs and benefits associated with different treatments plant population density, the partial budget technique as described by (CIMMYT, 1988) was applied. Economic analysis was done using the prevailing market prices for inputs at planting and outputs, at the time the crop was harvested. All costs and benefits were calculated on hectare basis of Ethiopian Birr (ETB). The inputs and/or concepts used in the partial budget analysis were the mean grain yield of each treatment in both years, the field price of sorghum grain sale price grain minus the costs of labor for land preparation, planting, seed), the gross field benefit (GFB) ha^{-1} (the product of the field price of the mean yield for each treatment), the field price of seed rate kg ha^{-1} and the wage rate of application, and the total costs that varied (TCV), which included the sum labor for land preparation and its wage for application. The net benefit (NB) was calculated as the difference between the GFB and the TCV. The actual yield was adjusted downward by 15% to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment. There was optimum plant population density, timely labor availability, and better management (e.g., weed control, rainfall) under the experimental conditions (CIMMYT, 1988).

The dominance analysis procedure as detailed in CIMMYT (1998) was used to select potentially profitable treatments from the range that was tested. The discarded and selected treatments using this technique were referred to as dominated and undominated treatments, respectively. The undominated treatments were ranked from the lowest to the highest cost. For each pair of ranked treatments, the percent marginal rate of return (MRR) was calculated. The MRR (%) between any pair of undominated treatments was the return per unit of investment in labor and seed. To obtain an estimate of these returns, the MRR (%) was calculated as changes in NB divided by changes in cost. Thus, the MRR of 100% was used indicating for every one ETB expended there is a return of one ETB for a given variable input.

A sensitivity analysis for different interventions was also carried out to test the recommendation made for its ability to withstand price changes. Sensitivity

analysis simply implied redoing the marginal analysis with the alternative prices. Through sensitivity analysis, the maximum acceptable field price of input was calculated with the minimum rate of return as described by Shah *et al*. (2009).

Statistical analysis

Analysis of variance (ANOVA) for all collected data was computed using R software version 3.5.3 statistical software R Core Team (2019-03- 11). Whenever the ANOVA results showed significant differences between sources of variation, the means were separated using Fisher's least significant difference (LSD).

Results and Discussion

Plant Height

The result of plant height did not show significant effect ($P < 0.05$) on the plant population density**.** The tallest plant height of 236.77 cm was recorded from the highest (285714**)** plant population density, and in contrast, the shortest (53333) plant height was recorded from one of the lowest densities. This implies that there was an increase in plant height with an increase in density the decline with further increase (Table 2). The current result was in agreement with Cusicanqui and Lauer (1999) and Ferreira *et al*. (2014) report; moreover, as plant density increases to an optimal point, increases in plant height, total tiller number, leaf area index (LAI), and leaf area duration (LAD) are generally observed.

Table 2. Across-season effect of plant population densities on plant height and girth of sorghum at Omonada

Plant population densities	Plant Height (cm)	Stem Diameter/ Girth (cm)
55*5(363636)	228.00	1.41b
55*10(181818)	225.17	1.35b
60*5(333333)	232.67	1.34b
60*10(166667)	235.33	1.55ab
60*15(111111)	232.50	1.47ab
65*5(307692)	228.17	1.44b
65*15(102564)	235.10	1.47ab
70*5(285714)	236.77	1.53ab
75*5(266667)	229.83	1.47ab
75*10(133333)	233.83	1.46ab
75*15(88889)	234.00	1.58ab
75*20(66667)	224.67	1.46ab
75*25(53333)	218.17	1.71a
75*30(44444)	225.33	1.56ab
Mean	29.97	1.49
LSD (0.05)	Ns	*
CV %	6.06	10.39

Stem Diameter (Stem girth)

The result of stem diameter (Girth) was a highly significant effect ($P < 0.05$) on the plant population density. The highest stem diameter of 1.71 cm was recorded from (53333) population density which was among the lowest density (Table 2). In contrast the lowest 1.41cm was recorded from the (363636) population density which was the highest density. The result showed that there was an increase in stem diameter as population density decreased gradually. It's due to low competition for moisture, nutrients and sun radiation facilitates growth of plant. Similarly, stem diameter decreased and plant height increased as plant density increased from 6.0 to 12.0 plant m^{-2} (Chaochen *et al*., 2017).

Above ground biomass yield

The results of the analysis of variance showed that the above-ground biomass of sorghum was significantly influenced by the main effect of plant population density (Table 3). The highest (11.65 t ha^{-1}) above- ground biomass yield was recorded from (363636) but the smallest (1.26 t ha^{-1}) was recorded at the lowest (53333) plant population density. It's obvious that an increase in seed rate results in a high plant height due to competition for sun light interception, which results directly in an increase in above ground biomass yield where there is no limitation of resources like moisture and nutrients. This might be due to the fact that plant population density has a linear relationship with above ground biomass yield increase or due to the number of plants stands per unit area with good plant growth and development. The current result is supported by Nyakudya and Stroosnijder (2014) reported that high plant densities could be supported under conditions of high rainfall or irrigation, with increasing plant density resulting in a greater effective rooting depth, a larger grain yield, and improved water-use efficiency for biomass formation.

Harvest index

The effect of plant population density on harvest index showed a significant effect ($P < 0.01$) (Table 3). The highest 45.81% harvest index was recorded from (44444), and in contrast, the lowest 28.52% was recorded from (363636) plant population density (Table 3). The harvest index result showed that as density increase the decrease in harvest index. The result was in agreement with Harshlata *et al*. (2018) the lowest plant density (11.11 $plants^{-2}$) established at a plant geometry of 60 x 15 cm resulted in highest harvest index of 19.38 compared to other plant density.

Grain Yield

The statistical analysis of grain yield showed a significant response to plant population density ($P <0.05$). The highest grain yield of 3.01 t ha^{-1} obtained from (181818) plant population density. This may be due to high density plants that do not produce tillers and grow the main plant and give high yields or no yield losses,

as that of low density planted and produce tillers result in nonuniform in maturity and leads to yield loss. But (Berenguer and Faci, 2001) also reported that sorghum can take advantage of tiller production during optimal or above average conditions, leading to near-optimum yields. Generally, the current result is in agreement with the research has suggested that decreasing tiller production can result in greater yield. Bandaru *et al*. (2006) showed that planting in clumps at higher densities decreased tiller production in sorghum which results in up to 100% increase in yields. Also yield losses have been found to be greater under lowers than higher population (Johnson and Mulvaney, 1980). They found out that within row plant spacing causes higher yield losses. The grain yield increases with increase in plant population density up to (363636) then starts to decline gradually to 2.65 t/ha. Itwas due to the inter and intra specific competition to radiation and nutrients were beyond the extreme.

Table 3. Across-season effect of plant population densities on grain, above ground biomass yield and harvest index of sorghum at Omonada

Plant population densities	Grain yield (t ha^{-1})	Above Ground Biomass (t ha^{-1})	Harvest Index (%)
55*5(363636)	2.65ab	11.65a	28.52a-d
55*10(181818)	3.01a	8.26a-c	38.76a-d
60*5(333333)	2.59ab	8.97ab	34.21d-f
60*10(166667)	2.53a-c	5.77b-d	43.23a-c
60*15(111111)	1.93a-c	4.72d-d	38.04b-d
65*5(307692)	2.53a-c	8.27a-c	36.59c-e
65*15(102564)	1.66bc	4.77b-d	37.63b-d
70*5(285714)	1.50bc	5.74b-d	29.27ef
75*5(266667)	2.27a-c	7.99a-c	36.26a-c
75*10(133333)	1.98a-c	4.36cd	42.55a-c
75*15(88889)	1.83a-c	4.19cd	41.80a-c
75*20(66667)	1.73bc	3.39d	44.90ab
75*25(53333)	1.26c	3.09d	38.41a-d
75*30(44444)	1.52bc	2.77d	45.81a
Mean	**2.07**	**6.00**	**38.28**
LSD (0.05)	*	*	**
CV %	**23.57**	**22.10**	**11.27**

Economic Viability of sorghum Abamelko plant population density

Analysis of variance (Table 3) showed that plant population density had a significant (P = 0.001) effect on the grain yield. An economic analysis of the results using the partial budget technique was thus appropriate (CIMMYT, 1988). The result of the partial budget analysis and the data used in the development of the partial budget are given in (Table 4). It was performed by considering fertilizer, seed and labour costs for land preparation and application as main input, mean grain yield obtained across season. The total costs of fertilizers (NPS = 15.90 ETB $kg^{-1}$and urea = 12.65 ETB $kg^{-1}$and sale of grain sorghum at around

Omonada an open market average price (35.29 ETB kg^{-1}). Dominance analysis (Table 3) led to the selection of treatments (44444), (66667), (88889), (111111), (133333), (166667) and (181818) ha^{-1} plant population density were ranked in increasing order of total costs that vary. The treatment having MRR below 100% was considered and unacceptable to farmers; thus, (133333) ha^{-1} plant population density was eliminated (CIMMYT, 1988) (Table 5). Therefore, this investigation remained with changes to (44444), (66667), (88889), (111111), (166667) and (181818) ha^{-1} plant population density as promising new practices for farmers under the prevailing price structure since they gave more than 100% MRR. This might suggest the use of inputs that result in maximum net benefits (Bekele, 2000).

This was because such a return would not offset the cost of capital (interest) and other related deal costs while still providing an attractive profit margin to serve as an incentive. Partial budget analysis based on the field prices of inputs and maize grain yield showed that the application of (166667) and (181818) ha^{-1} plant population density gave the highest net benefit (69105.19 ETB ha^{-1}) and (83327.77 ETB ha^{-1}) respectively, with acceptable MMR (676.36%) and (1390.69 %).

Market prices are ever-changing, and as such, a recalculation of the partial budget using a set of likely future prices i.e., sensitivity analysis, was essential to identify treatments which may likely remain stable and sustain satisfactory returns for farmers despite price fluctuations. The sensitivity analysis study indicates an increase in the field price of the total variable costs, and a fall in the price of maize grain, which represented a price variation of 15% (Table 5).

The price changes are sensitive under the market conditions prevailing around Omonada. The new prices were thus used to obtain the sensitivity analysis (Table 5) Changing from treatments (44444), (66667), (88889), (111111), (166667) and (181818) ha^{-1} plant population density to (66667), (166667) and (181818) ha^{-1} plant population density with MMR (254.73%), (301.69%) and (1027.90%), respectively (Table 5), which were above the minimum acceptable MRR of 100% except (44444), (88889) and (111111) ha^{-1} plant population density which was below the minimum acceptable MRR. These results agree with Saha *et al*. (1994) whose findings from coastal Kenya on maize showed that the application of 30 kg N ha^{-1} consistently gave acceptable economic returns.

Therefore, due to growth nature Abamelko variety it responds to the highest density (166667) and (181818) ha^{-1} plant population gives an economic yield response and also sustained acceptable even under a projected worsening trade conditions in Omonada, Jimma or based on partial budget analysis (166667) and (181818) ha^{-1} plant population density with MMR (301.69%) and (1027.90%) respectively with highest net benefit of (69105.19 ETB ha^{-1}) and (83327.77 ETB

ha^{-1}), respectively were promising new practices give an economic yield response and also sustained acceptable even under a projected worsening trade conditions in Omonada, Jimma. Farmers could thus choose any of the two new ha^{-1} plant population densities depending on their resources.

Table 4. Partial budget analysis for plant population density at current prices.

Plant population densities	Grain yield t ha^{-1}	Adjusted Grain Yield t ha^{-1}	Gross Field Benefit	TCV (ETB ha^{-1})	Net Benefit (ETB ha^{-1}	Dominance analysis
75*30(44444)	1.52	1.37	48276.72	3000	45276.72	Undominated
75*25(53333)	1.26	1.13	40018.86	3600.014	36418.85	dominated
75*20(66667)	1.73	1.56	54946.53	4500.068	50446.46	Undominated
75*15(88889)	1.83	1.65	58122.63	6000.068	52122.56	Undominated
65*15(102564)	1.66	1.49	52723.26	6923.139	45800.12	Dominated
60*15(111111)	1.93	1.74	61298.73	7500.068	53798.66	Undominated
75*10(133333)	1.98	1.78	62886.78	9000.068	53886.71	Undominated
60*10(166667)	2.53	2.28	80355.33	11250.14	69105.19	Undominated
55*10(181818)	3.01	2.71	95600.61	12272.84	83327.77	Undominated
75*5(266667)	2.27	2.04	72097.47	18000.2	54097.27	Dominated
70*5(285714)	1.5	1.35	47641.5	19285.89	28355.61	Dominated
65*5(307692)	2.53	2.28	80355.33	20769.42	59585.91	Dominated
60*5(333333)	2.59	2.33	82260.99	22500.2	59760.79	Dominated
55*5(363636)	2.65	2.39	84166.65	24545.68	59620.97	Dominated

TCV= total cost that varied, Retail price of grain =Birr 35.29 per kg; ETB = Ethiopian Birr; Fertilizer urea = Cost of Birr 12.65, per kg; NPs =Cost Birr 15.90 per kg; MMR= Marginal Rate of Return; NB = Net benefit;

Table 5. Partial budget with estimated marginal rate of return (%) for plant population density at current prices.

Plant population densities	TCV (ETB ha^{-1}	Net Benefit (ETB ha^{-1}	Raised Cost	Raised Benefit	MRR (%)
75*30(44444)	3000	45277			
75*20(66667)	4500	50446.46	1500.07	5169.74	344.63
75*15(88889)	6000	52122.56	1500.00	1676.10	111.74
60*15(111111)	7500	53798.66	1500.00	1676.10	111.74
75*10(133333)	9000	53886.71	1500.00	88.05	5.87
60*10(166667)	11250	69105.19	2250.07	15218.48	676.36
55*10(181818)	12273	83327.77	1022.70	14222.58	1390.69

TCV= total cost that varied, Retail price of grain =Birr 35.29 per kg; ETB = Ethiopian Birr; Fertilizer urea = Cost of Birr 12.65, per kg; NPs =Cost Birr 15.90 per kg; MMR= Marginal Rate of Return; NB = Net benefit;

Table 6. Sensitivity analysis of sorghum production based on a 15% rise in total cost and sorghum price of gross field benefit fall

Plant population densities	TVC (ETB ha^{-1})	NB (ETB ha^{-1})	Increment Cost	Increment Benefit	MRR (%)
75*30(44444)	48276.72	3450	---	---	---
75*20(66667)	54946.53	5175.078	1725.08	4394.28	254.73
75*15(88889)	58122.63	6900.078	1725.00	1424.69	82.59
60*15(111111)	61298.73	8625.078	1725.00	1424.68	82.59
60*10(166667)	80355.33	12937.66	4312.58	13010.55	301.69
55*10(181818)	95600.61	14113.76	1176.11	12089.19	1027.90

TCV= total cost that varied, Retail price of grain =Birr 35.29 per kg; ETB = Ethiopian Birr; Fertilizer urea = Cost of Birr 12.65, per kg; NPs =Cost Birr 15.90 per kg; MMR= Marginal Rate of Return; NB = Net benefit;

Conclusion and Recommendation

Field experiment was conducted for the two consecutive main cropping seasons on farmer's field in Jimma Zone, Omonada district, where sorghum is considered to be one of the major crops in the farming system. In both seasons, due to a sufficient amount of rainfall at the sowing period, better seedling emergence and stand establishment of sorghum were recorded, except for shoot fly damaging effects that controlled by chemical. Among the important parameters: stem diameter (girth), harvest index, above ground biomass and grain yield showed significant differences due to the plant population density but plant height did not. The partial budget analysis was done by including all treatments and the highest net benefits (69105.19 ETB ha^{-1}) and (83327.77 ETB ha^{-1}) obtained from (166667) and (181818) ha^{-1} plant population density with acceptable MMR (301.69%) and (1027.90%) respectively. Hence, to obtain the optimum economic return from the production of sorghum (Abamelko variety) at the study area, (166667) and (181818) ha^{-1} plant population densities had the highest comparable yield and net benefit. Therefore, (166667) and (181818) ha^{-1} plant population densities were sustained and effective in attaining higher yield and economic benefit even under projected worsening trade conditions in Omonada.

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Influence Of Spacing and Phosphate Fertilizer Rate on Yield and Yield Components of Sweet Lupine in West Shewa Zone, Oromia Region, Ethiopia

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Abstract

Sweet lupine is one of the legume plants which is a good protein and dietary fiber source that can tolerate acidity where faba bean and field pea could not perform well. Hence, this experiment was conducted to determine the appropriate seed and fertilizer rate. The treatments included complete factorial combinations of three inter-row spacings (30, 40, and 50 cm), three intra-rows spacing (7, 10, and 13 cm), and three phosphate fertilizers (23, 46, and 69 kg P2O5/ha) rate in the form of P2O5 laid out in a randomized complete block design with three replications. The ANOVA results confirmed that most of the interactions, including three-way P2O5 intra-row*inter-row spacing were non-significant for the studied parameters, with some exceptions. From the results, the year effect was significant on all parameters measured except grain yield. In contrast, the main effect of P2O5 fertilizer was non-significant on all parameters considered. The main effect of intra-row spacing had a significant (P<0.05) effect on days to flowering, days to physiological maturity, plant height, number of pods per plant, hundred seeds weight and grain yield. The main effect of inter-row spacing was significant (P<0.05) on days to flowering, number of pods per plant, and grain yield. Plant height and number of seeds per pod positively correlated with grain yield. Generally, a fertilizer rate of 23 kg P2O5/ha together with 7 cm intra-row spacing and 30 cm inter-row spacing was found to be optimum for sweet lupine production on Nitosols of West Shewa zone, central highlands of Ethiopia.*

Keywords: Acid soil, Intra-row, Inter-row, Phosphorus, Seed rate, Sweet Lupine

Introduction

Lupines are among the oldest crops known in agriculture, and their cultivation began over 2000 years ago around the Mediterranean Sea (Gladstones, 1970). According to Putnam *et al*. (1989), there are over 300 species of the genus *Lupinus* (L.), but many have high levels of alkaloids (bitter-tasting compounds) that make the seed unpalatable and sometimes toxic. But plant breeders in the 1920s Germany produced the first selections of alkaloid-free or "sweet" lupine, which can be directly consumed by humans or livestock. Like other grain legumes (beans, peas, lentils, etc.), the lupine plant fixes atmospheric nitrogen and produces seeds high in protein, 32-38% (Putnam *et al*., 1989; Brebaum and

Boland, 1995). Various scholars reported nitrogen fixation and accumulation rates between 20 and 400 kg N/ha/year, demonstrating nitrogen the effectiveness of lupin in fixing nitrogen (Brebaum and Boland, 1995; Yeheyis *et al*., 2010 and GRDC, 2018). Lupine plant residues provide the next culture with 32– 96 kg N/ha (Pospišil and Pospišil, 2015).

The white lupine in Ethiopia is, locally known as '"*Gibto*', an ancient traditional multipurpose crop that grows in the area's north-western part of Ethiopia in mixed crop-livestock farming systems (Yeheyis *et al*., 2010 and 2012). However, its use as livestock feed and human food is limited due to its relatively high alkaloid (1.43%) content (Yeheyis *et al*., 2011 and 2012). Lupine production by smallholder farmers in the area is targeted for its grain and soil fertility maintenance values. Its grain is used as a snack to prepare the local alcoholic drink, '"*Areke* ' (Yeheyis *et al*., 2010). On the other hand, sweet lupine is a new introduction to Ethiopia, for which little information is available regarding its production practices and other utilization aspects (Fikadu *et al*., 2021). However, it is currently gaining more attention from smallholder farmers due to its value as human food that can be used to prepare a traditional stew called '*Shiro* '*wot*' (Yeheyis *et al*., 2012; Fekadu, 2018).

Narrow-leafed lupine (L. *angustifolius*) varieties are most suited to acid soils with a pH of 4.5 – 7.0, formed with sand (or sand over clay) and well-structured loam soils (GRDC, 2017). In Ethiopia, the soil types in most traditional lupine growing areas are Nitosol and Acrisol, with soil pH ranging between 4 and 5 (Gebreselassie, 2002). However, the variety under this study, '"*Welela*' (L. *angustifolius*) showed superior performance on strongly acidic soils between pH 3.93 – 5.1 and exchangeable acidity 0.93 - 5.63, respectively (Fekadu, 2018). Hence, introducing hardy crops like 'Sweet 'lupine' into soil acidity-prone areas where other legume crops cannot be grown is a fundamental approach to combat protein-malnutrition and enhance soil fertility restoration (MoANR, 2016). Fekadu (2018) also stated that this variety is under production in some areas where highland pulse crops are out of production due to soil acidity problems. However, seed and fertilizer rates' effect on crop productivity is not yet determined.

Therefore, currently, the producers use seed and fertilizer rates recommended for faba bean, which is in line with the suggestions of Putnam *et al*. (1989), which propose using recommendations similar to field bean or soybean. Hence, in Ethiopia, a seed rate of 80 kg/ha for a broadcast planting or, in the case of row planting, 30 cm between rows and 7 cm between plants is being used together with initial fertilizer application equivalent to 100 kg DAP/ha (Yenesew *et al*., 2015; AR, 2017). However, as stated in Mülayim *et al*. (2002), O'Connell *et al*. (2003), and Yeheyis *et al*. (2012), different researchers reported different results on seed and fertilizer rates at different areas depending on the variety/cultivar, weather conditions during the growing season and site yield potentials.

Accordingly, a seed rate ranging from 75 kg/ha to 202 kg/ha or population densities ranging from 20 to 75 plants per square meter have been recommended around the globe (Goulden, 1976; Putnam *et al*., 1989; Oplinger and Martinka, 1991; López-Bellido *et al*. 2000; Mülayim *et al*. 2002; O'Connell *et al*., 2003; GRDC, 2017 and GRDC, 2018). Specific to Ethiopia and in particular to the study area, no recommendations have been made despite the importance of this crop to acid-prone areas where it could be a potential alternative legume crop in west Shewa where farmers abandoned the cultivation of faba bean and field pea due to acidity and various disease problems. Hence, this experiment was conducted to determine the appropriate seed and fertilizer rate to inform lupin-growing farmers.

Material and Methods

Area description

The experiment was conducted at Holeta, West Shewa zone, central Ethiopia, under rain-fed conditions for two consecutive years from 2019 to 2020. The experimental site is located between 09°03′ N latitude and 38°30′ E longitude, 30 km west of Addis Ababa, at an altitude of about 2400 m above sea level. The long-term average annual rainfall is 1100 mm, about 85% of which is received from June to September, with the remainder from January to May. The long-term average minimum and maximum air temperatures are 6.2°C and 22.1°C, respectively.

Soil sampling and analysis

One kg of composite soil sample was collected in a zigzag fashion from the whole plot to the depth of 0-30 cm at the time of sowing to determine soil reaction (pH), organic carbon, cation exchange capacity (CEC), total nitrogen, phosphorus, and potassium. Soil reaction (pH) was measured in water with a solid to liquid ratio of 1:2.5, as Murphy (1968) described. The Walkley and Black wet digestion method described by Tekalign (1991) was applied to determine organic carbon. The total nitrogen was determined following the Kjeldahl method (Berhanu, 1980). The Extractable phosphorus was determined by the Bray II method (Jones, 2003The Extractable potassium was determined by the ammonium acetate extraction method described by Nathan *et al*. (2012). The cation exchange capacity (CEC) was determined by the ammonium acetate extraction method described by (Metson, 1961).

Weather data collection

Daily rainfall and maximum and minimum temperature data were recorded at Holeta research center. Secondary data were also collected from Holeta meteorology station to see the long-term averages for comparison.

Treatments, experimental design, and management

The treatments included 3 x 3 x 3 complete factorial combinations of inter-row spacing (30, 40, and 50 cm), intra-row spacing (7, 10, and 13 cm), and phosphate fertilizer in the form of P_2O_5 (23, 46, and 69 kg P_2O_5/ha) laid out in a randomized complete block design with three replications. Nitrogen (N) fertilizer at the rate of 19 kg N/ha was applied uniformly to all treatments/plots. 38 kg P_2O_5/ha and 19 kg N/ha were obtained from 100 kg NPS fertilizer, and the remaining amount of P_2O_5 for the second level (8 kg P_2O_5/ha) and the third level (31 kg P_2O_5/ha) was added from TSP. The remaining amount of N for the first level (7.5 kg N/ha) was added from Urea. All the fertilizer was applied at the time of planting. The gross plot size of 4.0 m × 2.4 m (9.6 m^2) was used for all treatments, while the net plot size was made by excluding one outer row from each side. Thus, the net plot size for the respective inter-row spacing of 30, 40, and 50 cm was 4m*1.8m (7.2 m^2), 4m*1.6m (6.4 m^2), and 4m*1.5m (6 m^2), respectively. The number of rows per plot for the 30, 40, and 50 cm inter-row spacing was 8, 6, and 5 rows, respectively, and the number of plants per row for the 7, 10, and 13 cm intra-row spacing was 57, 40, and 31 germinated plants, respectively. The sweet lupine (*Lupinus angustijolius*), variety "'*Welela*' was used for this experiment. The germination percentage and 100 seeds weight were determined before planting to convert into a seed rate. The seed rate was calculated using the equation stated by Matthews (2005):

$$\text{Seed rate (kg/ha)} = \frac{\text{Target plant density } (m^{-2}) \text{ X 100 seed weight (g) X 10}}{\text{Germination percentage (\%) X Establishment percentage (decimal)}}$$

Consequently, to convert plant density into a seed rate, 100 seeds weight (for our purpose 13.75 g), germination rates (95%), and 15 % field loss (0.85 establishment rate) were used as estimation inputs. Two times hand weeding was undertaken.

Crop data collection, measurement, and analysis

Plant parameters collected were days to flowering, days to physiological maturity, plant height, the number of pods per plant and number of seeds per pod, 100 seeds weight, and grain yield. Data on plant height, number of pods per plant, and number of seeds per pod were measured from 10 randomly selected plants from the central rows of each plot. Days to flowering were recorded when 50% of the plants in a plot produced their first flower. At the same time, days to physiological maturity were recorded when 90% of the plants in a plot reached physiological maturity. Grain yield was measured from central rows of each plot while 100 seeds weight was measured in grams for randomly counted 100 seed samples from each net plot.

Data collected were subjected to the analysis of variance (ANOVA) following the statistical procedure stated by Gomez and Gomez (1984) for three factors factorial

experiments by using the General Analysis of Variance Procedures of GenStat for Windows Version 16 (VSN International, 2013). The mean comparison was performed using the Least Significant Difference (LSD) at a 5% significance level upon obtaining significant F-values of the factors and interaction (Gomez and Gomez, 1984). The two years of data were combined after testing the homogeneity of variance across the years using the Bartlett test (Gomez and Gomez, 1984).

Results and Discussion

Soil Physico-chemical properties of the experimental site

As presented in Table 1, the pH of experimental fields in both years was 4.42 to 5.48. and it was found to be strongly acidic to very strongly acidic, as Murphy (1968) rated it. According to Fekadu (2018), the variety under this study ('"*Welela*' - L. *angustifolius*) showed superior performance even below the above range (pH 3.93 – 5.10). Hence, the present soil test results indicate the suitability of the soil of the study sites for sweet lupine production. The organic carbon of the experimental fields in both years lies in the range of 1.67 to 2.011%, which is classified as medium (Tekalign, 1991). The total nitrogen percentage was in the range of 0.16 to 0.19%. According to Berhanu (1980), the total nitrogen content of the experimental fields in both years lies in the moderate range. The extractable soil phosphorous in the first year (2019) was 19.993 ppm which is classified as medium (Jones and Benton, 2003), while the available soil phosphorus in the second year (2020) was 5.26 ppm which is classified as low (Cottenie, 1980). The extractable soil potassium in the first year (2019) was 2.522 [cmol (+)/ kg soil], which is rated as very high (Nathan *et al*., 2012). The cation exchange capacity (CEC) in the first year (2019) was 20.04 cmol (+)/kg and classified as moderate (Metson, 1961). In general, CEC is used as a measure of soil fertility and nutrient retention capacity. Accordingly, soils high in CEC contents are considered agriculturally fertile.

Table 1. Soil physico-chemical properties of the experimental site

Parameter	Value		Rating/soil reaction class	
	2019	2020	2019	2020
pH	5.48	4.42	Strongly acidic	Very strongly acidic
Organic carbon (%)	2.011	1.67	Medium/moderate	Medium/moderate
Total nitrogen (%)	0.19	0.16	Medium	Medium
Extractable phosphorus (ppm)	19.993 (Extractable)	5.26 (available)	Medium	Low
Extractable potassium [cmol(+)/ kg soil]	2.522	nd	Very high	nd
CEC [cmol(+)/ kg soil]	20.04	nd	Moderate	nd

CEC = cat-ion exchange capacity, nd = not determined

Weather conditions during the crop growth period

According to the unpublished data from Holeta Meteorology station, the total rainfall for the period of July to December 2020 was higher (856.6 mm) than the year 2019 (741.7 mm) and the average of the year 2000-2018 (596.3 mm) for the same period.

Table 2. Nineteen years (2000 - 2018) average, the year 2019 and 2020 monthly rainfall, maximum and minimum temperatures of the sweet lupine growing period at Holeta

Year	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2000-2018 Min Temp˚C	9.2	8.8	7.7	5.0	5.8	2.6
2019 Min Temp˚C	10.4	10.0	6.5	3.8	6.0	3.8
2020 Min Temp˚C	9.5	9.5	8.5	3.5	2.5	2.0
2000-2018 Max Temp˚C	20.9	20.6	21.0	22.7	22.9	23.0
2019 Max Temp˚C	20.8	19.6	20.5	23.9	22.1	23.1
2020 Max Temp˚C	20.5	21.5	21.6	23.5	24.0	23.0
2000-2018 RFmm	217.7	216.1	126.6	18.0	11.2	6.7
2019 RFmm	249.0	356.1	97.0	7.8	28.2	3.6
2020 RFmm	263.4	334.2	216.2	31.6	8.0	3.2

Source: Holeta meteorology station (unpublished data)

A significant portion of the total annual rainfall received was between July and September in all years, while the highest was received in August. Generally, the total rainfall received for July to September indicated an increasing pattern in 2019 and 2020 compared to the average of nineteen years (2000 – 2018), except for September 2019 (Table 2). There was an increasing trend in maximum temperature from August to November in 2020 than 2019- and nineteen-year

averages. The minimum temperature decreased in 2020, while it was inconsistent in 2019 and nineteen years (2000 – 2018) average (Table 2). Generally, maximum and minimum temperature and total rainfall were more consistent in 2020 than 2019, and the 19 years average where fluctuations were observed.

Crop performance

A combined analysis of variance over the years (2019 and 2020) was performed for grain yield, and some agronomic parameters were considered. According to the results, most of the interactions, including the three-way interaction of P_2O_5*Intra-row*inter-row spacing, were non-significant for most parameters (Table 3). However, the two-way interactions of Yr*Intra-row and Yr*inter-row spacing on the number of pods per plant, P_2O_5*intra-row spacing on plant height, number of pods per plant and grain yield as well as the three-way interaction of Year*Intra-row*inter-row Spacing on grain yield, P_2O_5*Intra-row*inter-row spacing on the number of pods per plant were found significant.

On the other hand, grain yield and all the studied agronomic characters 'didn't respond to the applied phosphate fertilizer (Table 3). This could be due to the availability of a sufficient amount of soil phosphorus (Table 1). Earlier research results on lupine also indicated no yield difference from five years experiments. The main effect of the year showed a significant effect on all parameters measured, except grain yield, which is probably related to the inconsistency of rainfall amount and distribution and fluctuation of maximum temperature in both years, which was more pronounced in the year 2019 than the year 2020 and the long-term average (Table 2). Accordingly, significantly longer days to flower (67.6 days), taller plants (85.4 cm high), a higher number of pods per plant (60.9), and the heaviest 100 seeds weight (14.87 g) were recorded in the second year while significantly longer days to mature (154 days), and higher number of seeds per pod (4.8) was recorded in the first year. Lopez-Belido *et al*. (2005) reported the presence of considerable and unpredictable year-on-year variation in the seed yield of faba bean, despite adequate control of pests and diseases. These authors say yield shows a more significant response to yearly environmental conditions such as rainfall and maximum daily temperatures.

Table 3. Mean squares of ANOVA for grain yield, some phenological and growth parameters of sweet lupine as affected by phosphate, intra-row and inter-row spacing at Holeta, combined over the years (2019-2020)

Source of variation	DTF	DTM	Plh	NPPP	NSPP	HSW	GY
Year (Yr)	494.377**	392**	10952**	19822.6**	37.231**	47.423**	0.434ns
Rep (Yr)	7.1543	28.34	1103.82	1426.1	5.736	3.964	3.849
P_2O_5	0.043ns	0.784ns	38.75ns	81.8ns	0.121ns	0.493ns	0.189ns
Intra-row (Intra)	22.840**	19.117*	1071.04**	2520.2**	0.065ns	14.478**	7.047**
Inter-row (Inter)	6.691**	1.284ns	73.52ns	2525.3**	0.091ns	2.436ns	1.282*
Yr*P_2O_5	0.080ns	1.722ns	228.46ns	291ns	0.003ns	0.47ns	0.355ns
Yr*Intra	0.691ns	7.574ns	6.91ns	908.1**	0.082ns	0.161ns	0.704ns
Yr*Inter	2.469*	1.407ns	45.91ns	438.8*	0.172ns	0.128ns	0.037ns
P_2O_5*Intra	0.191ns	7.238ns	267.95*	319.8*	0.060ns	1.001ns	1.208*
P_2O_5*Inter	0.154ns	5.015ns	20.27ns	194.5ns	0.037ns	0.272ns	0.346ns
Intra*Inter	0.506ns	3.293ns	118.95ns	38.9ns	0.092ns	0.916ns	0.749ns
Yr*P_2O_5*Intra	0.617ns	5.435ns	82.81ns	219.7ns	0.061ns	0.229ns	0.226ns
Yr*P_2O_5*Inter	0.284ns	7.102ns	23.09ns	259.9ns	0.027ns	0.333ns	0.570ns
Yr*Intra*Inter	0.506ns	5.120ns	51.26ns	82.6ns	0.093ns	0.736ns	1.315*
P_2O_5*Intra*Inter	0.636ns	4.233ns	90.73ns	386.3**	0.043ns	0.307ns	0.393ns
Yr*P_2O_5*Intra*Inter	0.793ns	2.079ns	40.18ns	171.4ns	0.068ns	0.386ns	0.341ns
Residual	0.5883	4.623	78.91	118.1	0.164	1.004	0.3972

DTF=Days to 50% heading, DTM= Days to 90% physiological maturity, Plh= Plant height, NPPP= Number of pods per plant, NSPP= Number of seeds per pod, HSW= Hundred seeds weight, GY= Grain yield

Differences have been observed due to the application of P (Putnam *et al*., 989). Similarly, Sulas *et al*. (2016) reported the best performance of white lupine at the location where the soil had the lowest amount of available phosphorus. Moreover, Brebaum and Boland (1995) and Lambers *et al*. (2013) noted that the lupine crop could increase phosphorus availability through a deep taproot system and the secretion of organic acids from the root. Despite this, the interaction effect of P_2O_5 with intra-row spacing was significant ($P<0.05$) on plant height, number of pods per plant, and grain yield (Table 3). From the results, the tallest plants (84.3 cm) and highest grain yield (3.99 t/ha) were obtained at the combination of 46 kg P_2O_5/ha with 7 cm intra-row Spacing though not significantly different from the combination of 23 kg P_2O_5/ha with the intra-row spacing of 7 cm (Table 5). The present result is in line with the recommendations of Yenesew *et al*. (2015) and AR (2017) in which they suggested using intra-row spacing Spacing of 7 cm and applying P_2O_5 at the rate of 46 kg/ha. On the other hand, the highest number of pods per plant (63.82) was obtained at the combination of 69 kg P_2O_5/ha with the intra-row spacing of 13 cm (Table 5).

The main effect of intra-row spacing showed a significant ($P<0.05$) effect on all parameters considered except the number of seeds per pod (Table 3). Accordingly, days to flowering, days to physiological maturity, the number of pods per plant, and hundred seeds weight linearly increased as intra-row spacing increased from 7 cm to 13 cm (Table 4). On the other hand, the plant height and grain yield linearly decreased with increasing intra-row spacing from 7 cm to 13cm (Table 4). This result agrees with the suggestions of Withers (n.d.); Yenesew *et al*. (2015); and AR (2017), who suggested the use of narrower intra-row spacing of 7 cm. The main effect of inter-row spacing showed a significant ($P<0.05$) effect only on days to flowering, the number of pods per plant, and grain yield (Table 3). Accordingly, as inter-row spacing increased from 30 cm to 50 cm, there was a linear and significant ($P<0.05$) increase in days to flowering and the number of pods per plant while grain yield linearly and significantly ($P<0.05$) decreased as inter-row spacing increased from 30 to 50 cm (Table 4). In similar experiments, yield increases between 37-110% have been achieved for sweet lupine in Minnesota and Wisconsin trials by narrowing row spacing from 76 cm to 15 cm (Putnam *et al*., 1989). In another similar experiment, the grain yield of lupine (the average result of the varieties of L. *albus* and L. *angustifolius*) decreased by 29% as row spacing increased from 25 cm to 75 cm (Koetz *et al*., 2015).

In general, though the interaction effect of intra-row and inter-row spacing was found non-significant (Table 3), the earliest days to 50% flowering (65.2 and 65.5 days) and the earliest days to 90% physiological maturity (151.9 and 152.5 days) were obtained at the narrower spacing of 7 cm intra-row- and 30 cm inter-row spacing, respectively (Table 4) probably due to increased competition between plants for growth factors like moisture and essential nutrients which enhanced early flowering and maturity at closer spacing. As reported by Birhanu *et al*. (2020), the mean days to 50% flowering and 90% physiological maturity of chickpea was hastened by the use of narrower intra-row- and inter-row spacing, justifying that the hastened time of flowering and maturity in intra-row- and inter-row spacing might be due to competition for nutrients, moisture, and space. On the other hand, Fikadu *et al*. (2021) reported a non-significant difference between 30x7 cm, 30x15 cm, 40x15 cm, and 40x20 cm tied row spacing combinations on the effect of days to flowering and maturity of sweet lupine varieties. On the contrary, other authors like Farag (1994) for broad bean under irrigated conditions; Holshouser and Joshua (2002) for soybean; Almaz *et al*. (2016) for faba bean under vertisols conditions and Melaku (2018) for chickpeas reported that days to 50% flowering and 90% physiological maturity were significantly decreased as the inter-row- and/or intra-row spacing increased which might be the indication of the influence of plant population on days to flower initiation and physiological maturity varies from crop to crop as well as the prevailing environmental conditions under which the crops are grown. The tall plants (82 and 78.3 cm high) were obtained at the narrower spacing of 7 cm intra-row- and

30 cm inter-row Spacing, respectively (Table 4), probably due to competition for solar radiation. In a similar experiment, Fikadu *et al*. (2021) reported taller plants from narrower row spacing of 30 cm × 7 cm, indicating that the interplant competition will be too high under narrow spacing between plants, which may force the individual plant to grow taller. Wassermann (1987) also reported the tallest plants of *Lupinus albus* at a narrower inter-row Spacing of 25 cm than 50 and 75 cm, explaining that competition among the plants due to crowding either by increased seeding rate or by narrower row spacing resulted in significantly taller plants. Similarly, in chickpeas, the longest plant height was obtained at closer spacing than the wider one, probably due to the highest plant population under closer spacing that might have to afford several competitions among the crop for growth resources, especially the nutrient, moisture and light (Birhanu *et al*., 2020).

On the other hand, the higher number of pods per plant (57.7 and 57.2) was recorded at the wider spacing of 13 cm intra-row- and 50 cm inter-row Spacing, respectively (Table 4), probably due to lower competition effect for resources at wider row spacing. Fikadu *et al*. (2021) also obtained a higher number of pods per plant from wider spacing (40 cm × 20 cm) compared to the narrower spacing (30 cm × 7 cm), indicating that sweet lupines were affected by the number of branches. The heaviest 100 seeds' weight (14.88 g and 14.54 g) were also recorded at the wider spacing of 13 cm intra-row- and 50 cm inter-row Spacing (Table 4), probably due to lower competition effect for resources at wider spacing. Wassermann (1987) also reported the heaviest 100 seed weight for *Lupinus albus* at wider row spacing. In contrast, Fikadu *et al*. (2021) reported a non-significant difference between the narrower and wider inter-row- and intra-row spacing combinations (in which the main effect factors are not separately justified). The higher grain yield (3.90 and 3.69 t/ha) was obtained at the narrower spacing of 7 cm intra-row- and 30 cm inter-row Spacing, respectively (Table 4), probably related to the higher number of plants per square meter in the narrower spacing. Wassermann (1987) also reported higher grain yield for *Lupinus albus* at narrower inter-row spacing, justifying that a more equidistant spacing favored seed yield. In contrast, Fikadu *et al*. (2021) reported a non-significant difference between the narrower and wider inter-row- and intra-row spacing combinations (in which the main effect of the factors is not separately justified). According to Mondal *et al*. (2014), although the number of pods per plant was the lowest in closer spacing, seed yield per square meter was the highest due to increased plant accommodation in closer spacing than that of wider spacing.

In our study, only plant height and number of seeds per pod positively correlated with grain yield, reflecting the importance of plant height and number of seeds per pod in determining grain yield in the study area. On the other hand, a negative and significant ($p<0.001$) correlation was observed between grain yield and days to flowering and hundred seeds weight (Table 6). Similarly, days to physiological

maturity and the number of pods per plant showed a negative non-significant correlation with grain yield (Table 6). In agreement with this result, Fikadu *et al*. (2021) reported the presence of a positive and significant correlation between grain yield with plant height, number of seeds per pod, and hundred seeds weight, while a positive non-significant correlation with the number of pods per plant indicating that selection for plant height, number of seeds per pod, and hundred-seeds weight would help increase the seed yield in sweet lupine plants. In contrast, Goulden (1976) reported that the number of pods per plant was the factor most directly influencing seed yield per plant.

Depending on the above results, the lowest fertilizer rate of 23 kg P_2O_5/ha together with 7 cm intra-row- and 30 cm inter-row spacing (equivalent to 48 plants per square meter or a seed rate of 81 kg/ha using a 95% germination rate and 85% establishment as an input for a seed rate calculation) found to be optimum for the study area. The present result is in line with the suggestions of Yenesew *et al*. (2015 and AR (2017), except for fertilizer rate, in which they suggested the use of intra-row Spacing of 7 cm and inter-row Spacing of 30 cm or a seed rate of 80 kg/ha for a broadcast planting together with the application of P_2O_5 at the rate of 46 kg/ha.

Table 4. The main effect of phosphorus, intra- and inter-row spacing on grain yield, and some agronomic parameters of sweet lupine at Holeta, combined over the years (2019-2020)

Treatments	DTF	DTM	Plh (cm)	NPPP	NSPP	100 SWg	GY (t/ha)
Year							
1	64.1^{b}	154.1^{a}	68.9^{b}	38.8^{b}	4.8^{a}	13.78^{b}	3.56
2	67.6^{a}	151.0^{b}	85.4^{a}	60.9^{a}	3.8^{b}	14.87^{a}	3.46
Difference	-3.5	3.1	-16.5	-22.1	1.00	-1.09	0.1
P_2O_5 (kg/ha)							
23	65.9	152.6	76.2	48.7	4.3	14.43	3.53
46	65.8	152.7	77.5	49.7	4.4	14.25	3.56
69	65.9	152.4	77.8	51.1	4.3	14.29	3.45
LSD (5%)	ns	ns	ns	ns	ns	ns	ns
Intra-row spacing (cm)							
7	65.2^{c}	151.9^{b}	82.0^{a}	45.0^{b}	4.4	13.86^{b}	3.90^{a}
10	65.9^{b}	152.6^{ab}	76.3^{b}	46.9^{b}	4.3	14.24^{b}	3.45^{b}
13	66.5^{a}	153.1^{a}	73.2^{b}	57.6^{a}	4.3	14.88^{a}	3.19^{c}
Inter-row spacing (cm)							
30	65.5^{c}	152.5	78.3	43.6^{c}	4.3	14.11	3.69^{a}
40	65.8^{b}	152.4	77.2	48.7^{b}	4.4	14.33	3.45^{b}
50	66.2^{a}	152.7	76.0	57.2^{a}	4.3	14.54	3.40^{b}
Mean	65.8	152.6	77.2	49.8	4.3	14.33	3.51
CV (5%)	1.2	1.4	11.5	21.8	9.4	7.00	17.90

DTF=Days to 50% flowering, DTM= Days to 90% physiological maturity, Plh= Plant height, NPPP= Number of pods per plant, NSPP= Number of seeds per pod, HSW= Hundred seeds weight, GY= Grain yield

However, further studies using zero fertilizer rate and narrower intra-row- and inter-row spacing need to be considered as P_2O_5 showed no response, and the narrower spacing produced significantly higher grain yield as it might have become higher if further narrower rows had been used. As Putnam *et al*. (1989) discussed, yield increases between 37-110% have been achieved for sweet lupine by narrowing row spacing from 76 cm to 15 cm.

Table 5. Two-way interaction effects of potash with intra-row spacing on plant height, number of pods per plant and grain yield of sweet lupine at Holeta, combined over the years (2019-2020)

P_2O_5 (kg/ha)	Plant height (cm)			Number of pods per plant			Grain yield (t/ha)		
	Intra-row (cm)			Intra-row (cm)			Intra-row		
	7	10	13	7	10	13	7	10	13
23	80.1abc	72.1de	76.4bcd	44.63d	45.04cd	56.29b	3.96a	3.18cd	3.45bc
46	**84.3a**	78.9abc	69.2e	46.98cd	49.4bcd	52.83bc	**3.99a**	3.71ab	2.98d
69	81.6ab	78.0a-d	73.9cde	43.36d	46.16cd	**63.82a**	3.76ab	3.45bc	3.13cd

Table 6. Correlation coefficients between sweet lupine studied characters

	DTF	DTM	PLH	NPPP	NSPP	100SW	GY
DTF	-						
DTM	-0.3815**	-					
Plh	0.3667**	-0.598**	-				
NPPP	0.6879**	-0.274**	0.3113**	-			
NSPP	-0.7441**	0.4114**	-0.3383**	-0.6391**	-		
100SW	0.5675**	0.0047ns	-0.0878ns	0.3442**	-0.4179**	-	
GY	-0.2695**	-0.031ns	0.4579**	-0.1216ns	0.1215ns	-0.471**	-

DTF=Days to 50% heading, DTM= Days to 90% physiological maturity, PLH= Plant height, NPPP= Number of pods per plant, NSPP= Number of seeds per pod, HSW= Hundred seeds weight, GY= Grain yield

Conclusion and Recommendation

Most of the studied characters were significantly affected by the main effects of spacing rather than phosphate fertilizer and the interaction effects. Based on the ANOVA results, the lowest fertilizer rate of 23 kg P_2O_5/ha together with 7 cm intra-row spacing and 30cm inter-row Spacing (equivalent to 48 plants per square meter or a seed rate of 81 kg/ha) was found to be optimum for sweet lupine production in west Shewa *Nitosols* and similar agro-ecologies. In addition, further study must consider using zero fertilizer rates and narrower intra-row- and inter-row Spacing as P_2O_5 showed no response, and the tested narrower spacing produced significantly higher grain yield.

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Horticultural Crop Research Results

Determination of Appropriate Population Density and Pruning Methods for Hybrid Coffee in Southwest Ethiopia

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Abstract

Planting density systems may increase production per unit area along with population density up to a certain level. Under conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize all the growth factors efficiently. The physiological aspects and yield benefits of high tree population have been documented in Ethiopia and elsewhere in the major coffee growing countries. Though there is enormous potential of genetic and environmental components in most coffee growing areas in Ethiopia, the benefits of plant population density and bearing heads are not fully exploited in relation to hybrid coffee. An experiment was conducted on two hybrid coffee varieties recommended for Jimma and Gera, viz. Gawe and EIAR 50 were used, respectively to evaluate the yield and yield components. Seedlings of these hybrids were planted at three different spacing that correspond to three different plant population density and the plants were trained in three different pruning systems, making nine treatments. The treatments were arranged in a randomized complete block design with three replications in a factorial arrangement. At Jimma, the highest coffee yield (2333 kg ha-1) was recorded from the closer spacing of 2m x 2m with free growth training practice, whereas at Gera closer spacing of 2m x 2m with multiple stems capped not topped training gave the highest clean coffee of 2233 kg ha-1 yield. High number of dead and non-bearing branches was observed in free growth where the mutual shading was high to loss branch due to dark respiration. The same trend was observed on bearing and new branch growth which recorded the highest score. This might be due to the high number of the freely new growth verticals. Closer spacing of 2m x2m (2500 trees ha-1) with more than one vertical significantly promoted hybrid coffee yield under two contrasting coffee growing locations during the different cropping seasons. In conclusion, in this study increased number of verticals in different cropping seasons compensated the dead and non-bearing surface of old branches by growing newly productive center simultaneously.

Keywords: Hybrid coffee, spacing, verticals, yield

Introduction

Arabica coffee plantations used to be established at fewer than 2000 trees ha^{-1} (Carr, 2001), or even below 1000 trees ha^{-1} as for the multi-stemmed coffee in Brazil. However, coffee may be more suited for high-density plantings; indeed,

the productivity of dense plantings is generally much greater than that of traditional plantings (DaMatta, 2004). The compact plant stature and disease resistance of some modern coffee cultivars have allowed closer spacing, resulting in almost complete ground coverage and better uptake of available soil nutrients by denser rooting (van der Vossen, 2005). Moreover, in dense plantings, coffee roots develop deeper so that they take up water and nutrients from lower soil horizons (Cassidy and Kumar, 1984). Planting density systems may increase production per unit area along with population density up to a certain level. By contrast, the yield per tree usually decreases with closer planting, even though it may be quite variable among environments (Kuguru *et al*., 1978). The reduction in the fruit-bearing capacity of the trees with close spacing does not appear to be caused by a decrease in fruit setting (Kumar, 1978), nor by a reduction in the number or length of plagiotropic branches (DaMatta *et al*., 2007). It may be attributed to the effect of shading on the number of fruits per node and possibly the number of fruit-bearing nodes. Furthermore, Singh and Singh (2002) explained that establishment of optimum population per unit area of the field is essential to get maximum yield.

Under conditions of sufficient soil moisture and nutrients, higher population is necessary to utilize all the growth factors efficiently. The level of plant population should be such that maximum solar radiation is utilized. The full yield potential of an individual plant is fully exploited when sown at wider spacing. Yield per plant decreases gradually as plant population per unit area increases. However, the yield per unit area is increased due to efficient utilization of growth factors. The physiological aspects and yield benefits of high tree population have been documented in Ethiopia (Yilma, 1985) and elsewhere in the major coffee growing countries (Wringley, 1988).

In Ethiopia, the average national coffee yield as low as 600 to 700kg clean coffee ha^{-1} as compared to other coffee producing counties, primarily due to limited use of improved coffee technologies including close spacing practices. Among other factors, the predominant use of low population density of 2,500 trees ha^{-1} with a single stem tree management system may contribute to the low coffee productivity. With this concern many research attempts have been made to generate technologies which can help to attain high productivity per unit area by taking into account different crop intensification practices under distinct coffee growing environments (Yacob *et al*., 1996; Endale *et al*., 2008). The results revealed consistently increased coffee yield level with increasing population densities from 4,000 to 6,000 trees ha^{-1} and number of bearing heads (Yacob *et al*., 1993). Likewise, significant variation in vegetative growth performance was found between two distinct coffee cultivars with open and compact canopy nature when planted using a high-density planting system at Jima (Taye, 1996).

Though there is enormous potential of genetic and environmental components in most coffee growing areas in Ethiopia, the benefits of plant population density and bearing heads are not fully exploited in relation to hybrid coffee. Optimal planting density for Arabica coffee through spacing and number of bearing heads depends on several factors including cultivars, availability of water and nutrients, pruning systems, cropping patterns and air evaporative demand and temperature. The present study was therefore initiated to determine appropriate plant density and number of verticals that promote yield of hybrid coffee in southwest Ethiopia.

Materials and Methods

Description of study areas

The experiment was conducted during 2014 to 2021 for eight consecutive years at Jimma (1750 m.a.s.l) and Gera (1900 m.a.s.l) representing medium and high-altitude coffee areas, respectively. The study areas are located in southwest Ethiopia with high mono modal rainfall. The mean minimum and maximum temperatures for Jimma and Gera are 11.3-26.2°C and 10.4-24.0°C, in that order.

Experimental materials and procedure

Two hybrid coffee varieties recommended for Jimma and Gera areas, *viz.* Gawe and EIAR 50 were used, respectively. Gawe is more adaptable to mid altitude whereas EIAR 50 is mid to high altitudes. The canopy nature of both hybrid coffee varieties is intermediate. Seedlings of these hybrids were raised and planted at spacing of 2.5m x 2.5m, 2.0m x 2.5m, 2.0m x 2.0m, representing 1600, 2000 and 2500 trees ha^{-1} at each study site. All management practices were applied as recommended (Endale *et al.,* 2008) to ensure maximum field establishment and to commence the pruning and training treatments. The experimental plots were planted with *Accacia abysinca,* a permanent leguminous shade tree species which is suitable for the study areas. After a year of field transplanting, the young coffee plants were trained with three different pruning systems as described below.

Capped and topped multiple stems (CTMS): The newly growing stems were capped at 45cm height to get the required two vertical heads. The final height of the stem was 2.20m. The primary branches contained a secondary branch at each node on the alternate side of the primary. Secondary branches that had carried two crops were cut off and replaced by new secondary branches. Long drooping primaries were cut back to horizontal plane. Secondary branches were removed within 20cm from the main stem for opening the center for light interception and air circulation of the coffee tree. All unwanted suckers and upper primaries were cut off to allow sufficient light penetration and aeration within a tree canopy.

Capped and untopped multiple stems (CUTMS): Transplanted young coffee seedlings were capped at 45cm to encourage two heads growing freely. Branches that touched the ground and served as bridges for ants and other pests were removed. The trees were opened up by pruning the bottom primary to standard bearing length. All secondary growths were cut within 20cm from the main stem and any interlocking primaries in the middle of the tree and secondary branches growing upward, downward and towards the main stem were monitored and removed.

Free growth (FG): This treatment consisted only of slight handling (dried branches only) and desuckering (whippy and stunted young suckers) practices with no limitation of number of bearing heads, stem height and number of secondary branches on primaries.

Experimental design and data analysis

A randomized complete block design with factorial arrangement of nine treatment combinations (3 spacing x 3 pruning methods) was used in three replications. Coffee yield and yield components, dead, non-bearing, bearing and new primary branches, and number of verticals were recorded for each season. Furthermore, coffee quality was analyzed at Jimma ARC coffee quality laboratory for each treatment using standard procedure. The data were analyzed using SAS software (SAS, 2011). For the significant variations, treatment mean separation was performed according to Fisher's least significant difference (LSD) test at 5% probability level.

Results and Discussion

At Jimma, coffee yield differences due to spacing and training practice were significant across all cropping seasons. As a result, the highest coffee yield was recorded from the spacing of 2m x 2m (2,500 trees ha^{-1}) with free growth training practice, followed by 2m x 2.5m spacing (2,000 trees ha^{-1}) with free growth training gave mean clean coffee yields of 2333 kg ha^{-1} and 2294 kg ha^{-1}, respectively. In contrast, coffee trees planted at widest spacing of 2.5m x 2.5m (1,600 trees ha^{-1}) combined with capped multiple stems not topped training gave the lowest average yield of 1375 kg ha^{-1} (Table 1). The results depicted that free growth treatment gave significantly the highest coffee yield as compared to the other two training practices throughout the cropping seasons. Moreover, yield increased with increased number of verticals regardless of spacing in all the treatments. This could be related to the suitability of Jimma agro-ecology for high density planting system at least for medium-term productive life span of hybrid coffee variety.

Table 1. Mean clean coffee yield (kg ha^{-1}) of hybrid coffee as influenced by population density and pruning system at Jimma (2017-2021)

Spacing (m) by pruning	Population (trees ha^{-1})	2017	2018	2019	2020	2021	Mean
2.5x2.5 CTMS	1600	969.93bc	2633.34bc	791.35b	2488.84ab	1373.59c	1651.41bc
2.5x2.5 CUTMS	1600	549.99c	2106.04c	830.95b	1510.29b	1881.87bc	1375.83c
2.5x2.5 FG	1600	1240.37abc	2988.81ab	1215.55b	2892.81a	1840.31bc	2035.57ab
2x2.5 CTMS	2000	399.86c	2641.56bc	649.68b	3021.43a	1224.19c	1587.34bc
2x2.5 CUTMS	2000	888.23bc	2282.84c	787.34b	3014.78a	1520.56bc	1698.75bc
2x2.5 FG	2000	1628.25ab	2305.86c	2123.41a	2523.89ab	2892.38a	2294.76a
2x2 CTMS	2500	1640.25ab	2524.10bc	955.85b	3613.58a	1087.65c	1964.28ab
2x2 CUTMS	2500	825.49bc	3439.66a	579.75b	3373.99a	1772.25bc	1998.23ab
2x2 FG	2500	1954.19a	2488.15bc	2187.48a	2644.85ab	2394.83ab	2333.90a
Mean		1121.84	2601.151	1124.596	2787.162	1776.403	
F-test		**	**	**	**	**	**
CV(%)		45.66	13.88	37.25	25.43	29.18	14.37
LSD (5%)		886.5	624.9	725.2	1227	897.3	560.18

Legend: CTMS=capped and topped multiple stems, CUTMS= capped and un-topped multiple stems, FG= free growth

With regard to the tree productive center for the treatments, free growth is superior regardless of the different parameters and interaction effects. High number of dead and non-bearing branches was observed in free growth where the mutual shading is high to loss branch due to dark respiration. The same trend was observed on bearing and new branch growth which recorded the highest score. This might be due to the high number of freely new growth verticals. The two wider spacing and trained treatments were inferior in all four parameters due to the restriction of vertical height and horizontal length growth during the growing period in the different seasons (Table 2).

Table 2. Evaluation of tree productive center by the end of the experiment at Jimma

Spacing (m) by vertical	Population (trees ha^{-1})	Dead branch	Non-bearing branch	Bearing branch	New branch
2.5x2.5 CTMS	1600	22.52c	16.33cd	22.96bc	0.13d
2.5x2.5 CUTMS	1600	27.33c	27.80b	24.27bc	9.42cd
2.5x2.5 FG	1600	52.33b	40.0a	41.67ab	41.67b
2x2.5 CTMS	2000	26.73c	8.69d	18.31c	0.113d
2x2.5 CUTMS	2000	24.86c	21.67bc	26.75bc	9.4cd
2x2.5FG	2000	60.03ab	40.0a	42.11ab	40.33b
2x2 CTMS	2500	23.73c	14.8cd	14.53c	0.14d
2x2 CUTMS	2500	26.67c	12.33d	16.73c	14.02c
2x2 FG	2500	71.33a	42.77a	60.22a	71.33a
Mean		37.28	24.93	29.73	20.73
F-test		**	**	**	**
C.V (%)		20.50	25.58	37.57	26.18
LSD (5%)		13.23	11.04	19.33	9.39

Legend: CTMS=capped and topped multiple stems, CUTMS= capped and un-topped multiple stems, FG= free growth

At Gera, yield variations among the treatments were significant in all the cropping seasons. Similarly, the closer spacing gave the highest clean coffee yield as compared to the other treatment combinations. Closer spacing of 2m x 2m with multiple stems capped not topped training gave the highest yield of clean coffee (2233 kg ha^{-1}) in the overall mean of the cropping seasons (Table 3). This result is similar to the finding of Alemseged *et al.*, (2012). Inferior crop was harvested from relatively wider spacing of 2m x 2.5m with free growth treatment. In most cases, yield increased with increased number of verticals (Table 3). Though the effect of the interaction on coffee yield was inconsistent over the different cropping seasons, in most of the crop seasons higher yield was recorded for coffee trees planted in closer spacing irrespective of tree training. The present findings indicated that coffee trees gave about two-to-three-fold higher yield than the current national average yield of coffee ranging from 600-700 kg ha^{-1} clean

coffee. There was a slight yield oscillation at both locations due to seasonal and biannual variations (Gatahar *et al*., 1985). Like Jimma, the number of dead and non-bearing branch was higher in closer and free growth treatment combinations at Gera. Furthermore, similar result was found on bearing and new growth branches (Table 4). In this study, increased number of verticals in different cropping seasons compensated the dead and non-bearing surface of old branches and increased the bearing area by growing newly productive center simultaneously.

Table 3. Mean clean coffee yield (kg ha^{-1}) affected by population density and number of verticals at Gera, 2017-2021

Spacing (m) x vertical no	2017	2018	2019	2020	2021	Mean
2.5x2.5 CTMS	2353.87ab	1004	1614.33c	696.71c	2527.71ab	1518.96d
2.5x2.5 CUTMS	2022.12b	520.1	2231.67abc	791.5c	2337.55b	1561.13cd
2.5x2.5FG	1997.27b	441.7167	1792.67bc	1234abc	3171.3ab	1581.62cd
2x2.5 CTMS	2800.03a	450.7833	2347.33ab	835.73c	3526.61ab	1833.40abcd
2x2.5 CUTMS	1968.55b	534.96	1784.33bc	1647.43a	2828.62ab	1746.61bcd
2x2.5FG	2188.78ab	212.6267	2183.67abc	876.77bc	2702.40ab	1433.60d
2x2 CTMS	2643.12ab	739.69	2703.33a	1304abc	2911.74ab	2124.06ab
2x2 CUTMS	2611.56ab	852.92	2785.67a	1242.034abc	3718a	2233.05a
2x2FG	2348.149ab	436.7567	2594a	1502.961ab	3067ab	2007.86ab
Mean	2325.94	577.06	2226.33	1125.68	2976.77	
F-test	**	NS	**	**	**	**
C.V (%)	17.28	60.93	18.01	33.78	24.3	15.04
LSD (5%)	695.6	NS	694.1	658.2	1252	464

Legend: CTMS=capped and topped multiple stems, CUTMS= capped and un-topped multiple stems, FG= free growth

Table 4. Evaluation of tree productive center by the end of the experiment at Gera

Spacing (m) x verticals	Dead branch	Nonbearing branch	Bearing branch	New branch
2.5x2.5 CTMS	13.33d	9.00e	38.89e	0.27d
2.5x2.5 CUTMS	25.56c	15.00cd	51.67cde	9.33c
2.5x2.5FG	36.33ab	22.33ab	70.67abc	25.67ab
2x2.5 CTMS	12.33d	10.00de	56.56cde	0.27d
2x2.5 CUTMS	29.56bc	15.33cd	59.33bcde	9.00c
2x2.5FG	36.11ab	23.33a	89.33a	19.67b
2x2 CTMS	10.67d	12.67cde	42.11de	0.27d
2x2 CUTMS	26.33c	17.33bc	67.11abcd	9.33c
2x2FG	38.00a	26.33a	84.33ab	28.33a
Mean	25.36	16.81	62.22	11.35
F-test	**	**	**	**
CV(%)	19.21	19.86	25.65	42.09
LSD (5%)	8.43	5.78	27.62	8.27

Legend: CTMS=capped and topped multiple stems, CUTMS= capped and un-topped multiple stems, FG= free growth

Alternate bearing or the habit of the coffee tree to produce a heavy crop in one year and to produce a light crop or to "rest" in the second year seems to be a characteristic of the tree the world over (Taye *et al.*, 2001). The bearing habits of these hybrid coffee varieties at Jimma and Gera were no exception to this rule (Figure 1). Excessively heavy fruit production in one year was often accompanied by severe defoliation, small sun burned berries, and even dying-back of the lateral and often of the vertical branches, a condition appropriately called dieback. Though there was yield oscillation at the two locations, it seemed very slight and the yield was higher as compared to the normal trend (Figure 1).

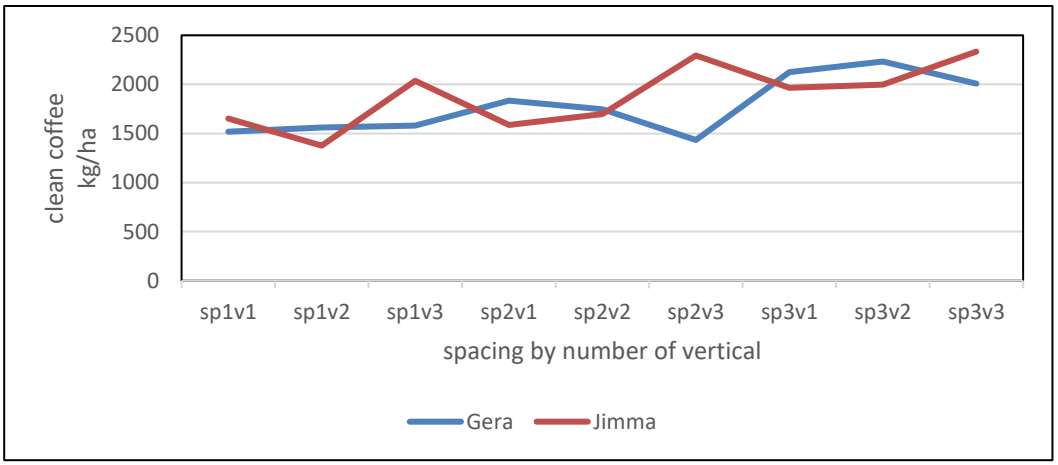

Figure1. Hybrid coffee yield trend across the study locations
Legend: sp1=2.5x2.5, sp2=2.5x2.0, sp3= 2x2; v1= capped and topped multiple stems, v2= capped and untopped multiple stem, v3= free growth

The results of coffee canopy diameter at the two locations indicated coffee tree height growth was restricted by the pruning and training practices. Accordingly, the canopy diameter became wider because of the enhanced apical dominance (Figure 2). According to Yacob *et al*. (1996), canopy volume can be dictated by number of bearing heads, angle orientation and plant height defines spatial arrangement and spacing in coffee. Taking into account the morphological growth characters like canopy spread and nature of stem of variety, and pruning systems to be used, spacing recommendations with its corresponding population densities have been documented (Tesfaye *et al.*, 1998).

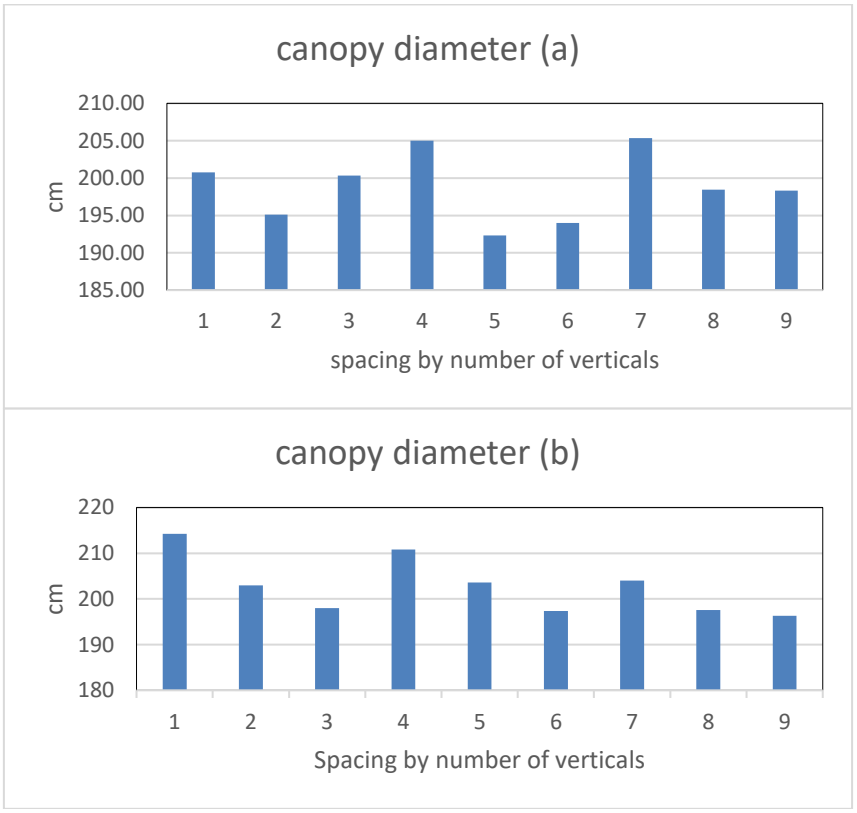

Figure 2. Coffee hybrid canopy diameter at Jimma (a) and Gera (b) (1=2.5x2.5CTMS, 2=2.5x2.5 CUTMS, 3=2.5x2.5 FG, 4=2x2.5 CTMS, 5=2x2.5 CUTMS, 6=2x2.5 FG, 7=2x2 CTMS, 8=2x2 CUTMS, 9=2x2FG)

In close spacing, the physiological problems of light, moisture and nutrient requiring process have been studied by several authors and it has been concluded that there exists a positive correlation between closer coffee spacing and efficient utilization of these environmental inputs (Kumar, 1978; Yilma, 1985). Among the various training methods followed in East Africa, conventional multiple stem and free growth which are widely used in Ethiopia are suitable to close spacing planting and simple to apply with low labor input (Yilma, 1985; Gathara and Kiara, 1985). In addition, as described by Alemseged *et al*. (2020) on free growth

tree management, the newly emerging suckers or bearing verticals are more contributing to yield contrary to the other training and pruning practices which depend only on the new branches. All new secondary and tertiary verticals /bearing heads/ on free growth should not grow at a time, rather increasing the number gradually without disturbing the crop to leaf ratio balance and formal architecture of the coffee tree. The yield advantage from free growth may be attributed to mutual shading by plant canopies and has the advantage of keeping the temperature of plants and the soil cooler. Because of the minimized leaf temperature and reduced light intensity, transpiration rates are lower and carbon assimilation would be more favored and consequently boost the coffee production.

Conclustion and Recommendation

In conclusion, the results showed that close spacing of 2m x 2m (2500 trees ha^{-1}) with more than one vertical significantly increased coffee yields at both coffee growing locations in the southwest Ethiopia. Average clean coffee yields increased with tree density irrespective of the tree training method across the study periods. The highest yield from the free growth system could stem from the increased growth of new vegetative and bearing surface areas throughout the study period under the mid and highland areas. In the present study, it can also be concluded that it is possible to increase number of verticals in different cropping seasons to compensate the dead and non-bearing surface of old branches by growing newly productive center simultaneously.

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Intercropping of Arabica Coffee with Enset in Jimma Zone, Southwestern Ethiopia

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Abstract

Diversification of coffee with different crops is very important for better resource use efficiency and productivity of component crops. Intercropping coffee with enset has a significant role in food security, improving soil fertility through the provision of in situ mulch, conserving soil and keeping soil moist, ensures sustainable coffee productivity through optimizing the amount of light intercepted, control coffee diseases and pests, and recycles more nutrients. A study was conducted at Gera Agricultural Research Sub-Center from 2014 to 2020 cropping seasons to draw recommendations on biologically and economically sound coffee to enset intercropping ratio. The treatments consisted of sole coffee, sole enset, one row of coffee to one row of enset (1C:1E), two rows of coffee to one row of enset (2C:1E), three rows of coffee to one row of enset (3C:1E) and stagger planting pattern which was enset planted at the center of four coffee trees at a distance of 4m. The treatments were arranged in a randomized complete block design with three replications. The result revealed significant differences (P≤ 0.05) among treatments for overall mean clean coffee yield, kocho and total quality. The highest overall mean clean coffee yield (1573.75 kg ha-1) was obtained from sole coffee followed by staggered and 2C:1E plantings that gave 1173.45 kg ha-1 and 1087.17 kg ha-1, respectively. Conversely, the lowest yield (678.1 kg ha-1) was obtained from equal ratio (1C:1E). In all cropping years the highest kocho yield (6276 kg ha-1) was obtained from equal ratio (1C:1E) followed by stagger planting which gave 5167 kg ha-1, whereas the lowest kocho yield (4399.5 kg ha-1) was obtained from 2C:1E. The highest bulla yield was obtained from 1C:1E followed by sole enset. The maximum Land Equivalent Ratio (LER) and yield advantage were obtained from staggered planting for the overall mean with the value of 2.06 and 0.766, respectively. In contrast, the lowest LER of 1.67 and 1.78 were obtained in 2016 cropping year and the overall years mean, respectively from 2C:1E planting. All intercropped treatments were more advantageous than sole planting because LER was greater than one. For total quality, the highest (81.83%) was obtained from both sole coffee and 1C:1E plantings, whereas the lowest total quality (80.28%) was obtained from staggered planting. In conclusion, staggered intercropping coffee with enset was the best way of planting system to enhance the productivity of the crops and overall yield advantage.

Keywords: Coffee, enset, cropping system, land equivalent ratio, yield advantage

Introduction

Currently, population is increased and there is limitation of land. More than 95% of the country's agricultural output is generated by smallholder farmers who, on

average, own less than one hectare of cultivated land. Diversification of coffee with different crops is very important for better resource use efficiency and productivity of component crops (Begum *et al*., 2015). Intercropping is the growth of two or more crops simultaneously on the same field with crop intensification in both time and space dimensions. According to (Taye *et al*., 2004; Taye *et al*., 2008; Van Asten *et al*., 2011) the coffee plant is intercropped with different crops such as banana, enset, citrus and avocado. Intercropping of coffee with enset has significant role in improving soil fertility through the provision of in situ mulch, conservation of soil and keep soil moist, ensures sustainable coffee productivity though optimizing the amount of light intercepted, control coffee diseases and pest, recycles more nutrients (Leta and Ashenafi, 2021). In addition, it provides improved farm earning for smallholder farmers, increased resilience to drought and extreme weather events, reducing the risk of coffee price fluctuations, ensuring food security, and getting sufficient food for their families and good returns (Amede and Taboge, 2007; Van Asten *et al*., 2011; Ratnadass *et al*., 2012). Furthermore, intercropping helps for efficient use of farm inputs including family labor, growth resources and weed control (Baumann *et al*., 2002). Growing two or more crops on the same land at the same time could increase crop yield per unit area, reduce risks associated with crop failure and price fall, balanced nutrition and additional income (Anteneh and Taye, 2015).

Enset is a locally domesticated crop with high nutrient contets, resilient to drought or flooding, and resistant to pests and diseases. It is a crop typically grown by smallholder farmers in southern Ethiopia mostly with close association with Arabica coffee for various purposes. Enset has long been used to guard families against hunger because of its low maintenance and high yields per unit area of land. A plant of 5 years old could produce up to 21kg of local food (Kocho, Bulla and Amcho) and 3.6 t ha^{-1} dry matter residue for enriching soil organic matter (Kippe, 2002). The unique feature of the South region coffee farming system is evidenced with existence of coffee and enset in almost the entire farms studied. This is attributed to the use of enset for provision of shade to coffee trees and dominantly used as major food crop in the area. Different recommendations were reported on intercropping of coffee with enset at Tepi and Awada (Behailu *et al*., 2020; Leta and Ashenafi, 2021). However, at high land agro-ecologies like Gera have not been addressed. Therefore, the objective of this study was to draw recommendations on biologically and economically sound coffee to enset intercropping ratio for southwest Ethiopia.

Materials and Methods

Description of study site

The experiment was conducted at Gera Research Sub-Center from 2014 to 2020 cropping seasons. Gera is located at 1900 m.a.s.l and receives 1877.8 mm rainfall

annually. The mean minimum and maximum temperatures are 10.8℃ and 25℃, respectively.

Treatments and experimental design

The treatments were consisted of sole coffee, sole enset, one row of coffee to one row of enset (1C:1E), two rows of coffee to one row of enset (2C:1E), three rows of coffee to one row of enset (3C:1E) and stagger planting pattern which was enset planted at the center of four coffee trees at a distance of 4m. The treatments were arranged in a randomized complete block design with three replications. One-year-old seedlings of local enset clone were planted in the field in March/April, 2010, at the spacing of 3m x 2m in sole plots, while the intra row spacing was 2m in intercropped plots. Likewise, in plot rows planted with coffee and enset was separated at a distance of 2.5m. In the stagger planting, one enset at the center of four coffee trees and with a stager fashion to the next row (Figure 1). The recommended and adaptable Arabica coffee cultivar with compact type (74165) was used. Coffee seedlings were raised in polyethylene tubes using the recommended nursery practices (Tesfaye *et al*., 2005). Coffee seedlings were transplanted to the field at a spacing of 2m x 2m four months after planting enset (Taye and Alemseged, 2005). Field management practices were applied as per recommendation for both crops. Coffee trees were trained in single stem and capped at 2m height, and all undesirable suckers, lateral growths of long drooping primaries and secondary branches growing within 15cm were controlled and removed throughout the course of the experiment.

Data collection

The yield of both coffee and enset (kocho and bulla) were recorded (Figure 3). Raw and cup qualities were evaluated according to coffee processing and quality analysis laboratory procedure of Abrar and Nigussie (2015) at Jimma Agricultural Research Center. In addition, land equivalent ratio (LER) and yield advantages were analyzed. LER was analyzed according to (Willey, 1979):

$$\text{LER} = \frac{Yij}{Yii} + \frac{Yji}{Yjj}$$

Where, Y is the yields of component crops per unit area, Yii and Yjj are sole crop yield of coffee and enset, respectively, Yij and Yji are intercropped yields of coffee and enset, respectively, LER>1 and LER <1 shows intercropping system favors the growth and yield of the component crops and the intercropping system negatively affects the growth and yield of the component crops grown in mixtures, respectively.

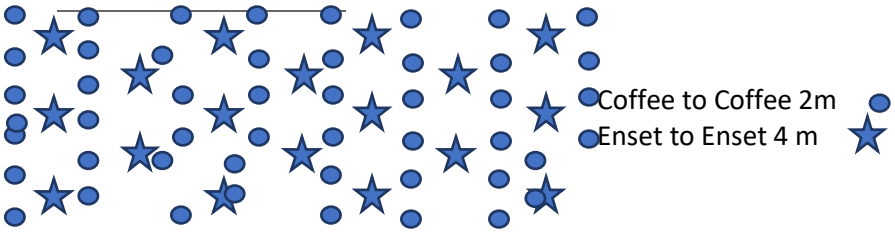

Figure1. Stagger way of planting in the field

Data analysis

All relevant data was summarized and subjected to analysis of variance (ANOVA) using SAS 9.0 version. Treatment mean separation was done by least significant differences (LSD) at 5% probability level.

Results and Discussion

Coffee yield

The statistical analysis showed that there were significant *($P \leq 0.05$)* differences in 2019 and 2020 cropping years, while highly significant *($P \leq 0.01$)* differences were observed among treatments in 2015, 2016 and 2018 cropping years and overall years for clean coffee yield. Furthermore, in 2014, 2016 and 2020 cropping years the highest mean clean coffee yield was obtained from sole coffee followed by staggered planting, whereas in 2015, 2018 and 2019 cropping years the highest mean clean coffee yield was obtained from sole coffee followed by 2C:1E (Table 1).

Likewise, the highest overall mean clean coffee yield (1573.8 kg ha^{-1}) was obtained from sole coffee followed by staggered and 2C:1E plantings that gave 1173.5 kg ha^{-1} and 1087.2 kg ha^{-1}, respectively. Conversely, the lowest yield (678.1 kg ha^{-1}) was obtained from equal ratio (1C:1E) of intercropping. The sole coffee and staggered planting exhibited about 132% and 73% more clean coffee yield than the 1C:1E planting, respectively. The overall mean clean coffee yield ranged from 678.6 kg ha^{-1} to 1573.8 kg ha^{-1} (Table 1). The highest overall mean clean coffee yield obtained from sole coffee and staggered planting might be due to the difference in plant population density and efficient utilization of light, moisture and nutrients. As plant population density increased, the clean coffee yield also increased. This result is in line with previous report by Behailu *et al*. (2020). Coffee yield was reported positively correlated with the population density of coffee trees (Nigussie *et al*., 2017). Furthermore, it was reported that coffee-enset strip intercropping significantly affected clean coffee yield (Leta and Ashenafi, 2021).

Table 3. Mean clean coffee yield from 2014-2020 cropping years and overall mean clean coffee yield (kg ha^{-1}) as affected by intercropping of Arabica coffee with enset

Treatments	Clean coffee yield (kg ha^{-1}) over years							
	2014	2015	2016	2017	2018	2019	2020	Overall mean
Sole Coffee	947.7	601.3a	2862.4a	505.3	2988.1a	806.1a	2305a	1573.75a
Sole Enset	-	-	-	-	-	-	-	-
1C:1E	505.9	75.5b	1126.6d	169.4	1314.2d	267.1b	1288b	678.1d
2C:1E	755.5	184.3b	1850c	265.6	2166.5b	348.3b	2040a	1087.17bc
3C:1E	731.5	81.7b	1987.8c	488.7	1575cd	316.6b	1724.8ab	986.6c
Staggered	903.6	146.4b	2404.6b	330.6	1917.5bc	309.6b	2201.8a	1173.45b
LSD (5%)	NS	241.9	396.55	NS	587.02	326.56	608.2	165.47
CV (%)	24.68	58.97	10.29	42.06	15.64	42.35	16.89	7.99

Means followed by similar letters are non-significant at 5% probability level

Coffee yield oscillation was observed in 2015, 2017 and 2019 cropping years (Figure 2). This might happen when enset plants were harvested coffee plants were exposed to sun light and reduced the shading effect to the coffee trees. In all cropping years, the lowest clean coffee yield was obtained from equal ratio of coffee to enset (1C:1E). The yield decrement was related with the decrease of coffee population density and the increase of enset as compared to other treatments (Figure 2). This result is in line with the finding by Behailu *et al*. (2020) who reported that when coffee population density decreased and enset per unit area increased the mean clean coffee yield was decreased at equal ratio (1C:1E). Similar findings were reported by Taye *et al.* (2008) who obtained the lowest yield from equal proportion of the two crops.

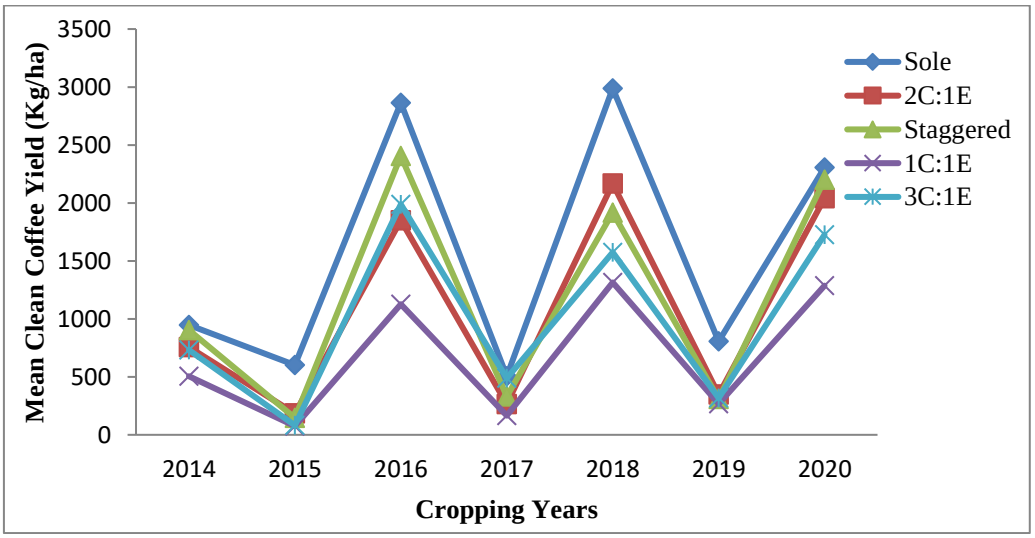

Figure 2. Mean clean coffee yield as influenced by intercropping of Arabica coffee with enset from 2014-2020 cropping years

Enset yield

The kocho yield result showed significant *($P \leq 0.05$)* differences for the first two harvests of 2013 and 2016 cropping years, and for the overall mean. The highest kocho yield was obtained from 1C:1E (6276 kg ha^{-1}) followed by stagger planting (5167 kg ha^{-1}) in all cropping years. Whereas, the lowest kocho yield (4399.5 kg ha^{-1}) was obtained from 2C:1E.

Figure 3. Enset at field and harvesting time

Significant bulla yield was obtained only in 2016 cropping year when equal ratio of coffee to enset and stagger plantings provided the highest yields of 126.18 kg ha^{-1} and 95.53 kg ha^{-1}, respectively (Table 2). Nevertheless, the overall mean of bulla yield was statistically insignificant; the highest mean bulla yield was harvested from 1C:1E planting (202.13 kg ha^{-1}) followed by sole enset (162.04 kg ha^{-1}). Conversely, the lowest bulla yield was harvested from 2C:1E planting patter which gave overall mean yield of 118.75 kg ha^{-1} (Table 2). Similar findings were reported (Taye, 2008; Behailu *et al*., 2020; Anteneh *et al*., 2015).

Table 4. Mean yields of kocho and bulla across cropping years as affected by intercropping of Arabica coffee with enset

Treatments	Kocho (kg ha^{-1})				Bulla (kg ha^{-1})			
	2013	2016	2020	Overall mean	2013	2016	2020	Overall mean
Sole coffee	-	-	-	-	-	-	-	-
Sole enset	4162b	5222.2c	4044.4	4476.2b	314.81	60.19b	111.11	162.04
1C:1E	6516a	7453.9a	4868.2	6279.3a	338.98	126.18a	141.24	202.13
2C:1E	3628.7	5352.7bc	4216.9	4399.5	120	94.53ab	141.09	118.75
3C:1E	3914.8b	6678.5ab	4022.2	4871.9b	176.3	81.48b	117.78	125.19
Staggered	4607b	6817.8a	4076.6	5167.1ab	254.06	95.53ab	123.3	157.63
LSD (5%)	1874	1428.7	NS	1235.5	NS	38.877	NS	NS
CV (%)	21.79	12.04	16	13.03	38.74	22.55	29.51	24.45

Means followed by similar letters are non-significant at 5% probability level

Land equivalent ratio (LER)

The highest LER was obtained from staggered planting in 2016 and 2020 cropping years with the values of 2.15 and 1.96, respectively. Likewise, the highest LER was obtained from staggered planting for overall mean with the value of 2.06. In contrast, the lowest LER of 1.67 and 1.78 were obtained from 2016 cropping year and overall mean, respectively from 2C:1E planting (Figure 4). All intercropped treatments were more beneficial than sole planting because the value of LER is more than one. It favored the growth and yield of the component crops for intercropped treatments which might be related to efficient utilization of resources (Thayamini and Brintha, 2010). The result is in line with the findings on advantages of coffee intercropping with enset, orange, potato and spice crops (Taye, 2008; Anteneh *et al*., 2015). Similar findings were reported by Taye *et al*. (2004) and Anteneh *et al*. (2015) on intercropping of coffee with avocado and potato that showed better LER as compared to sole of each crop.

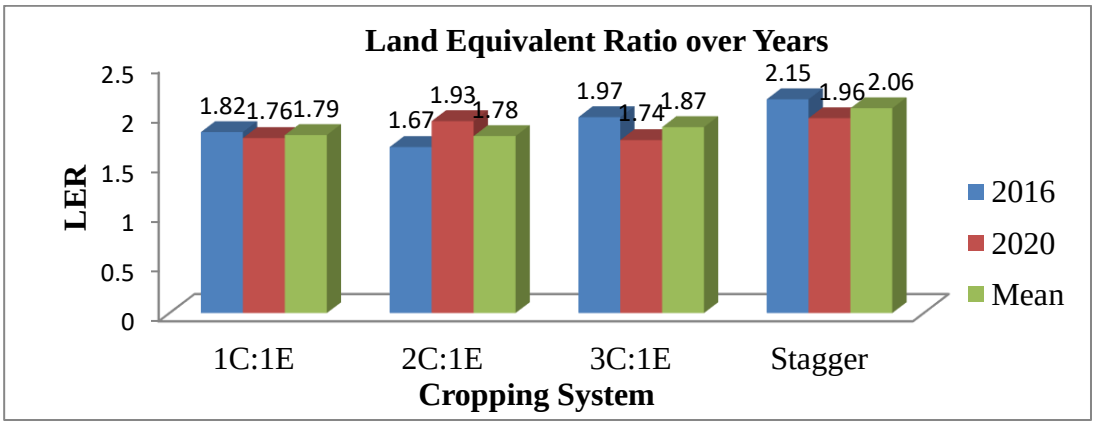

Figure 4. Land equivalent ratio of intercropping of coffee and enset

Yield advantage

The highest yield advantage (0.76) was obtained from staggered planting followed by 2C:1E treatment (0.69), whereas the lowest yield advantage (0.43) was obtained from equal ratio (1C:1E). Likewise, maximum yield advantage for cropping years of 2014, 2016 and 2020 with the values of 0.95, 0.84 and 0.96, respectively were obtained from staggered planting. Whereas, maximum values of 0.31, 0.73 and 0.43 yield advantages were obtained from 2C:1E in 2015, 2018 and 2019 cropping years, respectively (Table 3). Intercropping coffee with enset presented more advantage than sole coffee stand. Similar finding was reported by (Behailu *et al*., 2020) that higher yield advantage of coffee was obtained by intercropping coffee and enset than the sole coffee.

Table 5. Yield advantage of intercropping of coffee and enset

Treatments	Yield advantage of coffee							
	2014	2015	2016	2017	2018	2019	2020	Mean
Sole Coffee	-	-	-	-	-	-	-	-
Sole Enset	-	-	-	-	-	-	-	-
1C:1E	0.53	0.13	0.39	0.34	0.44	0.33	0.56	0.43
2C:1E	0.79	0.31	0.65	0.53	0.73	0.43	0.88	0.69
3C:1E	0.77	0.14	0.69	0.97	0.53	0.39	0.75	0.63
Staggered	0.95	0.24	0.84	0.65	0.64	0.38	0.96	0.76

Raw and cup quality

The results revealed that there were no significant differences among treatments ($P > 0.05$) for all raw quality of screen size, shape and make, color, odor and over all raw quality (Table 4). Likewise, the cup quality test parameters of aromatic intensity, aromatic quality, acidity, astringency, bitterness, body, flavor, organolaptic quality and cup quality showed non-significant differences. However, a significant difference ($P \leq 0.05$) was observed among treatments for total quality (Table 5). The highest total quality (81.83%) was achieved from both sole coffee and 1C:1E treatments, whereas the lowest total quality (80.277%) was obtained from staggered treatment (Table 5). All cup quality results were above 80% which is a highly acceptable range in cup test quality (Mikru *et al*., 2020).

Table 4. Effect of intercropping of coffee with enset on raw quality of coffee

Treatment	Screen number (14%)	Shape and make (15%)	Color (15%)	Odor (10%)	Raw (40%)
Sole Coffee	94.00	12.78	13.28	10.00	36.06
1C:1E	94.67	13.17	13.06	10.00	36.22
2C:1E	95.33	13.00	13.33	10.00	36.33
3C:1E	94.67	12.83	13.11	10.00	35.94
Staggered	93.67	12.78	13.39	10.00	36.17
LSD (0.05)	NS	NS	NS	NS	NS
CV (%)	1.558	1.37	1.745	0	0.834

NS= non-significant at 5% probability level

Table 5. Effect of intercropping of coffee with enset on cup and total quality of coffee

Treatment	AI (5%)	AQ (5%)	AC (10%)	AS (5%)	BI (5%)	BO (10%)	FL (10%)	OAQ (10%)	Cup (60%)	Total (100%)
Sole Coffee	4.06	4.11	7.44	4.00	3.94	7.44	7.33	7.44	45.78	81.830a
1C:1E	3.94	4.06	7.44	4.00	4.00	7.44	7.22	7.39	45.50	81.830a
2C:1E	4.00	4.00	7.33	3.83	3.94	7.28	7.17	7.22	44.78	80.95ab
3C:1E	3.89	3.83	7.33	3.89	3.94	7.39	7.17	7.28	44.72	80.95ab
Staggered	4.00	3.94	7.22	3.667	3.89	7.33	7.11	7.17	44.34	80.270b
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
CV (%)	3.53	5.059	2.252	4.449	3.851	1.593	2.25	1.734	1.383	0.663

AI= aromatic intensity, AQ= aromatic quality, AC= Acidity, AS= Astringency, BI= Bitterness, BO= Body, FL= Flavor, OAQ= Organolaptic quality, Means followed by similar letters are non-significant at 5% probability level

Conclusion and Recommendation

Intercropping is one of the cropping systems to achieve diversified and intensified crop production through better utilization of resources. Coffee-based intercropping system is important for efficient use of land and resources to increase productivity. The highest coffee yield was obtained from sole coffee followed by staggered and 2C:1E plantings. Likewise, maximum kocho yield was attained from 1C:1E followed by staggered, whereas the highest bulla yield was acquired from 1C:1E followed by sole enset. Conversely, the highest land equivalent ratio and yield advantage were obtained from staggered planting. In addition, total quality was significantly affected by cropping system. In conclusion, staggered intercropping of coffee with enset was the best way of planting system for enhancing the productivity of both crops.

It is advisable that a farmer has to raise new enset seedlings a year before harvesting of the matured enset for re-transplanting immediately after harvesting. When coffee is intercropped with enset, the influence of other shade trees should be minimized or avoided as much as possible to ensure sustainable coffee

production. By considering the limited farm size owned by farmers and the long period required for coffee trees to come into bearing, intercropping with crops like enset is the remedy to increase productivity. Therefore, staggered intercropping system is advisable for efficient use of land and increase the productivity in areas like Gera.

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Phenological Growth Patterns of Released Avocado Varieties at Melkassa, Central Rift Valley of Ethiopia

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Abstract

Avocado undergoes vegetative and reproductive cycles along the growing season. Each growth cycle has specific timing of recurrent biological event in which different phonological and developmental changes are taken place. Identification of time of each growth stage at particular area for particular variety gives the growers to schedule management practices required for improved productivity and quality. Study was conducted to assess visible phenological growth patterns and describe time-period relationships between phenological growth patterns of matured avocado trees at Melkassa Agricultural Research Center fruit orchard for three years (2019-2021). Six released avocado varieties grafted on local rootstocks established at the research center fifteen years back were used for the study: which includes Hass, Pinkerton, Bacon, Ettinger, Fuerte and Nabal. The varieties were planted with planting density of 6 m 6 m and uniform management practices were applied for all trees. The soil of the orchard is loam soil and furrow irrigated throughout the plantation life. Five sample trees per variety were selected randomly and 20 sample shoots, five from north, south, east and west sides of each sample tree. Sample branches were labelled and bi-weekly observation was made starting the first week of August. The visible growths of avocado varieties such as inflorescence emergence, flower flushing, shoot flushing, fruit set and harvesting periods were assessed throughout the year for three consecutive years. Data were recorded when at least 50% of the experimental fruit trees was in the same stage of development. The result showed that inflorescence emergence and flower flushing of all avocado varieties at Melkassa occurred from September to November due to low temperatures during this period. In addition, the study observed that all avocado varieties produced vegetative shoots flushing from September up to December. The observation indicated that the harvesting periods of all avocado varieties were concentrated in September and October. The study revealed that all varieties required nearly 11-12 months for fruits to mature and ready for harvesting. In depth future study is required for detail investigations based on avocado BBCH (Biologische Bundesanstalt, Bundessortenamt Chemische Industrie) scale for all varieties at major production areas of the country. This includes quantification of growths of all variables such as plant height, trunk height, stem diameter, root growth, canopy volume, fruits growth patterns (trends) and compositions, yield and yield efficiency of the varieties. Further, this study should continue with detail investigations on influences of environmental, weather elements and management practices on the physiological responses on those commercial avocado varieties and local land races of avocado at the major production areas.*

Keywords: Avocado, development, growth, phenology

Introduction

Avocado (*Persea americana* M.) production started in Ethiopia in the mid-1960. Since the introduction, seeds and seedlings were distributed all over Ethiopia in particular in the high rainfall areas of south and south western parts of the country. Avocado is successfully grown from nearly 1000 to 2300 m.a.s.l in Ethiopia and currently cultivated under both private small holders and commercial levels; and the area covered by avocado in the country reached more than 32,262 ha of land with an estimated annual total production of 259,186 tons of fresh avocado fruits (CSA, 2020/2021a, b). Because of high domestic, industrial and export demand, cluster commercialization of avocado development started in 2015/2016 in the country (www.ata.gov.et/our-approach/agricultural-commercialization-clusters-2/). Since then, tens of thousands of ha are covered by commercial varieties in the major regional states of Ethiopia.

Since the registration of commercial varieties such as Hass, Ettinger, Fuerte, Pinkerton, Bacon and Nabal (MoANR, 2008), millions of improved avocado seedlings (mainly Hass and Ettinger variety) are multiplied and being planted in clusters plantations in Amhara, Oromia, SNNPR, Sidama and South Western Ethiopia Peoples Regional States.

Once start fruiting, all avocado trees show defined and deferent phenological growth patterns (cyclic growths) such as inflorescence emergence, flowering, shoot flush, fruit set, fruits fall, exponential fruit growth, root flush and harvesting. They are among key visible growth patterns depending on existing season (climate), altitude factors and management practices (Whiley *et al.*, 1988; Paull and Duarte, 2011). Avocado planted in different agro ecologies follow different growth patterns of same cycles; in particular area they follow same annual growth cycle due to the specific climate of the area governing tree growth and development.

In order to improve yield and quality of matured avocado plantations, each avocado field management practices such as tree training, pruning, seasonal irrigation management, seasonal nutrient applications, and other field management practices should go with specific growth stages and timing of particular management practices (Wolstenholme, 1990; Schaffer *et al*., 2013). In addition, an understanding of the phenology elements of avocado is essential for interpreting physiological responses of the crop to environmental factors. Knowledge of the time of root and shoot growth, flowering and fruit set, and the relationships between these events with the seasons growing conditions will allow for application of irrigation, fertilization, and other cultural practices at optimum times (Whiley *et al*., 1988; Whiley and Wolstenholme, 1990). Thus, understanding developmental phenology for avocado varieties at particular sites

and application of required management practices could greatly enhance a grower's ability to plan corresponding management practices in relation to the events occurring within the tree. These phenological growth and development patterns of avocados were defined in the major avocado growing areas of the world such as California (Salazar-García *et al*, 1998), South Africa (Whiley, 1994), and Australia (Whiley *et al,* 1988). Since the geographical locations, seasons and environments of avocado growing regions vary, one should understand these growth events/ patterns for particular areas and particular variety before formulating management practices. It is presumed that geographic locations, environmental conditions and seasons govern fruits' developmental patterns including the varietal differences. Each crop variety responds to these factors in a similar or different ways depending on the maturity types (early, mid or late) including avocado (Wolstenholme, 2013). In Ethiopia, although avocado has become a very important fruit crop, little is known about the phonological growth patterns of the varieties under production. Thus, the objective of this paper was to assess key visible phenological growth patterns and describe time-period of commercial avocado varieties at Melkassa.

Materials and Methods

Description of study area

The study was conducted at Melkassa Agricultural Research Center (MARC); located at 39^0 21' E longitude and 8^0 24' N latitude and at an altitude of 1550 meters above sea level. MARC receives mean annual rainfall of 827 mm. The average annual minimum, mean and maximum temperatures are 14.0, 21.6 and 28.4°C, respectively. The dominant soil type of the center is Andosol of volcanic origin with pH ranging from 7.0 to 8.2. The soil was texturally classed as loam soil (Melkassa Agricultural Research Center Profile Booklet, 2020).

Study materials

The study was conducted for three consecutive years (2019 - 2021) on six commercial avocado varieties established fifteen years back grafted on local avocado rootstock materials. These varieties include Hass, Pinkerton, Bacon, Ettinger, Fuerte and Nabal. Since establishment, the same management practices were given to all avocado varieties. The orchard had a planting density of 6 m* 6 m; furrow irrigated throughout the year except during the rainy season (late June, July, August and mid of September).

Phenological Variables

Some key visible growth and development variables of avocado varieties were assessed throughout the study years. These variables include inflorescence flushing, flower flushing, shoot flushing, fruit set, harvesting periods and dormancy, which were recorded as per scale developed by BBCH (Biologische

Bundesanstalt, Bundessortenamt Chemische Industrie) scale (Alcaraz *et al.*, 2013). Modified BBCH scale for avocado was used for the study (Alcaraz *et al.*, 2013). Count data collection and observations were made on the phenological stages during vegetative and reproductive developmental stages of the varieties according to the BBCH scale. The count and observations were performed on sample of five trees from each variety. It was decided that, for data count and observations, at least 50% of the sample trees was in the same stage of development. During the three experimental years, sample of 20 shoots were observed every two weeks on sample trees' branches: five branches on the north side, five on the south side, five on the east side and five on the west side. The samples were marked and numbered starting the first week of August and ending the last week of July. Key visible growth stages suitable for the study were selected and data were recorded from sample shoots, branches and trees.

Inflorescence emergence

Sample avocado shoots were monitored every two weeks and the number of shoots which produced inflorescence were counted and converted into estimated percentages per direction/ side and per sample trees.

Flower flushing

Similarly, sample shoots from sample trees that went into flower flushing were counted and converted into estimated percentages per sides and per sample of the tree.

Shoot flushing

Sample shoots that developed into shoot flushing were counted and converted into estimated percentages per sides and per sample tree. These shoots are the once that developed in to vegetative part.

Fruit set and growth

Fruit set was estimated with the time period between flowering and fruits harvesting measured in days or months. Avocado trees have a continuous flowering that lasts at least for two to three months, and hence, continuous fruit harvesting is usually experienced, in which early flowered trees are harvested early and late ones are harvested late. The period between flowering and harvesting was taken as periods of fruit set and growth and data recording was conducted from the sample trees.

Harvesting period

Once the fruits are matured from sample shoots, it is ready for harvesting, the time periods between start of harvesting and end of harvesting periods were recorded from each sample trees and taken as harvesting period.

Climate data

Long term monthly climate data such as mean temperatures and rainfall were taken from Melkassa Agriculture Research Center Weather Station. These data were sketched with time series against phenological growth data recorded.

Data collection and analysis

Data were recorded from five sample trees per variety where sample branches were tagged on each sample tree for continuous monitoring. Data records were made bi-weekly throughout the year for three years (2019- 2021). Estimated numbers of shoots produced inflorescence and flowered (start and end), and numbers of terminal shoots developed into vegetative flush (start and end), and start of harvest and end of harvest were recorded in bi-weekly frequency. Percentage data per sides shoots were averaged over the sample branches, and average of sample branches were further averaged over the sample trees. The average data values for the respective parameters was averaged from the sample trees for each avocado variety.

Descriptive data analysis was made for the key variables such as 1) number of shoots producing inflorescence and flowering; 2) number of shoots producing vegetative flushing (start and end) and seasonal harvesting periods (start and end) were recorded from sample trees of six avocado varieties with the frequency of data recording in bi-weekly events.

Results and Discussion

Phenological growth cycles of avocado variety

The study has clearly identified cyclic growth patterns of all matured commercial avocado varieties at Melkassa Agricultural Research Center. There were visible seasonal-growth changes on sample avocado trees that occurred consistently within a year such as inflorescence emergence, flowering, shoot growth, fruit set, fruit growth and harvest.

An understanding of these cycles/ or a phenology model for particular avocado variety and locations could greatly enhance a grower's ability to plan management practices in relation to the events occurring within the tree (Arpaia *et al*., 1995). Knowledge of the time of root and shoot growth, flowering and fruit set, and the relationships between these events and with ecology of particular area will allow for application of irrigation, fertilization, and other cultural practices at optimum times. Similarly, Schaffer *et al*., (2013) mentioned that understanding of these phenology, growth habit and ecology of avocado is essential for interpreting physiological responses of the species and variety to environmental factors.

Inflorescence emergence

Once harvesting was completed from avocado tree, the tree stayed few weeks without any visible growth, preparing for the development of inflorescence

emergence and flower flushing. Prior to flowering each avocado shoot tips produced inflorescences. Figure 1a shows inflorescences emergence and Figure 1b shows avocado flowering at Melkassa. During this transition period, the shoot tips of avocado looked like dormant and not producing new leaves then earlier matured shoots produced massive inflorescence. The main (primary) inflorescence axis contained a secondary and tertiary axis. The exact date of inflorescences emergence from each branch and the tree was not clear from year to year; and the cause of inflorescences emergence was also not clear as there was a variation among the branches, trees of the same variety although low temperatures are the main causes (Chaikiattiyos *et al*., 1994).

The probable reason, as indicated in many literatures, prevailing lower temperatures at Melkassa might induce inflorescence emergence and flowering in all avocado varieties. The period from September to mid of January could be classified as Ethiopia's cool season when the overall climate is a little cooler than during the rest of the year. During this period all avocado varieties produced inflorescence and flowering. In addition, early harvesting would enhance early inflorescence emergence and late harvest delays inflorescence emergence of avocado. Vigor trees and the trees that did not produce heavy yield produced early inflorescence emergence in the next year. Avocado inflorescence emergence and flowering was continuous for nearly two months for each variety. Any mis-management during the previous years and the current year contributed to large quantity of fruits fall. In general, avocado flowering season of these commercial varieties coincided with cool and dry season with no rainfall where moisture (irrigation) was a key management required.

(a)

(b)

Figure 12: Inflorescence emergence (a) and flushing (b) stage of avocado tree

Flower flushing

All avocado varieties had extended periods of flowering at Melkassa with the corresponding extended harvesting. The continuous observations of avocado flowering assessment at Melkassa indicated that most of the avocado varieties flowered from late September to December every year (Table 1). Hass and Pinkerton varieties flowered earlier while the rest produced flowers in October and November.

Table 1: Commercial avocado flowering periods at Melkassa

Variety	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.
Bacon												
Ettinger												
Fuerte												
Bacon												
Hass												
Pinkerton												

The avocado flowering behavior is typical in many ways. The mature tree may produce in excess of a million flowers during the flowering period (Chaikiattiyos *et al*., 1994). The flowers occur in panicles of several dozens to hundreds of flowers borne on two different types of avocado inflorescences: determinate and indeterminate. In a determinate inflorescence, the tip of the shoot that bears the flowers will end in a floral bud whereas indeterminate inflorescences tend terminate with a vegetative bud. Once avocado flower buds open, they grow rapidly into flowers.

A tree can have hundreds of panicles and the tree as a whole can have up to a million flowers (Bergh, 1986). A typical full grown healthy avocado tree can produce up to a million flowers a year, but, on the average, fewer than 300- 400 flowers or less per tree will set fruit that will hold and develop to maturity and harvest (Bergh, 1986; Salazar-Garcia *et al*., 1998;).

After the inflorescence emergence, avocado started producing flowers, even flowering started before completion of inflorescence emergence (Figure 2). Florets at the terminal head opened first and florets at the base of inflorescence opened the last. High competition for foods is expected among flowers and berries where there are no sufficient reserve foods in the shoots, branches, and trees, and may be high flower, berry and fruit fall causing low yield with small size fruits.

Figure 2: Flower flushing stage of avocado

Vegetative shoots emergence and flushing

The time period of vegetative flush of avocado at Melkassa occured mainly from early September to December (Table 2). This occurrence was happening with avocado flowering and fruits set with high competition, in addition there was maximum fruits fall during this period. It may suggest that starch and other growth requirements need to reach certain levels and in balance with each other for the tree to carry maximum fruits number and sizes.

Table 2: Vegetative shoot flushing of commercial avocado varieties at Melkassa

Variety	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.
Bacon												
Ettinger												
Fuerte												
Bacon												
Hass												
Nabal												
Pinkerton												

The fruit-bearing branch growth pattern of an avocado tree is periodic, with alternating periods of growth and rest. Buds are established during periods of rest. Schaffer *et al*., (2013) generalized that to understand the overall response of the tree to the environment, it is important to consider leaf and shoot developmental stages; the time from bud-break to full leaf expansion in field-grown avocado trees is approximately 30 days, and leaves attain positive net CO_2 assimilation values slightly before or at full leaf expansion.

Both flowering and vegetative shoot emergence together have extended periods that surely caused further extended harvesting period. The first emerged flowers set fruits first and harvested first and the last flowered set fruits, harvested last.

The key vegetative growths of avocado are shoot flushes, heavy peripheral flowering synchronized by cold, water "expensive" flowering, very low fruit set during critical phase, crop load adjustment throughout fruit setting, and irregular fruiting (Whiley *et al*., 1988). Thus, one should understand particular reproductive and vegetative growths of avocado varieties in particular areas and seasons, so that specific agronomic management practices could be applied for a given variety and production area for higher yield and quality.

New shoot emergence and flushing in avocado took place immediately after opening of flowering in many branches (Figure 3). Avocado branches had both determinate and indeterminate shoots; the determinate shoots are those shoots that end with inflorescence and flowering. The indeterminate shoots are those shoots that end with vegetative buds or vegetative shoots without flowering (Figure 4).

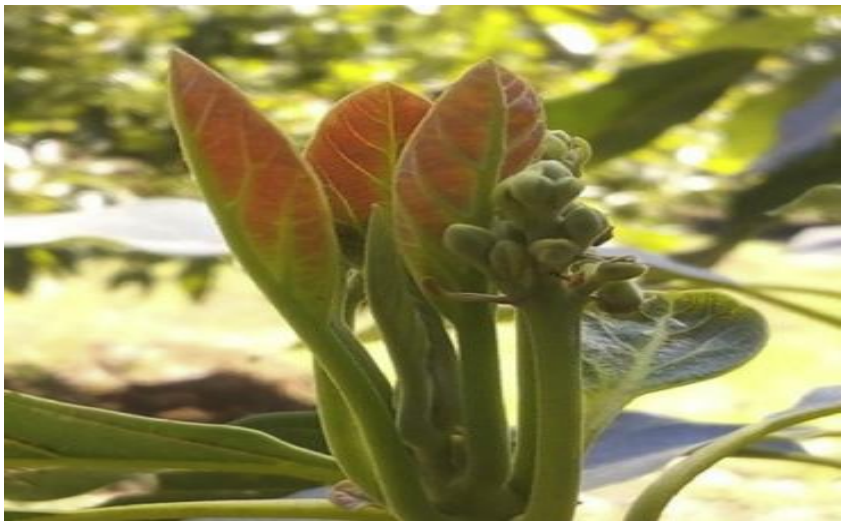

Figure 3: Vegetative flushing stage with in inflorescence of avocado

Figure 4: Vegetative flushing stage of avocado without inflorescence development

The panicles are usually determinate (no leafy buds emerging from the panicle), but some are indeterminate (with leafy buds eventually growing from the panicle). This growth period is followed by severe competition between flowers, between fruit lets, and between young succulent vegetative shoots that have very succulent leaves with deep brown colors. This competition followed by hundreds of thousands of flower fall, fruit-lets fall and berry fall continues until the tree stabilize sink-source relationship (Whiley *et al*., 1988; Salazar-García *et al*., 2013).

Some avocado branches produced vegetative shoots continuously from both stems ended with flower panicle and stems with no flower panicle or stems where all flowers shed down. Once appeared, these succulent vegetative shoots showed fast growth and attained maximum growth with predetermined number of leaves, then after some time grew fully mature that would be used for bud stick source for the next year or that will flower during the next year.

In avocado, only some apices flower; others continue the vegetative growth of the tree; thus, the primary axis meristem plays two roles, one is to produce inflorescence bracts and the other is to produce leaf primordia (Salazar-García *et al*., 2013). All avocado varieties produced young shoots with tiny and succulent leaves during the vegetative flushing period. These young shoots with leaves mature while the fruits are falling off with high leaf fall (Whiley *et al*., 1988; Salazar-García *et al*., 2013). The time period that the leaves turn from sink to source deserves research.

Leaf abscissions

All avocado varieties had a heavy leaf abscission after flowering and started of fruit set at Melkassa. This might be due to competitions for resources among inflorescence, growing berries, and young emerging shoot flushes; these leaf abscissions usually associated with moisture stress, added with insufficient nutrients for growing fruits and shoots of the tree. The time and reason for high leaf fall deserves further research as leaf fall was associated with fruits fall.

Moisture stress, nutrient deficiency, lack of enough tree carbohydrates reserve and other growth factors and any stress would contribute to early flower and fruits drop in avocado even until the final harvest. When exactly peak berry and fruit drop stops at Melkassa will be further investigated. Leaves of avocado were continuously replenished although leaf drop ws generally highest during flowering and early fruit set. Schaffer *et al*., (2013) found that avocado leaf longevity ranges from 12 to 18 months.

Fruits drop

Fruits drop of avocado started at the time of flower opening which might be because of lack of pollination, competitions among florets, and opening flowers, as hundreds and thousands of flowers are produced per branches, competitions among growing fruits, and between succulent shoots (Figure 5). There was a heavy fruit drop and sometimes associated with leaf drop. Physiologically, unfit growing fruits were shed by the avocado tree and the remaining fruits stayed on the tree and grew until harvest.

Figure 5: Fruits drop stage of avocado tree

Once avocado fruits started flowering, a mass of flowers opens together and depending up on the competition, the large part of these flowers fall down simultaneously and mass of open flowers shed down together (Salazar-García *et*

al., 2013). It was reported that nearly 0.001% of avocado flowers reach maturity (Whiley *et al*., 1988).

Fruits set and growth

After the flowers were open, fruit set occured. It continued until only few fruits (300- 400 fruits) remained on the tree. Still large parts of berries and the remaining fruits continued to fall down and finally few avocado fruits matured and reached harvestable size. The fruits set periods for all tested commercial varieties: flowering took place from September to November and harvesting was done from September to October at Melkassa. Thus, it took nearly 11-12 months for all avocado varieties' fruits to get harvestable size at Melkassa (Figure 6).

Figure 6. Fruits set and growth of avocados

Harvesting periods

The harvesting periods of commercial avocado varieties at Melkassa showed that harvesting was concentrated from September to October (Table 3). Past research studies showed that harvesting of Hass avocado varies according to the climate of the area (Whiley *et al*., 1988; Schaffer *et al*., 2013). In the warmest areas (e.g. coastal southern California), Hass avocado is harvested after approximately 11 months after peak bloom. In the coolest growing region, Hass can be harvested after about 18–22 months after peak bloom (e.g., the central California coast). In contrast, Hass grown in warm subtropical climates may be harvested 8 months after peak bloom, with less potential for prolonged on-tree storage, and with a higher percentage of small fruit.

Table 3: Harvesting periods of commercial avocado varieties at Melkassa

Variety	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Bacon												
Ettinger												
Fuerte												
Bacon												
Hass												
Nabal												
Pinkerton												

As avocadoes are planted across the country at all ranges of altitudes (from 1100 to 2200 m above sea levels), through identifications of major production area even minor producing sites; it is possible to capture exact flowering/ harvesting periods. Once matured, avocado fruits could stay hanging on the tree for few weeks or months, but most avocado branches will not produce new flowers and fruits while the previous fruits are hanging on the tree. Once the fruits matured, leaving the fruits on the tree and any late harvest would affect the next year yield of the tree. It seems that with early harvest like in early September one can make avocado plantation early flowering, with all appropriate management practices, one can harvest earlier yields and these phenomena should be confirmed.

Dormancy

There was no dormancy for avocado trees between fruits harvest and new inflorescence and flower opening and shoot flushing, as inflorescence emergence first followed by flower opening then immediately these followed by vegetative flushing that appeared concurrently. One can see flowering and vegetative flushing on an avocado tree/ branch while fruits harvest was not yet completed at Melkassa (Figure 7). This clearly indicates that there is no dormancy in an avocado at this particular area.

Figure 7. Flowering, shoot flush of avocado while fruits harvest is not yet completed

The physical appearance of avocado shoots (alternating end of vegetative growth) ready for inflorescence emergence are shown in Figure 8. Salazar-García *et al*., (2013) reported that dormancy is not dictated in avocado trees and management required should be given throughout the year. As there is no dormancy in avocado, , inducing any stress towards fruits harvesting and after harvesting drastically affect flower initiation and flushing, that affect next year's tree yield performance.

Figure 8. Physical appearance of avocado shoots (alternating growth) ready for inflorescence emergence

Climate

The study has clearly showed that there were clear phenological growth patterns along the seasons at Melkassa. There were clear variations among the seasons rather than varieties. Differences in avocado cultivar, latitude, climate and shoot

age are factors that influence tree phenology and affect the time and stage of development when apical buds become committed to flowering (Whiley *et al*., 1988; Salazar-García *et al*., 2013). Among the weather elements temperatures are influencing avocado growth and development (Wolstenholme, 2013). Thus, relating existing temperature trends of a particular area is important for forecasting the current and future growth patterns of avocado and formulating optimum management required for the plantations.

Temperature

Flowering in subtropical avocado cultivars is induced by a period of low temperature (Salazar-García *et al*., 2013). Hass did not flower when kept at temperatures of 30/25, 25/20 or 20/5 ^{0}C (day/night), but did flower when exposed to 3-4 months of 15/10, 18/15, 20/15 and 23/18 ^{0}C (day/ night). Under the two last temperature regimes the flowering was delayed and sparse (Buttrose and Alexander, 1978). Low temperature (LT) is a factor known to inhibit or enhance floral initiation in avocado that can be used to identify an anatomical change associated with commitment to flowering (Salazar-García *et al*., 2013).

Low heat unit accumulation leads to very late 'Hass' minimum legal maturity, 13–18 months after flowering and well into the next fruiting season (Wolstenholme, 2013). Studies found that day length and water stress does not seem to be a factor in flower induction in avocados; further, water stress did not appear to increase avocado flowering in trees subjected to either high temperatures or low temperatures. Flowering was delayed after the water stress (compared to the non-stressed control trees) occurred about a month after cessation of the stress (Chaikiattiyos *et al*., 1994).

Flowering in avocado cultivars is induced by a period of low temperature which starts falling in September at Melkassa (Figure 9). This decline in temperature was associated with opening of mass of avocado flower panicles in most of the varieties. Low temperatures in October, December and January induced most avocado shoot tips for flower development. Moisture stress at this period must be avoided.

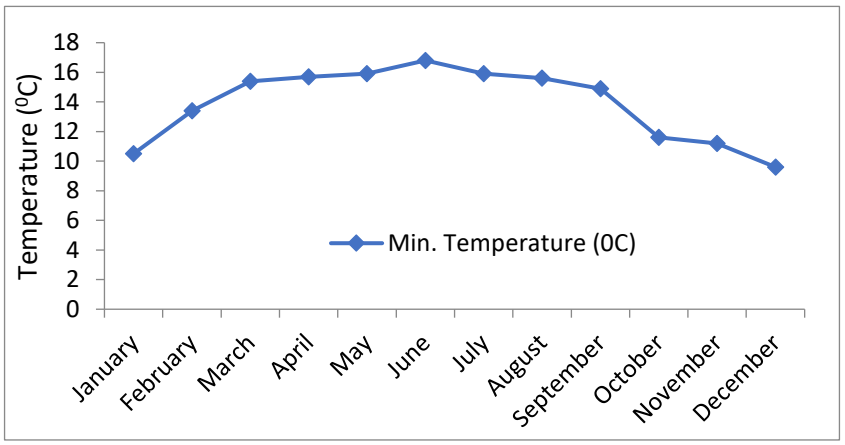

Figure 9: Monthly long term average minimum temperatures at Melkassa

Vegetative shoots emerged with in flower panicle during the cool periods once flowering was completed, and then vegetative shoots grew vigorously with fruits development as temperature increased starting from February (Figure 10). As leaves transition through various morphological stages from emergence to senescence and from sink (net carbon importers) to source (net carbon exporters), their carbon contribution to the tree changes as does their response to environmental variables (Dickson *et al*., 2000). Maximum temperature at Melkassa dropped in June (Figure 10) which is the period associated with avocado fruits maturity for all varieties.

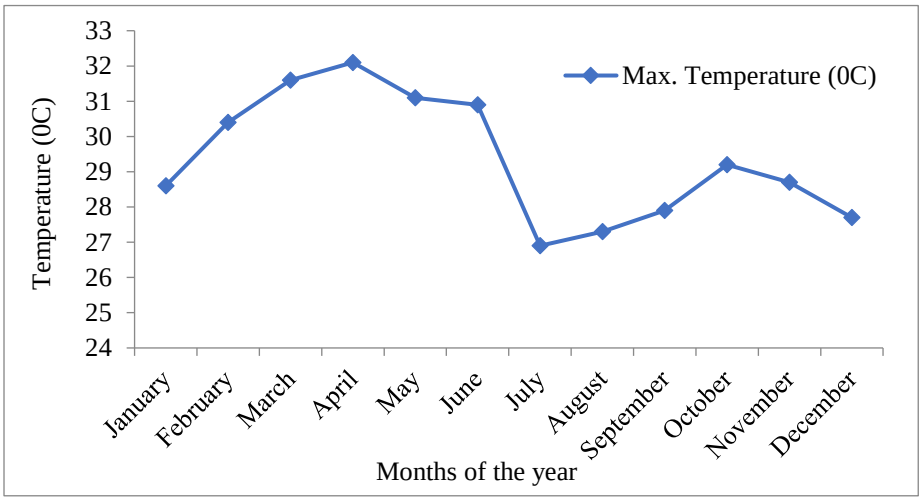

Figure 10: Monthly long term average maximum temperatures at Melkassa

Rainfall

Melkassa, has three seasons: which includes humid and wet season from July to mid of September, cool and dry from mid-September to first week of January, and hot and dry season starting mid of January and ends in June. The long-term

average rainfall data at Melkassa shows, rainfall starts at the end of June and ends at the mid of September (Figure 11). Full irrigation is required starting from mid of September up to mid of June as there are many critical periods for irrigation and for nutrients (Whiley *et al*, 1988). If sufficient irrigation is not given, heavy fruit fall is expected in avocado.

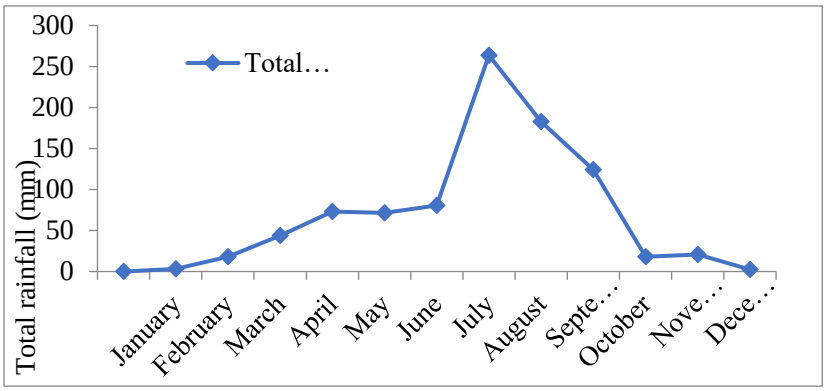

Figure 11: Monthly long term total rainfall at Melkassa

Implications for Agronomic Managements

Understanding the developmental growth stages of avocado varieties at a given environment is of paramount importance to decide and manage the application of the required crop management practices; this could greatly enhance the final yield harvest. In the presence of environmental constraints such as water scarcity, irrigation management strategies help to contribute to final yield and fruit quality in avocado (Wolstenholme, 2013) as it influences the tree physiology as roots, leaves, flowers and fruits compete for water and the necessary energy resources.

Based on avocado growth model, similar time-period were observed for the growth patterns at Melkassa (Whiley *et al.*, 1988). One of the critical growth stages is during flower development in August and September, which lead to fruiting stage and hence, avocado tree requires Phosphate, Potassium, Calcium, Zinc and Boron followed by foliar application of Zinc that coincides with vegetative flushing period. Further seasonal nutrient requirements should be evaluated based on the soil types to achieve the potential yields and quality. Another critical growth period is at the late fruit set in April and May time-period at Melkassa where Nitrogen, Potassium, Boron, Phosphate and Calcium are again required. There is also the third critical growth period around mid-January and early February at Melkassa where fruiting avocado should be supplied with Nitrogen, Potassium and Boron with Zinc foliar application. In addition, water availability influences soil nutrient availability and uptake and the production of important amino acids required for growth and development.

Conclusion and Recommendation

This study identified the optimum periods for inflorescence emergence and flower flushing for all avocado varieties such as Hass, Ettinger, Pinkerton, Bacon, Fuerte and Nabal at Melkassa which occurred from September to November, in which low temperatures prevailed during this period. Similarly, the study showed that all varieties required nearly 11-12 months for fruits to mature and ready for harvesting at Melkassa. In addition, the study observed that in all the varieties, vegetative shoot flushing occurred from September to December; while harvesting periods were concentrated from September to October.

Based on the major results obtained and observations made, understanding the growth and phonological stages of avocado tree is complex and varies among varieties, trees, branches as well as seasons. For future reference and better understanding, further investigation needs to be carried out with detail data collection including physiological parameters that can help to reach out and improve the knowledge on the subject in need and easily manipulate the varieties for optimum fruit harvest and quality. Therefore, the following are suggested: Detail quantifications of phenological patterns of avocado should be further studied with key avocado variety at major production areas of the country including: root growth, shoot flushes, bud break, fruit expansion rates, fruits growth patterns and composition, canopy volume, yield and yield efficiency, reason for leaf fall during flowering and immediately after flowering.

The differentiation from vegetative buds to reproductive buds and flower induction period for each variety of avocado at Melkassa and in other major production areas, must be studied as there is very short period between final harvest and appearance of new inflorescence. Further effect of any stresses during this transition should be identified. Cyclic growth in relation to potential bearing (biennial, alternate, on year, off year, irregular or uneven bearing).

Identification of Agro-ecology based variety specific growth cycle is necessary; which intern helps to identify critical growth stages and periods where irrigation and nutrients are required. Land race avocados should be included in the further phenological study as they contribute to the supply of fruits for domestic consumption and for oil production throughout the year. Finally, precise and standardized description of the phonological growth stages of the varieties should be studied based on the BBCH (Alcaraz *et al.,* 2013) model in the future.

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Phenological Growth Patterns of Commercial Mango Varieties at Melkassa, Central Rift Valley of Ethiopia

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Abstract

The key cyclic growth and development in adult mango trees include bud development, leaf development, shoot development, inflorescence emergence, flowering, fruit development, fruit maturity and senescence. Each growth cycle has specific time period and needs specific management requirements. Identification of the optimum time period of each growth pattern at particular location gives the producers the opportunity to schedule and apply the required management practice for improved productivity. A study was conducted at Melkassa Agricultural Research Center to assess the key visible phenological growths patterns and describe time-period relationships between phenological growth patterns of matured mango trees. The study was superimposed on mango orchard composed of four commercial mango varieties (Apple mango, Kent, Keitt and Tommy Atkins). The orchard has received uniform field managements since establishment. Five sample trees were selected randomly per variety; from which twenty sample shoots (five shoots on the north side, five on the south side, five on the east side and five on the west side) were tagged for data collection. Sample branches were labelled and bi-weekly observation was made starting the first week of August. The key visible phenological growth of mango varieties such as inflorescence and flower flushing, shoot flushing, fruit set, and harvesting periods and dormancy were assessed throughout the year for three consecutive years. Data were recorded when at least 50% of the sample trees was in the same stage of development. The result indicated that mango inflorescence and flower flushing took place from November to February, while shoot flushing took place from October to November for all varieties. The average fruit set took 7 to 8 months and harvested in June to July of each year for the varieties. The future study requires detail investigations based on mango BBCH (Biologische Bundesanstalt, Bundessortenamt Chemische Industrie) scale at lowland production areas of the country focusing on quantification of growths of all variables such as plant height, trunk height, stem diameter and root growth, canopy volume, fruits growth patterns and composition, yield and yield efficiency before formulation of optimum management practices at particular place.

Keywords: Mango, development, growth, phenology

Introduction

Mango (*Mangifera indica* L.) is a predominantly tropical species although the tree usually grows and produce more successfully in frost-free subtropical latitudes with a marked dry season and high heat accumulation (Schaffer *et al*., 2009). Although the exact date of mango introduction in Ethiopia was not recorded, local (land races) mango types are cultivated throughout the lowlands of Ethiopia (Yeshitila and Nessel, 2003; Tewodros *et al*., 2014; Tewodros *et al*., 2019a; Tewodros *et al*., 2019b). It is widely cultivated in almost all low-lying altitude areas in Ethiopia grow from Afambo (< 300 m.a.s.l; located to near the international border with Djibouti) up to Melkassa area (1550 m.a.s.l). On the other hand, mango grows under very wide climate areas in Ethiopia from long mono-modal rainfall areas of south western and western Ethiopia, to the bi-modal rainfall areas in southern Ethiopia such as Gamo and Gofa Zones up to short mono-modal rainfall areas of eastern parts of the country such as Harari, Babile and Gode areas.

Mango is one of the most widely grown fruit crops in Ethiopia and currently preceded by banana and avocado in terms of economic importance (CSA, 2019/2020). A total of 10537.93 tons of fresh mango was produced from 16363.48 ha of land in Ethiopia (CSA, 2019/2020).

Through introductions and testing of commercial varieties, four high quality varieties were registered for use (MoANR, 2008). Since then, nurseries were established and production technologies have been generated; and these varieties have been multiplied and distributed for growers by various development partners reaching the scale of commercial cluster production in various regional states of Ethiopia (Edossa *et al*., 2016; Edossa *et al*., 2019).

Growth patterns in mango trees is not continuous (Nakasone *et al*., 1955; Davenport, 2009; Knight *et al*., 2009) and mango trees grow through a series of growth events; which are influenced by variety, environment, and management practices - this in turn impacts on productivity. The sequence of key growth stages in mango from harvest includes 1) shoot flush 2) flower flush 3) shoot dormancy 4) flowering 5) fruit set 6) fruit development and 7) harvest (Davenport, 2009; Rajan *et al*., 2011).

Apical buds spend most of the time in rest. Growth occurs as intermittent, ephemeral flushes of shoots from apical or lateral buds (Naik and Mohan Rao, 1942; Davenport, 2009). Stems are quiescent or resting terminal vegetative structures on branches from which shoot growth occurs. Shoots are elongating vegetative or reproductive structures that emerge from apical or lateral buds of stems (Nakasone *et al*., 1955; Davenport, 2009). Among tree growth patterns,

vegetative flushing, flowering and fruit set are the most critical of all events occurring on matured mango. Given favorable growth conditions, and available high-quality varieties, the timing and intensity of flowering greatly determine when and how much fruits are produced.

Understanding mango developmental patterns such as flowering and flushing in major production areas is essential to efficiently utilize the required agronomic, irrigation, nutrient, diseases and insect pest management practices, which helps to manage harvesting and trading scheduling (Nakasone *et al*., 1955; Knight *et al*., 2009; Schaffer *et al*., 2009). Though the productivity of mango is governed by various factors like genetic and environmental variables, it is very low in Ethiopia compared to the crop potential; which is about 20-30 ton/ha at the research center (Edossa *et al*., 2019). Thus, all mango growers, extension agents, business people, exporters and processors should understand time series growths patterns of mango varieties so that specific management practices could be applied for a given variety and production area. The present study was therefore, conducted to assess key visible phenological growths patterns and describe time-period relationships between phenological growth patterns of commercial mango varieties at Melkassa.

Materials and Methods

Description of study area

The study was conducted for three years (2019-2021) at Melkassa Agricultural Research Center; located at $39^0$21' E longitude and $8^0$24' N latitude and at an altitude of 1550 meters above sea level. MARC receives mean annual rainfall of 827 mm. The average annual minimum, mean and maximum temperatures are 14.0, 21.6 and 28.4°C, respectively. The dominant soil type of the center is Andosol of volcanic origin with pH ranging from 7.0 to 8.2. The soil was texturally classed as loam soil (Melkassa Agricultural Research Center Profile Booklet, 2020).

Plant materials

The study was conducted in orchard of four commercial mango varieties grafted on local mango rootstock established at MARC fifteen years ago. The varieties include Apple mango, Kent (mid-season to late), Keitt (late season), and Tommy Atkins (early to mid-season) (Knight *et al*., 2009). The orchard had a planting density of 6 m* 6 m. Since transplanting same managements practices were given for all trees used for experimentation. The orchard was furrow irrigated throughout the plantation life and throughout the year except during the rainy season (late June, July, August and mid of September).

Phenological data

Some key visible growth and development variables of mango varieties were assessed throughout the study period. These visible growths include inflorescence flushing, flower flushing, shoot flushing, fruit set, and harvesting periods and dormancy, which were recorded as per scale developed by BBCH scale (Biologische Bundesanstalt, Bundessortenamt Chemische Industrie) (Hernández Delgado *et al*., 2010; Rajan *et al*., 2011).

Rajan *et al*., (2011) classified the different growth stages of mango according to the BBCH scale in to eight classes such as, 0) Bud development, 1) Leaf development, 3) shoot development, 5) inflorescence emergence, 6) flowering, 7) fruit development, 8) maturity of the fruits, and 9) senescence with sub divisions under each stage. Some count data were made on the key visible patterns of phenological stages of vegetative and reproductive development of mango varieties during the study durations according to the BBCH scale. The count and observation of vegetative and reproductive development was performed on sample of five trees per variety. For data recording and count, it was decided that at least 50% of the experimental trees was in the same stage of development. During the three years, sample of 20 shoots were observed every two weeks on five sample trees, five sample branches on the north side, five on the south side, five on the east side and five on the west side branches of each sample tree, labelled with numbers, starting the first week of August and ending the last week of July. The key visible phenological growth of mango varieties were assessed throughout the study years including shoot flushing, dormancy period, inflorescence development, flower flushing, fruit set, and harvesting.

Shoot flushing

Mango shoots from sample trees that developed into shoot flushing were assessed, counted and converted into estimated percentages per sides and per sample tree. These shoots are the one that grow into vegetative growth of the branch.

Dormancy period

Dormancy period of mango branch is the time periods between completion of vegetative growth after many flushing and start of either inflorescence emergence or / and start of again vegetative flushing. Fruits harvesting from each tip of the branches and the time of new vegetative flushing start at this point. Most mango trees stop visible growth after harvest and take some time for growth resumption.

Inflorescence development

Shoots were visited every two weeks and the number of shoots that developed into inflorescence were counted and converted into estimated percentages per sides and per sample tree.

Flower flushing

Similarly, shoots that developed into inflorescence emergence and flower flushing were counted and the number of shoots were converted into estimated percentages per position and per sample tree.

Fruit set

Mango fruit set was estimated with the time period between completion of flowering and fruits harvesting measured in months. Mango trees have a continuous flowering during the specified period of time, correspondingly mango tees have similar continuous harvesting where early flowered fruits harvested earlier and late flowered fruits harvested latter. The period between flowering and harvesting was taken as periods of fruits set.

Harvesting

Once the mango fruits were matured, it is ready for harvesting; hence the time periods between start of harvesting and end of harvesting periods at Melkassa were recorded from each sample trees and taken as harvesting period.

Climate data

Average maximum, minimum and mean monthly temperatures and rainfall data were taken from Melkassa Weather Station.

Data collection and analysis

Descriptive data analysis was used. The percentage data per mango shoot were averaged over the sample branches, and average of sample branches were further averaged over the sample trees. The average of sample trees was averaged again over the sample trees per avocado variety. The bi-weekly intervals data from a given variety were averaged and related with time series.

Results and Discussions

The study found that growth in mango is not a continuous process and it has a cyclic growth where one can only see one of the stages at a time. The study revealed that all mango varieties at Melkassa showed distinct growth stages; each of the growth stage was described.

Phenological growth cycle

The study revealed that mango varieties planted at Melkassa showed a series of growth apparent events. These events were influenced mostly by the environment, and to some extent by management practices and by variety. The visible sequence of growth stages was shoot flushing, shoot dormancy, inflorescence flushing, flower flushing, fruit set, fruit development and harvesting. The data showed that there was an extended time period for each visible phenological growth pattern studied on the four mango varieties.

Growth in mango is not continuous (Nakasone *et al*., 1955; Davenport, 2013); each growth flush is followed by a period of apparent difference growth pattern (PIP COLEACP, 2013). The mango tree's phenological cycle is strongly influenced by weather conditions (Schaffer *et al*., 2013); for mango trees to flower, there must be a marked halt in growth. This occurs as a result of a drop in average temperatures and/or a marked dry period.

Shoot flushing

In depth observations of commercial mango varieties showed maximum shoot flushing from October to November at Melkassa (Table 1). Mango new shoots growth showed different colors and stages. Most branches in dormancy stages produced first fast growth deep brown color shoots. These shoots then turned to yellow color and finally became deep color, then stopped visible growth before all they entered in to the resting stage (Figure 1). All these stages of same shoots are with in short time periods. All branches might not go in to these growth stages, there might be half of the tree or one third of the tree or might be one scaffold or branch or very few parts of the branch show these phases. The reason behind all these variations on the same tree needs further study. Still one can see variations in growth between branches at any time of the tree even during harvesting.

Table 13. Shoot flushing periods of mango varieties at Melkassa

Variety	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.
Apple Mango												
Tommy Atkins												
Kent												
Keitt												

Flushes of vegetative extension growth of mango stems terminated with formation of determinate panicles. Several weeks to a few months after separation of the last flower or fruit from these panicles were required for the central axis of the panicle or rachis to dry and mechanically separate from the supporting stem, depending on the longevity of attached fruit. Five to ten lateral vegetative shoots typically develop from axillary buds located at the terminal intercalation positioned in a compact whorl surrounding the panicle scar of each stem (Davenport, 2013). These lateral shoots become the branch points of many stems. When these matured shoots in dormant stages were ready for waiting cool temperature and if cool temperatures come; all shoots of same stage produced inflorescences and flowers when if hot temperatures came it again produced vegetative flushes in a cycle way.

Vegetative shoots develop a prescribed number of nodes during growth before entering a resting state as a stem (Davenport, 2013). Depending on the

environment, periods of stem rest were generally short in young plants but usually lasted several months between episodes of growth in mature trees. Vegetative growth occurred up to three or four times a year on individual branches, depending upon cultivar and growth conditions. Initiation of these lateral vegetative shoots occurred 2–3 months after desiccation of panicles which fail to set fruit. Fruit-bearing stems do not initiate new lateral shoots until several months after separation of fruit and rachis from the stem (Kulkarni and Rameshwar, 1989). Such delayed vegetative growth can reduce the potential for new shoots to flower during the next flowering season (Singh, 1972; Monselise and Goldschmidt, 1982). The apical bud of stems was at rest for most of the year in mature trees. Stems on centennial trees typically produced only one vegetative flush during the year.

Flushes of vegetative growth occur on groups of stems borne on scaffolding branches in isolated sections of tree canopy (Davenport, 2013). Flushing stems are usually connected at some common branch point within the tree limbs. Asynchronous flushes of growth at various times in random portions of a tree canopy may appear to be continuous growth but are simply flushes occurring in various parts of the total canopy over time. Flushes of vegetative extension growth of mango stems terminate with formation of determinate panicles. Several weeks to a few months after separation of the last flower or fruit from these panicles are required for the central axis of the panicle or rachis to dry and mechanically separate from the supporting stem, depending on the longevity of attached fruit. Five to ten lateral vegetative shoots typically develop from axillary buds located at the terminal intercalation positioned in a compact whorl surrounding the panicle scar of each stem (*Anon*.). This growth stage did not take longer time periods. All these shoots were deep brown color and soon turned in to yellow and then in to deep green color (Figure 1).

Figure 1. Shoot flushing stage of mango tree

Many mango trees undergo a number times vegetative shoot flushing in a year whereas there is only once inflorescence appearance on a given tree or where there is dormancy on one side, there is vegetative shoots flushing on the other side.

Resting (dormancy) period

After harvest all mango branches which set fruits got into resting period and stayed without any visible growth until vegetative flushing. Once dormancy period was completed the majority of mango branches produced vegetative flushes (Figure 1).

A flush event in mango is one in which the resting buds on many stems in a section of tree canopy initiate growth (asynchronous flush in tropics) or when the entire canopy initiates bud growth at once (synchronous flush in sub-tropical area) (Fernando *et al*., 2014).

Once shoot flushing was completed in mango tree and the color of all leaves turned in to deep green color, all shoots stayed without any visible apparent developmental changes (Figure 2). This time period might be the time for shoot growth flush period and shoot dormancy. It was estimated that late October to late November is the time period for starting of no growth at Melkassa.

Shoot dormancy provides time for the tree to accumulate sufficient carbohydrate reserves for flowering. Vegetative dormancy is required in mangoes before flowering and this dormancy can be induced by temperature or water stress, however high productivity is related to the successful completion of the other growth phases, not just stress. In the normal growth cycle of tree crops, shoot flushing generally follows vegetative flush, however in mangoes root flushing is poorly understood.

Shoots on mango stems are quiescent or resting terminal vegetative structures on branches from which shoot growth occurs (Davenport, 2013). Shoots are elongating vegetative or reproductive structures that emerge from apical or lateral buds of stems.

Figure 2. Resting stage of mango

Inflorescence emergence and flowering

The study observations showed that there were massive tens thousands of inflorescences emerged from branches stayed in dormancy from November to February from all mango varieties (Figure 3).

Figure 3. Inflorescence and flowering stage of mango

Davenport, (2000) and Davenport, (2003) reported that cool temperatures in the subtropics stimulate mango flowering and age of the last vegetative flush have an important bearing on its ability to flower in marginally cool or warm temperatures of the tropics.

The period from December to February could be classified as Ethiopia's 'cool season when the overall climate is a little cooler than during the rest of the year. This period at Melkassa coincided with mango flowering in the country (Table 2). Davenport, (2013) explained that flowering flushes generally occur after extended periods of stem rest in the low-latitude tropics or during cool winter months in the high-latitude tropics and subtropics.

Table 2. Inflorescence and flowering period of mango varieties at Melkassa

Variety	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.
Apple Mango												
Tommy Atkins												
Kent												
Keitt												

Fruits drop

Abscission of flowers and fruitlets drop in mango is accomplished by rapid formation of a separation layer in the abscission zone in the pedicel-peduncle junction (Barnell, 1939). The majority of panicles lose all fruitlets (Núñez-Elisea and Davenport, 1983). Of the 8–13% of perfect flowers setting fruit, < 1% reach maturity (Singh, 1978; Gunjate *et al*., 1983; Prakash and Ram, 1984).

Fruits set and growth

Following flowering which took place from December to February at Melkassa, correspondingly harvesting took place from June to July at Melkassa (Figure 4). These periods would take nearly from seven to eight months. During these fruits set period all mango trees under productions require full irrigation, nutrient applications and other pest management control systems.

Figure 4. Fruits set of mangos

Harvesting period

Harvesting started in mango in June and continued up to August (Table 3). Tommy Atkins matured first and followed by other varieties. This period was the last period of mango supply in the country and one could not find mango fruits after this period. There are almost no mango fruits after this period until probably next January in all towns and cities in Ethiopia including Addis Ababa market.

Table 3. Harvesting periods of mango varieties at Melkassa

Variety	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	July	Aug.
Apple Mango												
Tommy Atkins												
Kent												
Keitt												

Mango has a long fruiting season in Ethiopia which usually starts around December and ends around July and one can get mango fruits produced in the country during season period. Through the use of early and late-bearing cultivars and development of mango plantations in more diverse lowland areas, possibility

of longer harvesting and supply period of mango fruits could be achieved in Ethiopia (Yordanos *et al*., 2019; and Yigzaw *et al*., 2014).

Overlapping of growth stages on mango trees (crazy growth)

It is very common to see overlapping of different mango growth stages such as shoot flush, shoot dormancy, flowering, fruit set and fruit development on same mango trees and branches at the same time. This non-uniform growth and development bring complexities in identifying proper management practices required at a given period of time.

Mango trees has phenological cycle, having synchronous growth and flowering in the subtropics due to the occurrence of mild winter (Cull, 1991), whereas mango has asynchronous growth and flowering and has a long juvenile phase in the tropics (Galán Saúco, 1996).

Fernando *et al*., (2014) identified, easily observable set of developmental stages during vegetative and flowering flushes and fruiting events to characterize the changes through which individual growing mango shoots pass in the tropics. Individual non-growing stems are in the resting stage, when the apical bud (following a previous vegetative growth event) or lateral buds (following a previous flowering event) are dormant. They found that mixed shoots, bearing both leaves and lateral inflorescences at each node, exhibit characteristics of both vegetative and flowering shoots. Each stem terminal or groups of stem terminals borne on scaffolding branches act as independent structures influenced by environmental conditions, such as temperature, water relations, and nutrition coupled with their physiological age resulting in widely variable tree responses even in similar environments. They concluded that aside from phenotypic differences in distinctive shoot and stem developmental stages in mango, attempts to ascribe a distinct phenological pattern of mango tree growth and development are impractical. In tropical temperature conditions floral inductions occur in stems that have achieved adequate time in rest since the previous shoots (Davenport, 2009).

Climate data

Temperatures

Temperature is probably the most important environmental variable to consider when selecting mango cultivars for particular sites. The mean temperature range for optimum growth of mango is about 24°C– 30°C (Mukherjee, 1953; Whiley *et al*., 1989). In addition, temperature plays a key role in mango flowering. For mango flower induction, the ideal temperature seems to be around 10–15°C. The cooler temperatures in the subtropics are normally followed by flowering, with temperatures about 5°C inducing more male flowers on the inflorescence; and

panicle growth does occur at 12.5°C, when no vegetative shoots are produced (Schaff er *et al*., 1994).

Mango grows on 1200 m in the tropics, although the best production occurs at less than 800 m (Paull and Duarte, 2011). A temperature around 33°C seems to be the ideal for flowering and fruit maturation and between 25 and 27° for vegetative growth (Davenport, 2009). The lowest temperatures from 8^0C to 10^0C occurred in December up to February at Melkassa (Figure 5). Galán Saúco, (2018) summarized the effect of temperature patterns that moderate cold winter (minimum temperatures around 10º to 15ºC) induce abundant flowering, followed by relatively warm spring (minimum temperatures above 15ºC) to favour good fruit set. These cooler temperatures improve flower induction and cause early bearing and lower annual growth rates which help to control size and favour high-density plantings. This indicates high temperature after February at Melkassa favoured good mango fruits set which is similar to subtropical climate mango production areas.

The large majority of mango trees produced flowering due to low temperatures existed from November to early January at Melkassa since low temperatures induce flowering, correspondingly mango flowered during December matured in June to July at Melkassa. Under optimum temperatures with non-limiting nutrients and water, the mango trees remain vegetative with growth flushes occurring at regular intervals (Schaffer *et al*., 2009).

The large size and poor cropping of mango trees in the humid lowland tropics are well known, and there is a direct relationship between temperature and the frequency of vegetative flushes (Schaffer *et al*., 2009; Nakasone *et al*., 1955). Trees grown at 20°C days/15°C nights (20/15°C) required 20 weeks (mean of ten cultivars) to complete a growth/ dormancy cycle while at 30/25°C the same cycle was completed in 6 weeks (Whiley *et al*., 1989).

For mango trees to flower, there must be a marked halt in growth; this occurs as a result of a drop in average temperatures and/or a marked dry period (PIP COLEACP, 2013). In the tropical evergreen tree mango, cool temperature is the only factor known to induce flowering, but does not ensure floral initiation will occur because there are important interactions with vegetative growth (Chaikiattiyos *et al*., 1994). Low temperatures in mango induced shoot tips went into inflorescences and flower development; whereas high temperatures induce shoot tips in to vegetative development (Figure 5).

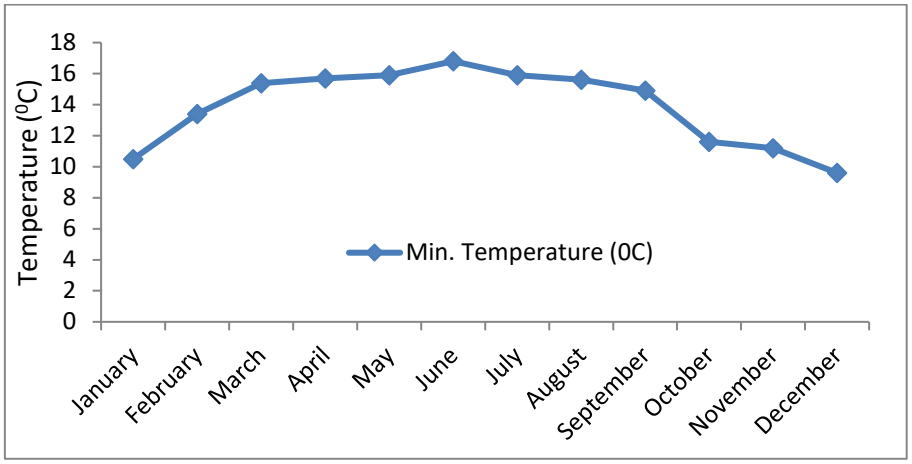

Figure 5. Monthly long term average minimum temperatures at Melkassa

The occurrences of high temperatures during February and March induced shoot tips to grow in to vegetative shoot development. High prevailing temperatures in February at Melkassa induced the development of vegetative tip of mango into vegetative flushes (Figure 6). However, the study results found in wide variation of shoot flushing among the branches. Some branches produced vegetative branches repeatedly while other branches stayed in dormant stages. Thus, there was a wide variation of repeated vegetative flushing with irregular inflorescence flushing among different branches of same trees resulting crazy trees.

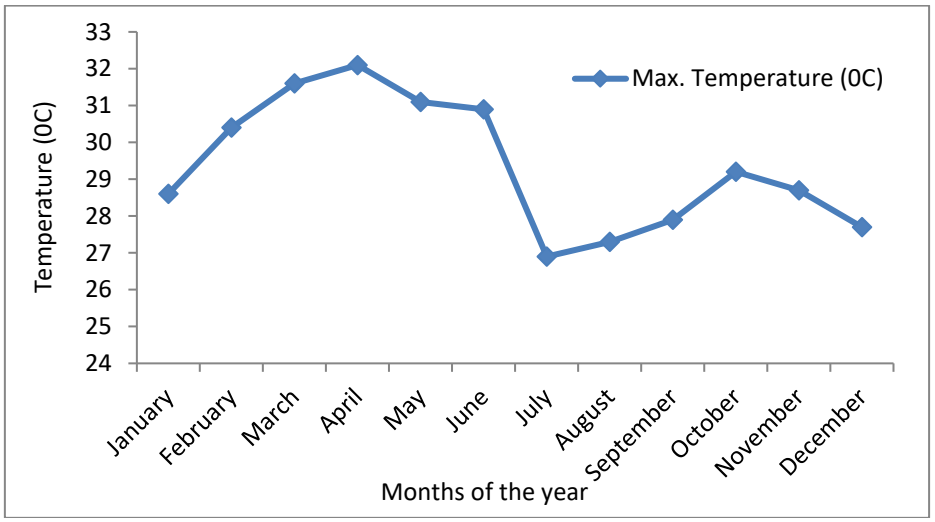

Figure 6. Monthly long term average maximum temperatures at Melkassa

Rainfall

High rainfall occurred at Melkassa from July, August and up to mid of September (Figure 7). Once mango harvesting was completed around June, all branches and shoots of most varieties produced vegetative flushes irregularly and the growth

periods of young flushes with deep brown color took short time, the leaves of young shoots with deep brown color turned in to yellow color leaves, and finally all leaves became deep green color went in to dormancy.

Although mango is considered to be drought tolerant, water deficits during the reproductive cycle can have severe effects on the retention and early growth of mango fruit (Schaffer *et al*., 2009). As mango trees produced inflorescence and flowering during December-February when there was no rain shower at Melkassa, the trees were supplemented with irrigation.

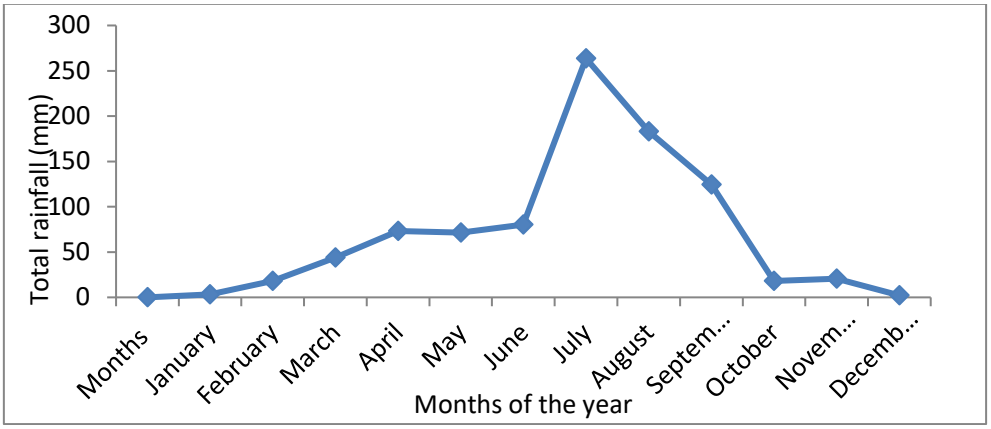

Figure 7. Monthly long term total rainfall at Melkassa

The vegetative flush growth of mango during the rainy season, goes with the cyclic root growth flush (Devenport, 2013). Sufficient application of irrigation water after the end of rainfall (around from mid of September) is essential as the trees are preparing for flowering.

Implications for agronomic managements

Each different growth phase has specific nutritional needs, so a key component of mango nutrition management is to match fertilizers application to demand. Other important considerations include pest and disease management, particularly with the postharvest flush. This flush builds the reserves for flowering so it is important not just to feed the flush, but also to protect it. Flushing post-harvest uses stored resources to develop. To allow trees to accumulate adequate reserves for flowering, it is important that stresses, which include poor nutrition and irrigation practices and pests and diseases, are reduced during the key growth events of flushing, flowering and fruit set and development.

Productivity of mangoes at particular place is a reflection of the clear growth events of the cycle, and appropriate management interventions and in some instances residual influence of previous management and environment factors. Not all growth events are desirable as unwanted shoot flushing events can cause

fruit drop, yield reduction or poor fruit quality and internal disorders (Schaffer *et al*., 2009).

Conclusion and Recommendation

This paper presented several hypothetical cyclic growth patterns of mango shoot development and flowering at Melkassa. Each growth pattern consists of a series of visible and invisible growth patterns that further research on flowering and crop yield could be better understood in the major production areas, climate regions and varieties.

The study found that mango inflorescence and flower flushing took place from November to February for all commercial varieties at Melkassa. Similarly, the average fruits set periods at Melkassa would take 7 to 8 months**.** The shoot flushing for all mango varieties took place from October to November. The current observations indicated that harvesting of all mango varieties at Melkassa concentrated from June to July. This result indicates that although there is longer period of mango harvesting in Ethiopia from different production areas, mango from Melkassa area is harvested during the last periods of mango harvesting season in Ethiopia.

Based on the current mango growth pattern, Melkassa area, the climate patterns are similar to sub-tropical areas, where the occurrence of minimum temperature is similar to slight winter of subtropical area; and the lowland areas of Ethiopia might represent the tropical mango production systems where the trees show different phenological growth patterns that require completely different management practice and this preliminary information deserves future research including key lowland areas. The time periods for critical growth (water and nutrients) for each mango variety and for each location should be further clearly identified so that optimum management practices are provided where and when necessary, expecting high yield and quality of fresh mango fruits. Rain stops in early September in the Central Rift Valley, Melkassa area while mango trees are preparing for shoot flush. This period might be one of the critical when fruit bearing branches are formed and getting strong shoot that bear good fruits. Once the majority of shoots were flushed in October and November, intern these shoots got matured and turned into dormancy; these shoots continued with inflorescence emergence and flowering in the following December. The key management, irrigation should start immediately after rain stops (mid of September), since this time period is the period of inflorescence and flower development, withholding irrigation during these critical time-periods drastically affect the fruits yield, quality, tree growth and economic life of the tree.

1. Detail phenological patterns of mango varieties, should be further studied with key varieties and at key lowland production areas, includes quantification of growths of all variables such as shoot length and diameter, leaf area, canopy volume and root growth; number of panicles per tree, number of flowers per panicle, initial fruit setting %, fruit retention %, fruit dropping %, preharvest fruit dropping %, harvesting date, and yield and yield efficiency per tree. Studies on the pomological characteristics of mango fruits: including physical fruit properties that are fruit weight, and edible to non- edible portions, and chemical fruit properties such as total soluble solids, total and reducing sugars, total acidity, fiber, tannins and vitamin C content needs further study. The reason for flower falls during flowering and fruits fall during fruits set should be find out before formulation of time period for optimum management practices that are will be required for mango orchard. Similarly, rates of fruits drops and development should be studied further.
2. Future studies on the cyclic growth patterns of mango should include variety, climate and environmental factors that induces each growth stage with the time period; and the proportion of stems that remain in rest and those that produce vegetative shoots as well as the proportion of reproductive shoots. It also includes reasons for 'on' year and 'off' year with how to minimize the alternate bearing throughout plantation life.
3. Since Melkassa area is high altitude area for mango (1550 m.a.s.ll), mango grows and best performs under lowland agro-ecologies, it is assumed that climate and altitude in each particular agro-ecology influences each phenological growth variables of mango, whereas variability among the mango varieties have its own phenological pattern. Thus, this study should be further continued by considering detail investigations on influences of environmental and weather parameters and physiological responses levels in the lowland areas before tangible conclusions are drawn. These further assists what and where to improve for high mango productivity and quality in the country in particular for those commercial mango varieties. For more phenological growth and development studies of matured mango fruits in Ethiopia, more attentions should be given to lowlands.
4. The growth and developmental phenology of mango tree should be further studied in relation to seasonal weather elements and dynamics of key mango diseases and insects in the area.
5. The growth and development of mango land races should be also further studied as these land races produce large supply of mango fruits to the nation; used for domestic fresh consumptions and used for industrial processing in the country.

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Evaluation of Carrot (Daucus Carota Subsp. Sativus) Varieties for Yield and Yield Related Traits Under Wondo Genet and Negelle Arsi Conditions

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Abstract

Carrot is the most important root crop produced worldwide. However, the production of carrot is affected by many factors like environmental conditions, season, and inherent genotype characters. In order to recommend a variety to a given locality for production, an adaptation test needs to be done with the prevailing environmental conditions. A field experiment was conducted to evaluate the performance of two carrot varieties (Haramaya-I and Nantes) for two years (2019 to 2020) at Wondo Genet and Negelle Arsi in Ethiopia. Randomized complete block design (RCBD) with four replications was used for the field experiment and different yield and yield related traits were evaluated. The results showed that, except marketable and total root yield, root core diameter, root length, root weight, and unmarketable root yield were significantly influenced by variety. The maximum root core diameter (2.86 cm), root length (12.83 cm), root weight (49.64 g), and unmarketable root yield (2.01t ha-1) were obtained from Haramaya-I variety. Location also exerted significant influence on root yield of the varieties. Regardless of the varieties used, at Negelle Arsi 66.98% increase in marketable yield and 65.37% increase in total yield were obtained over Wondo Genet. Though variation in years showed statistically similar marketable yield, the interaction of year with environment (location) affected root diameter, marketable, unmarketable yield, and total root yield of carrot. The higher root diameter (2.877 cm) was obtained at Wondo Genet in 2020; while the higher marketable (29 t ha-1) and total root yield (31.56 t ha-1) were obtained at Negelle Arsi in 2019. Nevertheless, further tests with a greater number of varieties have to be done by considering more parameters related to growers' preferences; so that conclusive and reliable recommendations could be made.

Keywords: Carrot, Environment, Interaction, Locations, Root yield, Varieties

Introduction

Carrot is globally well-known and its production and productivity have shown an increasing trend from time to time. Singh *et al*., (2012) and FAO (2013) respectively reported a carrot production of 24 and 37.2 million tons globally. Carrot worldwide acceptance might be due to its high vitamin A content, acceptable taste, ease of production at wider agro ecologies both under irrigation and rain fed and relatively long storage life at low temperature. Carrot is grown

for both diet and health benefits since the carrot storage root is a good source of carotenoids, vitamins, and dietary fiber and is also rich in minerals and antioxidants (Arscott *et al.*, 2010).

Carrot cultivars are classified according to shape and root length. It could be conical, spherical or cylindrical. According to Rosenfeld *et al*. (1998), carrot root shape is determined primarily by genotype but can also be influenced by climate conditions during root growth. Quality of carrots can be classified by external quality parameters such as root length, diameter, color and absence of defects, as well as internal quality parameters such as firmness, total soluble solid, and carotene content (Mazza, 1989; Rubatzky *et al*., 1999). Yield and quality characteristics of carrots benefit from cooler growing conditions (10 to 15°C). At temperatures above 25°C, the respiration rate of the plant increases, resulting in lower yields (Rubatzky *et al*., 1999). Carrot yields and root length were also influenced by the water content during the vegetative period (Henkel, 1970). Environmental factors influence growth, yield and quality of carrots in many different ways. Suojala (2000) reported that low precipitation at the end of the growing season may promote dying of the oldest leaves. Furthermore, low soil moisture will force the plants to invest in root extension growth rather than storage root development resulting in a reduction in root yield (Lada, and Stiles, 2004). The choice of genotypes for extensive ranges of environments on the basis of their mean yield, i.e., without considering the specific adaptation of each genotype in each environment, is a decision that facilitates the work of plant breeders. This is one reason why it can be difficult to select genotypes for regions that have different soil and climatic features (Cruz and Castoldi, 1991).

Although the exact time of introduction of carrots to Ethiopia is not known, the crop has been known since the early 1960s in the research system. Research on carrots in Ethiopia was started at Alemaya College of Agriculture (now Haramaya University) using imported seeds of eight varieties from Kenya in the early 1960s. Among the eight varieties tested, Nantes and Chantenay were identified as high yielders (Kidanemariam, 1969; Kifle-Iyesus, 1994). Carrot production has been expanding since then and the total production reached 223,762.04 quintals on 4,998 hectares of land (CSA, 2020/21). On the other hand, vitamin A deficiency is widespread in the country while the prevalence reached to 2 to 15-fold higher than the World Health Organization (WHO) cut-off point (0.5%) for public significance (Haile-Meskel, 2011).

After the introduction of those varieties to Ethiopia, carrot production has become a common practice and feed the local markets and also transported to national market, Addis Ababa from different corners of the country. Even though the crop is produced in large amount there is lack of improved varieties adapted to the areas under production. Though carrot is highly needed by the producers, there is a high

demand of seeds of improved varieties as the seeds of those commercial varieties are imported from abroad and sold at high price in the markets which the farmers can't afford. So far only one open pollinated carrot variety (Haramaya 1) has been released for production in the country by Haramaya University. It's high yielding, and the ability to produce seed in the cooler highland areas of the country makes it a better variety than the commercial ones. However, its production has been limited to certain areas of the country and has not been expanded elsewhere. Hence, the current study was initiated to conduct adaptation trial to evaluate and recommend a suitable variety (ies) for farmers around West Arsi Zone in Oromia and Sidama regions.

Materials and Methods

Description of experimental sites

The study was conducted during 2019 and 2020 cropping seasons at Wondo Genet Agricultural Research Center (WGARC) in Sidama region and Negelle Arsi in west Arsi zone of Oromia region under rain fed condition. WGARC is located at 07° 19.1' N and 38° 38' E at the elevation of 1780 m.a.s.l. The area receives a mean annual rainfall of 1128 mm with minimum and maximum temperature of 12.02 and 26.72°C respectively. Negelle Arsi is located at 7°05'N and 39°29'E at the elevation of 1895 m.a.s.l and receives a mean annual rainfall of 964 mm with minimum and maximum temperature of 12.94 and 27.34°c, respectively.

Treatments and experimental procedures

Haramaya-I carrot variety was evaluated with a commercial variety- Nantes as standard check. Seeds of Haramaya-I was obtained from Holeta Agricultural Research Center and that of the Nantes was purchased from the local market, which is of course originally introduced from abroad and become very popular in main carrot growing areas in Ethiopia.

The two carrot varieties: Haramaya I and Nantes as treatments were arranged in randomized complete block design (RCBD) with four replications. Seeds of the varieties were sown on seed bed having a size of 3 meter width and 4 meter length. During planting a 20 cm by 5 cm spacing was used between rows and plants respectively. To control the interference, a spacing of 1.5 m between blocks and 1m between plots were maintained. Plants in the middle rows per plot constituted the net plot which measured 1 m x 1m was used as the sampling unit. All appropriate agronomic practices such as weeding and hoeing were done uniformly on the experimental plots.

Data on root core diameter (cm), root length (cm), root weight (g), total root yield (t ha^{-1}), marketable root yield (t ha^{-1}) and unmarketable root yield (t ha^{-1}) were collected and analyzed using SAS computer software version 9.3. The Analysis

of variance (ANOVA) was done using SAS PROC GLM (2012) and comparison between treatment means was done using Least Significant Difference (LSD) test at $P< 0.05$.

Results and Discussion

The combined mean analysis showed that there were significant differences among the varieties of carrot for root core diameter, root length, root weight and unmarketable yield per hectare (Table 1). However, marketable root yield and total root yield per hectare were not significantly influenced by the varieties. The highest root core diameter, root length and root weight were obtained from Haramaya-I and the lowest was from Nantes variety. Similarly, high unmarketable root yield was obtained from Haramaya-I (Table 1). The difference occurred between the two varieties for different traits could be attributed to genotype difference though the yield was not statistically different. Absence of significant difference in marketable yield between the two varieties together with the lower unmarketable yield obtained from Nantes variety widens the possibility to use Nantes variety for the study area over Haramaya I.

Table 1. The overall mean performance of two carrot varieties tested during 2019 and 2020.

Tested Varieties	Root Core Diameter (cm)	Root Length (cm)	Root Weight (g)	Marketable Yield (t ha^{-1})	Unmarketable Yield (t ha^{-1})	Total Yield (t ha^{-1})
Haramaya-I	2.86[a]	12.83[a]	49.64[a]	19.02	2.01[a]	21.09
Nantes	2.14[b]	9.57[b]	35.28[b]	19.93	1.35[b]	21.29
$LSD_{0.05}$	0.26	1.46	7.62	ns	0.47	ns

Means followed by the same letter with in the same column are statistically non-significant at $P < 0.05$.

Locations also, affected yield parameters of carrot. Marketable, unmarketable and total root yield of carrot was influenced by the locations. The highest marketable root yield (23.11 t ha^{-1}), unmarketable root yield (2.013 t ha^{-1}) and total root yield (25.12 t ha^{-1}) were obtained at Negelle Arsi and the lowest from Wondo Genet (Table 2).

The overall locations mean performance of the two carrot varieties evaluated during 2019 and 2020 cropping seasons.

Locations	Root Core Diameter (cm)	Root Length (cm)	Root Weight (g)	Marketable Yield (t ha^{-1})	Un Marketable Yield (t ha^{-1})	Total Yield (t ha^{-1})
Wondo Genet	2.43	10.94	39.88	13.84^{b}	1.35^{b}	15.19^{b}
Negelle Arsi	2.57	11.46	44.74	23.11^{a}	2.01^{a}	25.12^{a}
$LSD_{0.05}$	ns	ns	Ns	4.48	0.47	4.03

Means followed by the same letter with in the same column are statistically non-significant at P < 0.05.

The result showed that environment can affect growth and yield of carrot. Suojala (2000) reported that low rainfall at the end of the growing season may promote dying of the leaves which decrease photosynthesis that can aggravate decrease in yield. Furthermore, unbalanced soil moisture will force the plants to invest in root extension growth rather than storage root development resulting in a reduction in root yield (Lada, and Stiles, 2004). Not only by the effect of environment and variety, carrot yield also affected by year of production. Environmental condition in the first year might be different from the second year as a result of climate fluctuation, which influences the results.

The interaction of year and location affected the performance of carrot during the experiment. The highest root core diameter was scored in 2020 at Wondo Genet and the lowest was also seen at Wondo Genet in 2019. This might be due to seasonal variations. The highest total root yield (31.56 ton ha^{-1}) was obtained from Negelle Arsi in 2019 and the lowest was obtained from Wondo Genet in 2019 (Table 3). The difference in yield variation might be due to the difference in production area which are different in agro-ecology since different agro-ecology has different microclimate.

Table 3. Mean performance of carrot as influenced by interaction effect of locations and testing years for its parameters.

Year	Locations	Root Core Diameter (cm)	Marketable Yield (t ha^{-1})	Total Root Yield (t ha^{-1})
2019	Wondo Genet	1.99^{b}	6.75^{c}	8.19^{c}
2019	Negelle Arsi	2.64^{a}	29.00^{a}	31.56^{a}
2020	Wondo Genet	2.88^{a}	20.93^{b}	22.18^{b}
2020	Negelle Arsi	2.49^{ab}	21.23^{b}	22.81^{b}
$LSD_{0.05}$		0.61	6.04	5.67
CV (%)		23.58	30.12	26.03

Means followed by the same letter with in the same column are statistically non-significant at P < 0.05.

As shown in Table (4), root core diameter, root length and unmarketable yield per hectare have been affected by varieties and locations (environment); but

marketable yield was not affected by the interactions of varieties and locations. The higher root core diameter (2.97 cm) was obtained from Haramaya-I and the lower root core diameter (1.89 cm) was recorded for Nantes at Wondo Genet. Different genotypes may respond differently in the same locations. Similarly, root length and root core diameter have been affected by environment and variety. But unmarketable root yield responded differently other than the two parameters. The higher unmarketable root yield (2.58 t ha^{-1}) was recorded for Haramaya-I at Negelle Arsi, while the lower (1.26 t ha^{-1}) was at Wondo Genet for Nantes. The interaction occurs due to different responses of genotypes to environmental changes (Ramalho *et al*., 1993).

Table 4. Mean performance of carrot as influenced by interaction effect of varieties and locations for selected parameters.

Varieties	Locations	Root Core Diameter (cm)	Root length (cm)	Marketable yield (t ha^{-1})	Unmarketable Yield (t ha^{-1})
Haramaya-I	Wondo Genet	2.97a	13.57a	18.96	1.43b
Haramaya-I	Negelle Arsi	2.74ab	12.08^{ab}	20.56	2.58a
Nantes	Wondo Genet	1.89c	8.31c	18.55	1.26b
Nantes	Negelle Arsi	2.38bc	10.83b	20.34	1.44b
$LSD_{0.05}$		0.53	2.01	ns	0.70
CV (%)		20.79	17.47	30.11	40.88

Means followed by the same letter with in the same column are statistically non-significant at P < 0.05

Conclusion and Recommendation

Evaluation of carrot varieties was conducted at Wondo Genet Agricultural Research Center - on station and at Negelle Arsi- farmers' training center (FTC) for two years (2019 and 2020). The results of the study showed that different growth and yield components of the two carrot varieties responded differently at the two testing sites although the overall mean root yield performance of the two varieties were not statistically different. Individual factors and their interactions affected the growth, yield and yield components of carrot. When we compare the two varieties (Nantes and Haramaya-I) there was no significant difference in yield potential among them; but variation was observed when interacted with the production season (year) and the locations (environment). The maximum root yield (31.56 t ha^{-1}) was obtained in 2019 at Negelle Arsi environmental condition. In conclusion from the results obtained, Negelle Arsi location was found to be better for production of carrot than Wondo Genet though variation was detected between the two testing seasons. This indicates that the performance of carrot production is influenced by different environmental factors, production seasons and inherent character of the genotype. So, this and other factors should be considered in carrot production system.

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Morphological variability revealed genetic diversity in Shallot (Allium cepa var. aggregatum) segregating populations

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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 (DZARC). 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 genoytypes 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, repectively. 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 doweny mildew severity. It had also high inter-cluster distances with other clusters. The principal componenet analysis identified seven components, five of which contributed to 83.1% of the variation. Generally, the eight genotyes with better yield were recommended for further variety trials under different environments while maintaining the other genotypes as a source of variation for future breeding activities.

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

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 262 thousand tons of onion and shallot on 28.2 thousand hectares of land (CSA 2018).

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. 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 varietities, 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 in 2019 and 2020 rainy season. The DZARC is located 47 km southeast of Addis Ababa at 080 44'N latitude and 380 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 DZSHT005-02/90) 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 per plant was a mean of flower stalks 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.

The study was undertaken at Debre Zeit Agricultural Research Center, Ethiopia. It comprised of 60 genotypes which were generated through natural open-pollinating accessions collected from different parts of Ethiopia. Seeds of the segregating genotypes were collected from their parents and were selected for uniformity in size, shape and color of bulbs and leaves for three consecutive seasons and maintained through vegetative propagation. Twenty uniform bulbs of each genotype were planted on a ridge comprising two rows. The experiment was laid-out using an augmented design in three blocks. Huruta, Minjar and DZSHT-005-02/90 were planted as controls (check varieties) and replicated in each block. All agronomic practices were undertaken as recommended by Getachew *et. al.* (2008). Data on yield per plant, weight and height of bulbs, number of bulb splits were recorded from five randomly selected plants. Bolting percentage, and number of flower stalks per plant were measured as the proportion of bolted plants with respect to the total number of plants and number of stalks which developed flower umbels per plant respectively. Downy mildew severity was recorded on plot bases and recorded as 1 to 5 scale.

Analysis of variance was undertaken using the control genotypes (varieties) and the variance was used to separate means of the test and control genotypes. Cluster analysis was done using the unweighted pair-group method with arithmetic

average (UPGMA) (Fielding, 2007) using Minitab (Minitab® 19.2020) and R statistical software (R Core Team, 2020). The 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, Score and Loading plots and bi-plot were generated using the same software.

Results and Discussion

Mean preformace 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 classfied tham 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 verenalization at 8 or 12^{o}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 photosynthete partitioning to flower stalks than to bulbs (Wallace *et. al,* 1993).

Table 1. Bulb and bolting characterstics of sixty shallot genotypes generated from open pollinated accssions along with three checks

Genotype Code	Genotype	Bulb yield/ plant(g)	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(g)	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-	94.73bc	54.1	65.2	4.58	55.39d-j	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-	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	37.49g-n	0.95bc	2.38	44	DZSHT-OP-001-3-	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	53.63e-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-	57.02c-i	39.43	70.5	4.38	0.76pq	1.03bc	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

Genotype Code	Genotype	Bulb yield/ plant(g)	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(g)	Bulb diameter (mm)	Bulb height (mm)	No. bulb splits	Bolting (%)	No. flower stalks/ plant	Downy Mildew (1-5 scale)
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-	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-	41.33ghi	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-	39.83	55.8	3.65	47.59e-	2.48abc	2.88									

Cluster analysis

Cluster analysis of the genotypes based on the seven variables grouped the genotypes into seven clusters. Simiarity 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 *el. al.*(2019) also reported that Indonesian shallot genotypes were divided into three major groups and differences within a group demonstrated the existance 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 doweny 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-ecologiacl 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 differerntiate 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 hetrosis. 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. Fitrana 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 (D2) 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

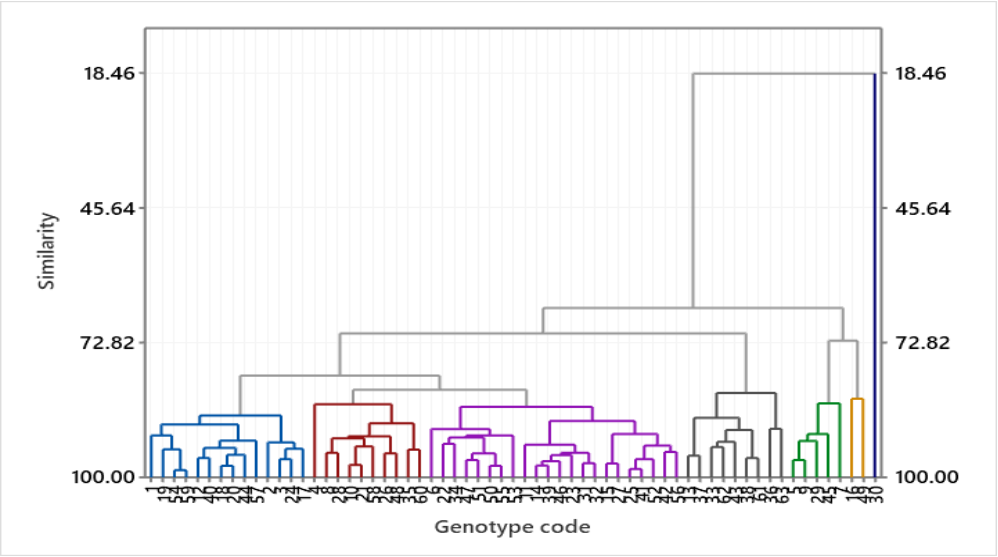

Figure 1. Dendrogram showing hierarchical clustering patterns of sixty three shallot genotypes for seven traits

Principal Componenet 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 stakes/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 diamter. On the other hand, percent bolting, number of flowerstalks/plant and downy mildew severity were unrelated to yield and yield componenets. 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.

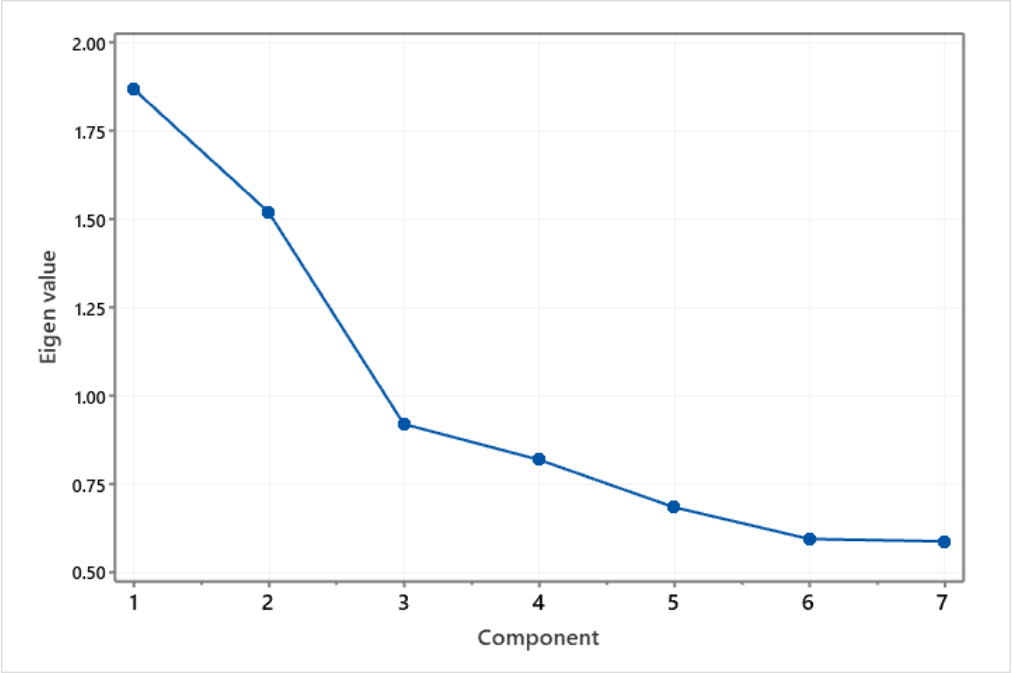

Figure 2. Scree plot of the seven variables

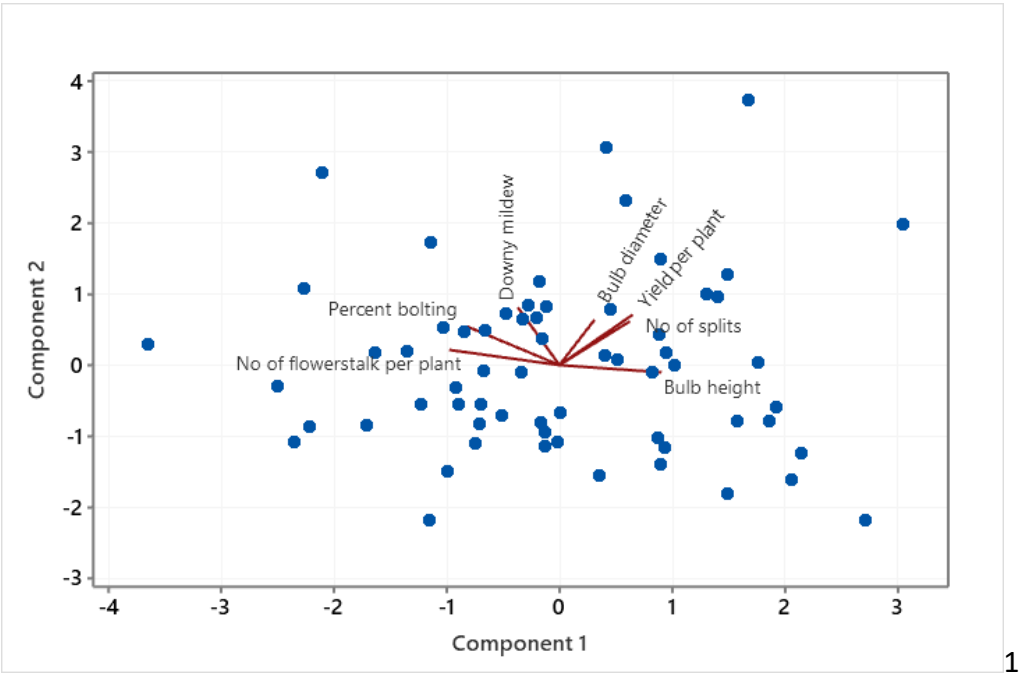

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Figure 3. Bi-plot of principal componenents 1 and 2

Conclusion 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 genoytypes 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 seven morphological traits. The principal componenet 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.

Acknowledgements

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Evaluation of Tomato (Solanum Lycopersicum L.) Varieties Under Different Salt Stress Levels

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Abstract

Tomato is a crop of immense economic importance worldwide and salinity is one of the major abiotic factors limiting its production and productivity in Ethiopia. The study was conducted to assess growth, physiological activities and yield responses of two tomato varieties to six different salinity levels. The study was carried out in a greenhouse at Teppi Agricultural Research Center in 2018/19. Each treatment combination (variety and salinity level) was replicated three times and arranged in Randomized Complete Block Design in factorial arrangement. Most traits measured on tomato plants were significantly affected by salinity levels (P<0.0001). The highest shoot fresh weight (163.13 g/plant), shoot dry matter (32.8 g/plant) and leaf area (26.93 cm2) were recorded for the control treatment. The highest root fresh weight (12.27 g/plant), root dry weight (5.53 g/plant) and fruit yield (22.71 ton/ha) were recorded at 1dSm-1 for variety Melka Shola; while the lowest shoot fresh weight (79.9 g/plant), shoot dry matter (22.67g/plant), leaf area (17.63 cm2), root fresh weight (6.12g/plant), root dry weight (3.8g/plant) and fruit yield (16.73 ton/ha) were recorded at 5 dSm-1 for variety ARP tomato-d2. The highest and the lowest values of photosynthetic rate (0.82 µmolCo2m-2s-1 and 0.47 µmolCo2m-2s-1 respectively) were obtained from the control treatment and the highest salinity level for variety Melka Shola; whereas, corresponding values of (0.84µmolCo2m-2s-1 and 0.56 µmolCo2m-2s-1 were recorded for variety ARP tomato-d2. Results of laboratory analysis showed that, sodium and Na/K significantly increased with increased salinity level. However, potassium, sulfur and phosphorus showed significant decrease with increasing salinity level. Melka Shola was found to be more salt tolerant as compared to ARP tomato-d2. Since the present experiment was conducted for one season and under controlled condition, it deserves further evaluation and verification under field condition in salt affected areas and the effect of salinity on tomato quality also deserves further investigation.

Keywords: Irrigation water salinity, Photosynthetic rate, Tomato yield.

Introduction

Tomato (*Solanum lycopersicum* L.) belongs to the *Solanaceae* family. It is a crop of immense economic importance worldwide (Ashraf, 2004). Global production of tomato was estimated over 164 million metric tons from 4.73 million ha of land (FAO, 2014). The current tomato production in Ethiopia is estimated to 41,948.27 tons from 6,433.73 hectare of land with average productivity of 6.52ton/ha (CSA,

2021). Its consumption has been linked to reduced risks of cancer especially prostate cancer and reduced occurrence of cardiovascular diseases (EL-Gaied *et al*.,2013;), because it is rich in high amounts of antioxidants (Sacco *et al*., 2013). Tomato has high nutritional value and it is the second most important vegetable crop next to potato (Liza *et al*., 2013).

Salinity has been a major issue in the past many years in the whole world since it is one of the consequences of climate change with the rise of the ocean's level. When there is not enough precipitation, the water rich in salts rises from the groundwater by capillarity, favoring the accumulation of salts in the upper layer of the soil, where they continually accumulate in the absence of precipitation. These natural events cause what is referred to as primary salinization, which is different from secondary salinization, determined, instead, by human intervention (Guo *et al*., 2019). Due to its deleterious effects on crop growth and yield, salinity stress should have given particular attention (Machado and Serralheiro, 2017). Soil salinization could occur due to inappropriate irrigation methods, in areas with high rates of evapotranspiration, irrigation with saline water and inappropriate drainage conditions (Rozema and Flowers, 2008).

Salt stress have three effects on plants. First, they play a role in water uptake due to the osmotic effect. Salinity stress (soluble salts) lower the osmotic potential. This causes difficulty in water uptake by roots. In addition to osmotic effect, salinity stress could also result in toxic effect especially NaCl, due to the competition of Na^+ with other cations such as Ca^+ (Bytr *et al*., 2018). High uptake of Na and Cl ions also result in nutrient imbalance in plants (Evelin *et al*., 2009). Consequently, it affects plant growth and yield.

The reduced lumen size of xylem vessels of the plants conductive tissues is among the effects of salinity on plants at the morphological level (Guerriero *et al*., 2017). Salt stress have an impact on lipids that constitute the cell membrane and can therefore compromise its composition and stability (Daliakopoulos *et al*., 2016). One of the responses of plants at the onset of salt stress is the production of antioxidant molecules, as well as enzymes scavenging reactive oxygen species (ROS) (Berni *et al*., 2009). The chemical structure of antioxidants allows hydrogen atom transfer mechanism to occur via pure H transfer (Di Muo *et al*., 2013).

Some plant species can be specifically adapted to grow on soils with high salinity conditions (Furtado *et al*., 2019). They develop tolerance mechanisms by producing antioxidants and osmo-protectants to bring about tolerance against oxidative stress and osmotic stress, respectively (Garrido *et al*., 2014). It has been suggested that more research is needed to identify the variety which will perform better at germination stage and give higher yield under high soil salinity condition

(Daliakopoulos *et al*., 2016). Thus, a study was conducted to evaluate released tomato varieties under different salinity levels to determine the effect of different salinity levels of irrigation water on growth and yield of released tomato varieties and identify potential sources of salt tolerance for future breeding activities.

Materials and Methods

Descriptions of the Study Areas

The experiment was implemented at Teppi Agricultural Research Center during 2018/2019 main cropping season in the greenhouse. Teppi is located in South Western part of Ethiopia in SNNP Regional State at an elevation of 1200 m.a.s.l and it is situated at 7°10'54.5" N Latitude and 35°25'04.3"E Longitude. The average maximum and minimum monthly temperatures in the greenhouse were 22.5 and 28.6°C, whereas the maximum and minimum relative humidity was 41 and 72.3% respectively, for the experiment season.

Treatments (Tomato varieties and salt levels)

For the greenhouse experiment, two best varieties (ARP tomato-d2 and Melka Shola) were used. The experiment consisted of a total number of twelve treatment combinations (six salt levels (tap water as control (0.15 dSm^{-1}) and 1, 2, 3, 4 and 5 dSm^{-1} salt levels) and two varieties (ARP tomato d-2 and Melka Shola).

Experimental design and management

The experiment was laid out in a Randomized Complete Block Design (RCBD) in factorial arrangement with three replications. Ten pots were used per plot and arranged by keeping 30 cm and 1m spacing between plants and between rows, respectively. The size of each pot was 30 cm in diameter and 35 cm in height. Seeds of both varieties were sown on seedling trays and watered using non-saline water for 30 days. Growth media was prepared from forest soil and sand in 3:1 ratio, respectively, filled in pots one month prior to transplanting and arranged in the greenhouse. Soil samples were taken from the prepared media. Then, saturated soil paste (soil samples saturated with distilled water) was prepared, the soil water was then extracted and EC and pH of the extract were measured using conductivity meter and pH meter, respectively, before application of the treatments.

After 30 days, seedlings were transplanted to the pots and irrigated uniformly for ten days with non-saline water. Saline solutions were prepared in separate containers to get the desired electrical conductivity and the containers were labeled according to the treatment solution (control, 1,2,3,4 and 5 dSm^{-1}). Each container was filled with tap water and the treatment solutions were prepared by adding 0.64, 1.28, 1.92, 2.56 and 3.2 grams of NaCl salt per a liter of water for 1, 2, 3, 4 and 5 dSm^{-1} respectively. Then, application of saline water treatments

started after the seedlings were watered with non-saline water for ten days according to the water requirement of the crop and 16% leaching requirement was applied.

Plant tissue analysis was done at Horticoop Ethiopia (Horticulture) PLC Soil and Plant Analysis Laboratory at Debre Zeit after harvesting the crop. The concentration of nutrients (Calcium, Potassium, Sodium, Magnesium, Phosphorus, Sulfur and Na+ /K^+ ratio in the tomato plant tissue) was analyzed after harvest. 1N hydrochloric acid (diluted 83.3 ml concentrated HCl to 1L deionized H_2O) and 6N hydrochloric acid (diluted 50 ml concentrated HCl to 100 ml deionized H_2O) were used as reagents. The following procedures were followed for ashing of plant tissue to determine the concentration of Na, K, Mg, Ca, P and S in the plant tissue and overall processes.

A plant tissue sample of 1.25 g was weighed in to "high form" porcelain crucible. Sample was placed in to furnace and the temperature was increased gradually until it reached 540^{o}C where samples were ashed for six hours. Samples were then wetted with small amount of deionized water, then 5-10ml of 6N HCL and brought to near dryness on hot plate. Ash was dissolved by adding 10 ml 1N HCl to crucible. Dissolved ash was transferred quantitatively in to 100 ml volumetric flasks. Samples were washed down and diluted with deionized water and shake. Finally, aliquot was collected into ICP test tube and the concentration of each nutrient were measured using Mehlich III method (Mehlich, 1984).

Data collection and analysis

Growth parameters

Number of leaves/plants: Five sample plants were selected per each plot at 36 days after the commencement of treatment application and number of leaves on each plant was counted and the average value was used for analysis.

Leaf Area: Leaf area was measured using a Photoelectric Leaf Area Measure GDX-500. Nine leaves per plant were taken from different positions on the plant and the area of each leaf was measured at 36 and 65 days after the commencement of treatment application and the average value was used for analysis.

Plant Height: Five plants were randomly selected from each plot at flowering stage and plant height was measured from the base to the tip of the stem by using pocket meter.

Shoot fresh and dry weight per plant: After harvesting, all the shoots of five randomly selected plants were collected and fresh weight was recorded immediately. Then after, shoots were chopped into very thin pieces and were dried in an oven at 75 °C until a constant weight was obtained and dry mass was

measured in gram by using digital balance and finally the average values were used for analysis.

Root fresh and dry weight per plant: After harvesting, all the roots of five randomly selected plants were collected and fresh weight was recorded immediately. Then, roots were chopped into very thin pieces and were dried in an oven at 75 °C until a constant weight was obtained. Root dry mass was measured in gram by using digital balance and finally the average values were used for analysis. Root to shoot ratio was calculated from the dry matter yield of shoots and roots.

Physiological data

Photosynthetic rate was measured using Chlorophyll Fluorometer at flowering stage. Five green and fully expanded leaves were selected per plot and photosynthetic rate was measured during 10 AM to 5 PM time of the day.

Tomato fruit yield

Fruit yield (ton/ha) was recorded on plant basis and then converted in to ha. Data was subjected to Analysis of variance (ANOVA) using SAS PROC CORR (SAS Institute, 2008) version 9.0.

Treatment means were separated by using Duncan's Multiple Range Test at 5% probability level for all the parameters recorded in both laboratory and green house experiments.

Results

Leaf number

No significant difference was obtained between salinity levels nor between varieties and their interaction ($P>0.05$) for leaf number per plant.

Leaf Area

Both salinity level and variety and their interaction significantly ($p<0.0001$) affected leaf area of tomato plants. The highest leaf area (26.93 cm^2), was recorded for the control treatment with variety Melka Shola, whereas the lowest value (17.63 cm^2) was recorded at $5dSm^{-1}$for the variety ARP tomato d-2. Melka Shola showed higher leaf area values as compared to ARP for all the salinity treatments (Figure 1).

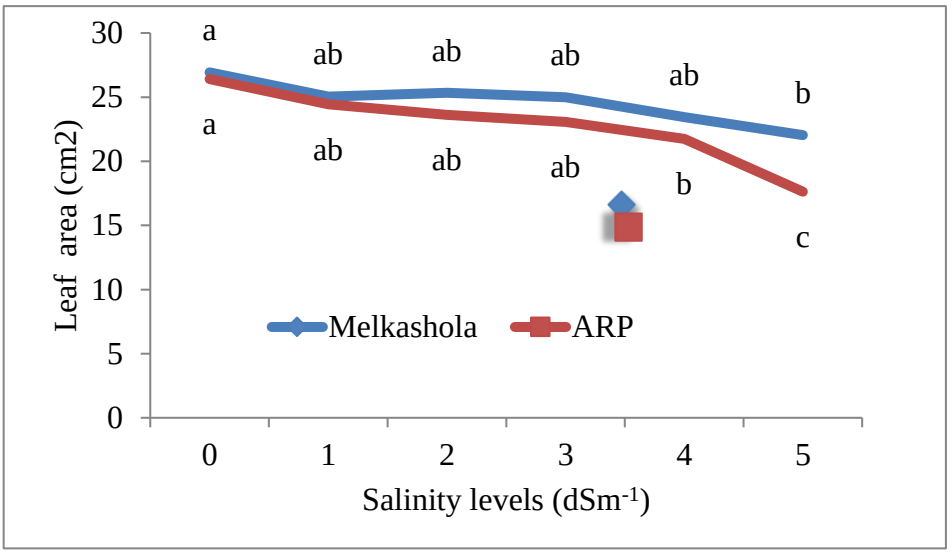

Figure 14. Leaf area of tomato as affected by salinity level and variety

Plant height

Plant height was significantly affected by the main factors (salinity level and variety) and their interaction (P<0.0001). The tallest (127 cm) and the shortest (93.33 cm) tomato plants were obtained under the control treatment and at highest salinity level respectively for variety Melka Shola, whereas, 151.11cm and 98.89 cm plant heights were recorded for variety ARP tomato d-2 under the corresponding salinity levels (Figure 2).

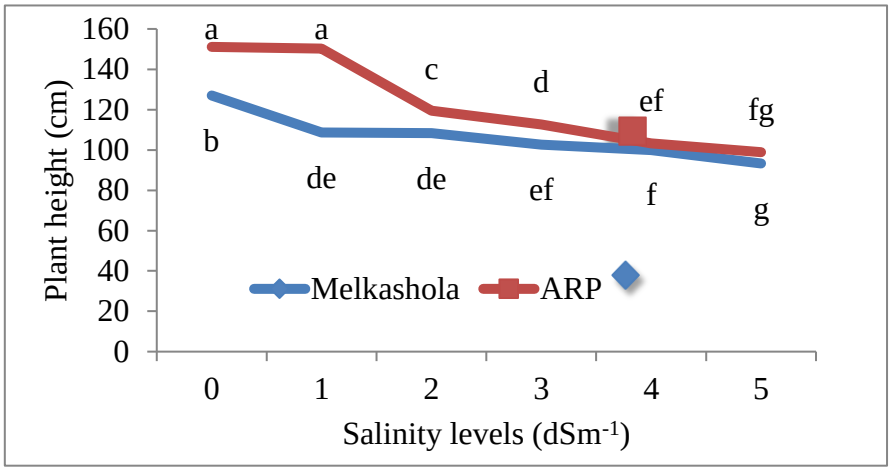

Figure 2. Plant height of tomato as affected by salinity and variety

Shoot fresh weight

Shoot fresh weight/ plant was significantly affected by salinity levels, varieties and their interactions ($P < 0.0001$) for shoot fresh weight/plant. The highest shoot fresh weight was recorded for the control treatment (163.13 g/plant) and 1 dSm^{-1} (162.33g/plant) respectively for variety Melka Shola. Whereas shoot fresh weight of 153.07 g/plant and 159.67g/plant were recorded under 1 dSm^{-1} and 2 dSm^{-1} salt levels for variety ARP tomato d-2 respectively (Figure 3). The highest salinity concentration of 5 dSm^{-1}NaCl resulted in the lowest average shoot fresh weight (79.9g/plant) in variety ARP tomato d-2.

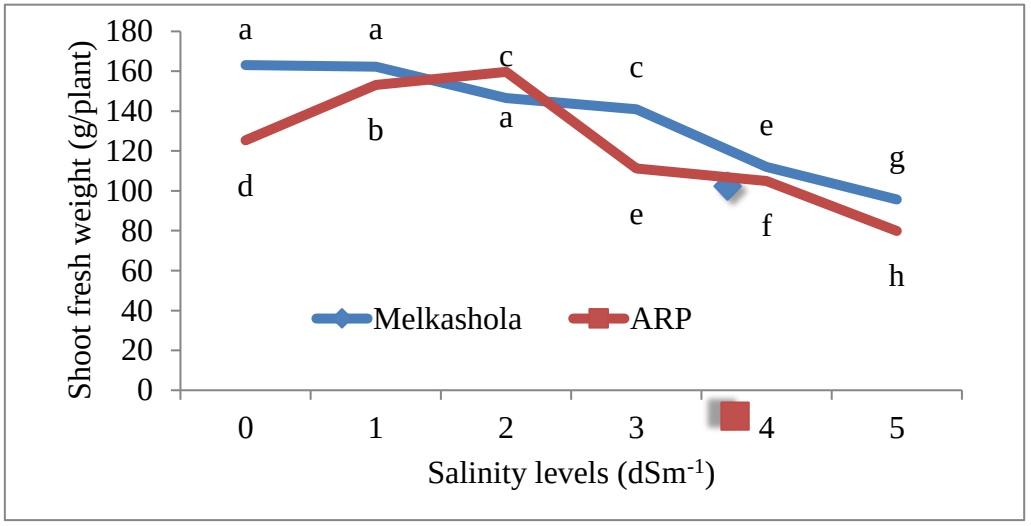

Figure 3. Shoot fresh weight of tomato as affected by the interaction of salinity level and variety

Shoot dry weight

Similar to shoot fresh weight, shoot dry weight was significantly influenced by the main factors (salinity level and variety) and their interaction ($p<0.0001$). The highest average shoot dry weight (32.8 g/plant) was recorded for the control treatment with variety Melka Shola, whereas the lowest value (22.67 g/plant) was recorded from the highest salt level (5 dSm^{-1}) with variety ARP tomato d-2 (Figure 4).

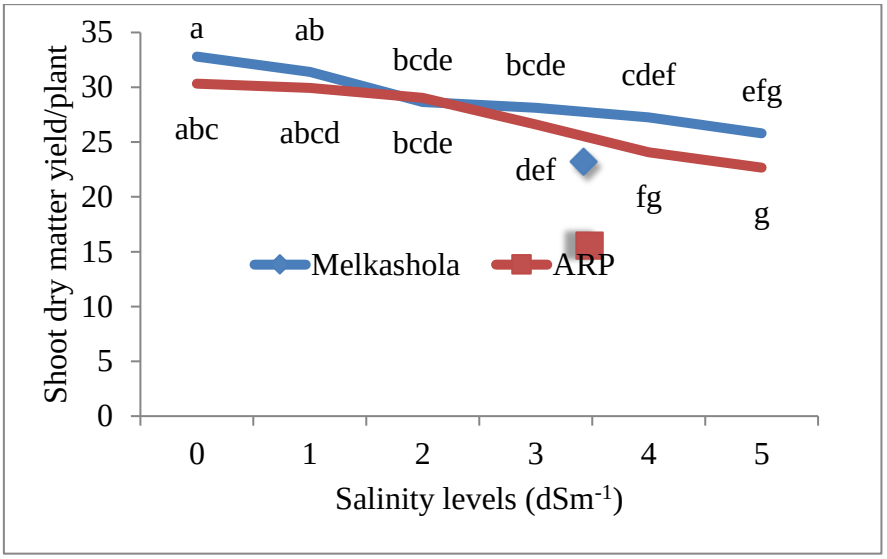

Figure 4. Shoot dry matter of tomato as affected by the interaction of salinity level and variety

Root fresh weight

Significant difference was obtained in root fresh weight due to the main factors (salinity level and variety) and their interaction ($p<0.0001$). The highest average root fresh weight (12.27g/plant), was recorded at 1dSm^{-1} with variety Melka Shola, whereas the lowest value (6.12g/plant) was recorded at 5dSm^{-1}for variety ARP tomato d-2 (Figure 5).

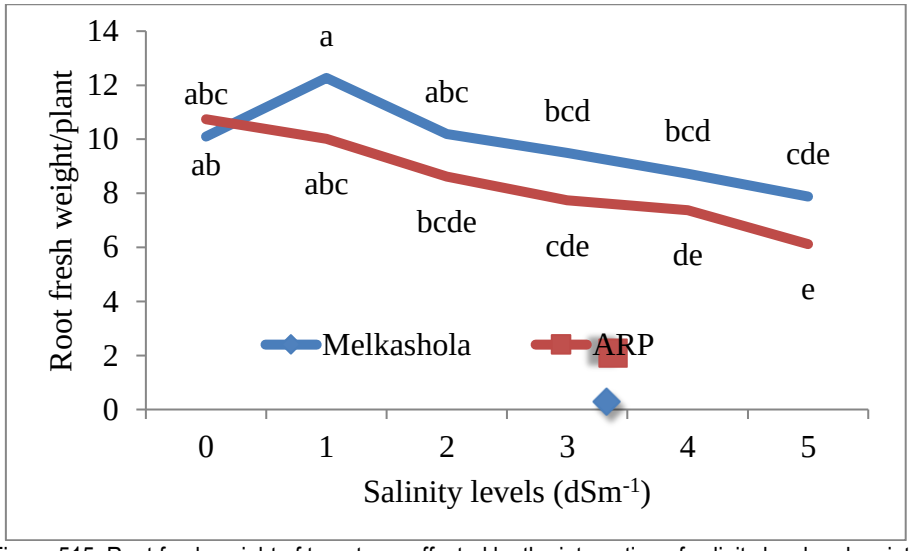

Figure 515. Root fresh weight of tomato as affected by the interaction of salinity level and variety

Root dry weight

Similarly root dry weight was also affected by salinity levels, varieties and their interaction ($P<0.0001$). The highest average root dry weight (5.53 g/plant), was

recorded at 1dSm^{-1} from for variety Melka Shola, whereas the lowest (3.8 g/plant) was recorded at 5dSm^{-1} from variety ARP tomato d-2 (Figure 6). Both varieties showed decreasing root dry matter along with increasing salinity concentrations. However, variety Melka Shola had better dry matter accumulation under higher salinity stress as compared to ARP tomato d-2.

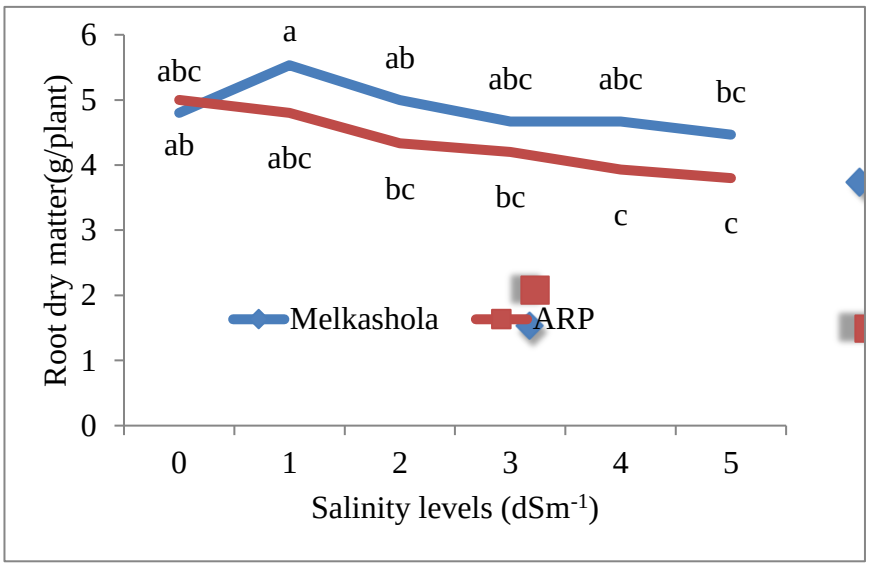

Figure 6. Root dry weight of tomato as affected by the interaction of salinity level and variety

Root to shoot ratio

Root to shoot ratio was not affected by salinity, variety, and their interaction ($P>0.05$). However, lower root to shoot ratio was recorded for the lowest salt concentration. It was observed that, root to shoot ratio increased with increasing salt concentrations, indicating that, tomato root was less affected by the salinity stress than did the shoot part, although there was no significant difference between the treatments (Table 1).

Photosynthetic rate

Salinity levels, varieties and their interaction were significant ($P<0.0001$) on the rate of photosynthesis. The highest and the lowest photosynthetic rates (0.82 µmolm^{-2}s^{-1} and 0.47 µmolm^{-2}s^{-1}) of tomato leaves were recorded for the control treatment and highest salinity level respectively for variety Melka Shola, whereas the respective values of 0.84 µmolm^{-2}s^{-1} and 0.56 µmolm^{-2}s^{-1} were for variety ARP tomato d-2 (Figure 7).

It was observed that increasing salinity level from 1 to 5dSm^{-1}NaCl significantly reduced photosynthetic rate of tomato compared with the control treatment for both varieties. Unlike for the other parameters, variety ARP exhibited higher photosynthetic rate as compared to Melka Shola.

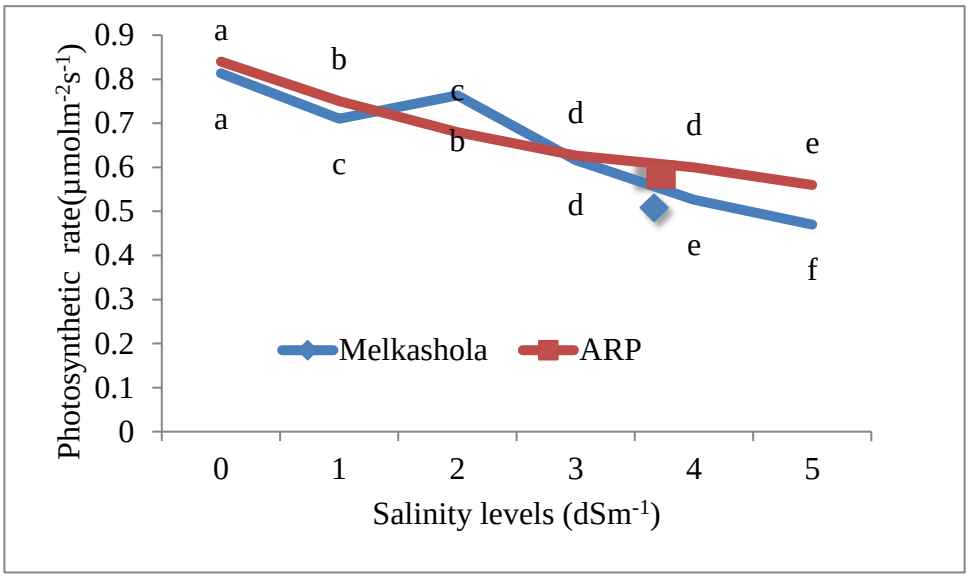

Figure 7. Photosynthetic rate of tomato as affected by the interaction of salinity level and variety

Fruit yield

Fruit yield of tomato was significantly affected by salinity level, variety and their interaction ($P<0.0001$). The highest fruit yields of 214.8, 227.1 and 215.9 q/ha were recorded from the control, 1 and 2 dSm^{-1} salt levels for variety Melka Shola respectively. At the same salt levels 213.4, 217.8 and 196.5 q/ha fruit yields were obtained from variety ARP tomato d-2 respectively. The minimum yield (167.3 q/ha) was recorded at the highest salt concentration ($5dSm^{-1}$) from variety ARP tomato d-2 (Figure 8). In general, it was observed that increased concentrations of NaCl significantly reduced tomato yield. The result indicated that the highest salinity concentration of NaCl highly affected tomato yield of both varieties. However, variety Melka Shola showed better relative tolerance as compared to ARP tomato d-2.

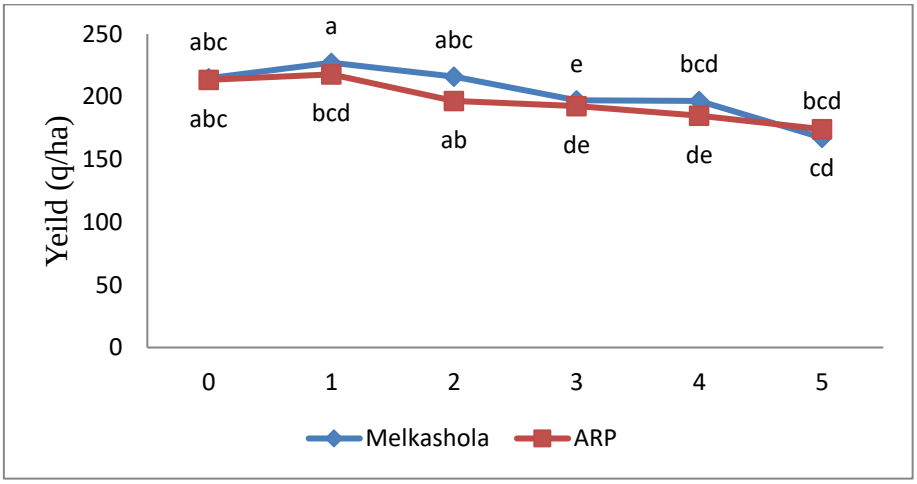

Figure 8. Yield of tomato as affected by the interaction of salinity level and variety

Plant tissue nutrients

Concentration of plant tissue nutrients in tomato plants was significantly influenced by the interaction effect of salinity and variety ($P<0.0001$). Na^+/K^+ ratio, potassium, sodium and sulfur concentrations in tomato plant tissue were affected. However, no significant effect was obtained on Ca, Mg, and P concentrations ($P>0.05$). This indicates that Ca, Mg and P were not affected by NaCl concentrations in tomato tissues. This could be probably due to the reason that these nutrients were sufficiently up taken by the varieties without being replaced by Na^+. Though there was no significant difference for these nutrients, they showed a decreasing trend as salinity level increased.

Table 1. The main effects of salinity and variety on plant tissue concentration of Calcium, Magnesium and Phosphorus on leaf number and root to shoot ratio in tomato

Salt level (dSm^{-1})	Leaf number per plant	Root to shoot ratio	Calcium	Magnesium	Phosphorus
Control	10.17	0.16	3.30	0.77	0.20
1	11.23	0.17	3.43	0.79	0.17
2	10.34	0.16	3.36	0.83	0.17
3	9.87	0.16	3.43	0.77	0.20
4	9.57	0.17	3.48	0.75	0.17
5	9.47	0.17	3.69	0.81	0.18
Mean	10.10	0.16	3.44	0.78	0.18
CV	12.76	11.22	11.20	10.29	19.80
CR	NS	NS	NS	NS	NS
Variety					
Melka Shola	10.13	0.17	3.58[a]	0.79	0.19
ARP tomato	10.08	0.16	3.31[b]	0.78	0.17
Mean	10.10	0.16	3.44	0.78	0.18
CV	12.65	10.80	10.87	9.95	18.80
CR	NS	NS	0.25	NS	NS

CV= Co efficient of variation, CR =Critical range, NS =Non-significant

The concentration of K^+ in tomato plant tissue showed significant decrease at 5 dSm^{-1} salinity level for variety ARP. In contrast, K^+ concentration was not significantly affected by increasing salt level for variety Melka Shola (Figure 9). However, the decreasing trend in concentration of potassium (K^+) at higher salinity level was observed for both varieties.

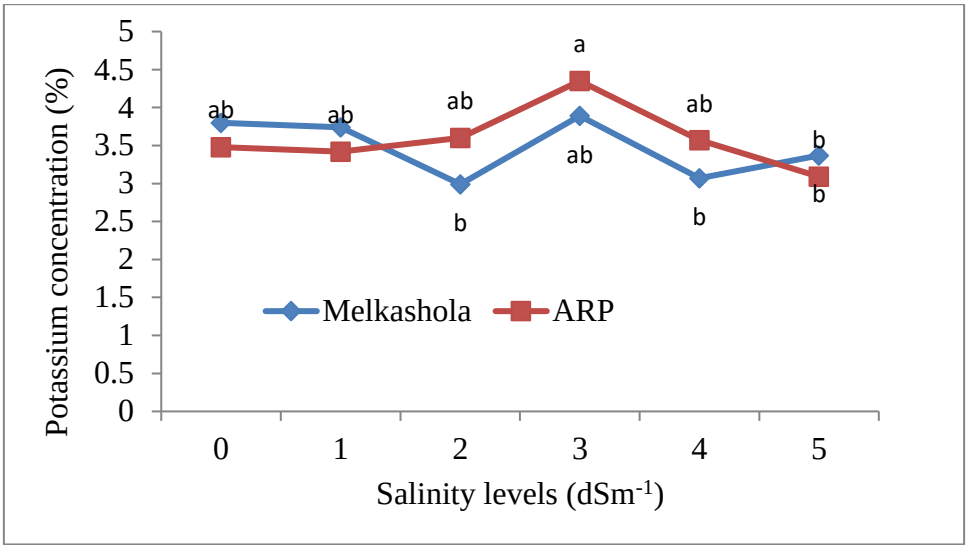

Figure 9. Potassium concentration as affected by the interaction of salinity level and variety

Increasing irrigation water salinity level resulted in a significant increase of Na^+ concentration of tomato plant tissue and the increase reached the highest (0.56%) value at 5 dSm^{-1} compared with the control (0.16%) specifically for variety ARP (Figure 10). In the present study, both tomato varieties showed an increase in Na^+ while decreased tissue K^+ contents. However, variety Melka Shola exhibited the minimum concentration of Na^+. On the other hand, ARP tomato-2 showed elevated Na^+ contents as compared to Melka Shola.

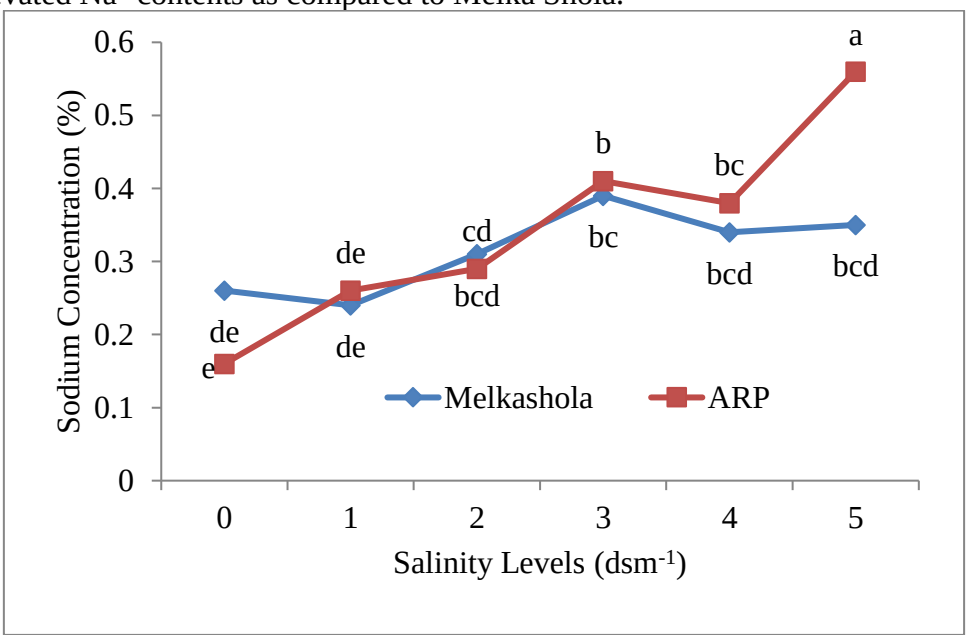

Figure 10. Sodium concentrations as affected by the interaction of salinity level and variety

Maximum reduction of sulfur content in tomato plant tissue was noted at 5 dSm^{-1} salinity level. On the other hand, maximum values were recorded for the lower salinity level as shown in Figure 11. The results showed that salinity had significant effect on concentration of sulfur in the tomato plant tissue. Increased salinity concentrations significantly affected the uptake of K, S and Na/K ratio.

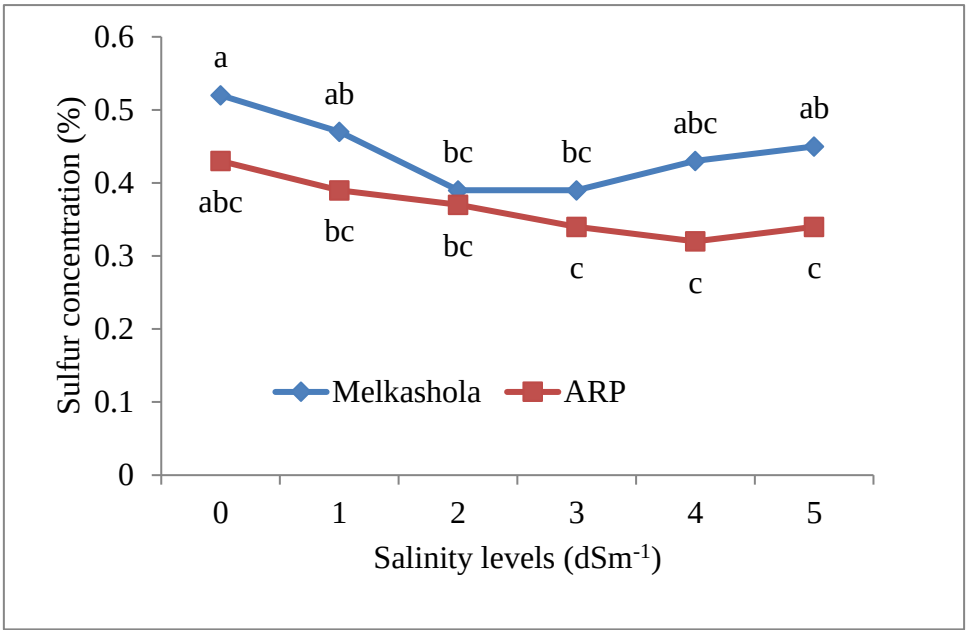

Figure 11. Sulfur concentrations as affected by the interaction of salinity level and variety

The highest average Na^+/K^+ ratio in tomato plant tissue was recorded for the highest salt concentration of variety ARP tomato d-2. The control treatment exhibited the lowest average Na^+/K^+ ratio in tomato plant tissue. It was observed that increasing salinity level significantly increased Na^+/K^+ ratio in the plant tissue as compared with the control treatment (Figure 12). Hence, the highest Na^+/K^+ ratio (0.184) was recorded for 5dSm^{-1} while the lowest value (0.047) was for the control treatment.

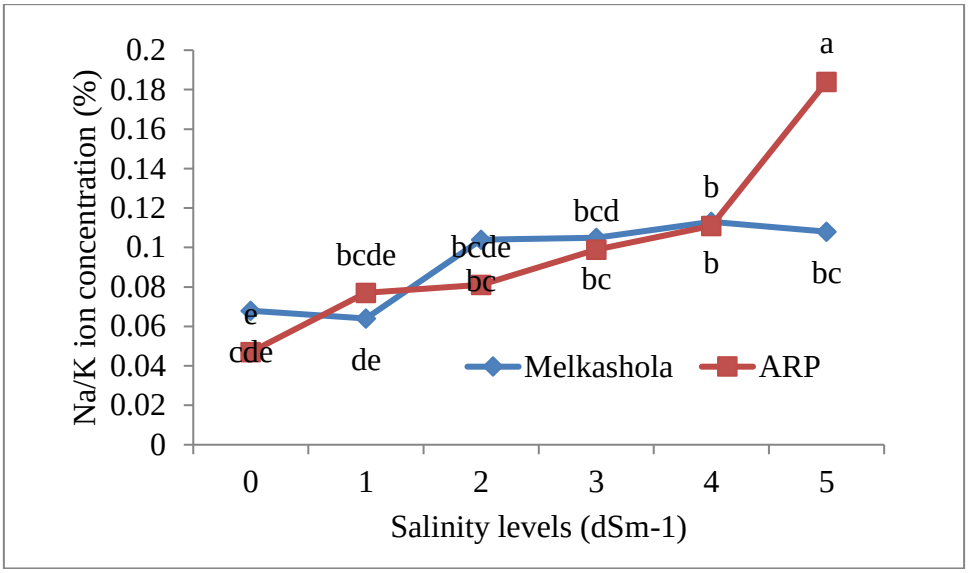

Figure 12. Sodium/Potassium ratio concentrations as affected by the interaction of salinity level and variety

Discussion

From the experiment, different visual symptoms such as wilting, yellowing of leaves, chlorosis of green parts, leaf tip burning, and necrosis of leaves, and scorching of the oldest leaves were observed after being treated with the salinized irrigation water and the symptoms were higher at higher salinity concentrations as compared to the control. Similar result has been reported by Julkowska and Testerink (2015), indicating that salinity stress leads to an ion imbalance causing necrosis and premature death of older leaves. The reason in leaf area reduction under salinity stress could be as a result of physiological dryness and due to other growth parameters related to photosynthetic products. In line with this, (Rubio *et al*., 2009) reported that the reduction in tomato leaf area under salt stress could be probably due to the reduction of growth parameters contributing to photosynthetic products. Bruria (2015) reported that reduction in the rate of leaf surface expansion followed by a cessation of expansion as the stress intensifies is among the earliest response to salt stress.

In the present study, plant height showed significant reduction for all varieties. Shabani *et al*., (2012) reported similar result indicating that tomato plant height was highly reduced with increasing NaCl concentration. Shoot fresh weight significantly decreased as the salinity level increased from the control to the highest. This is due to the exosmosis of water and plasmolysis of plant cells as a result of hypertonic solution of the treatments. In addition to this, plants undertake stomatal closure under high salt concentration due to water stress to safeguard the loss of water through transpiration. This may result in the reduction of photosynthetic rate and assimilate production. In another way, high salt

concentration may result in the lower hydrolysis of enzymes responsible for different metabolic activities of the plant.

The result also indicated that tomato varieties responded differently to different salt levels, where variety Melka Shola had higher shoot fresh weight as compared to ARP tomato d-2. This could be probably due to the better potential of Melka Shola to selective ion accumulation or exclusion and ion compartmentalization. Similarly, Munns and Tester (2008) reported that the adverse effects of salt stress on plant growth are mainly due to its toxic and osmotic effects. Amir *et al*. (2011), Hamed *et al*. (2011) and Jogendra *et al*. (2011), reported that shoot was affected drastically in plants grown under salt stress than in control environment. The decrease in shoot fresh weight with increase in salt concentration was in line with the results reported by Kamrani *et al*. (2013) and Osakabe *et al*. (2014) indicating that salt stress brings about osmotic stress and subsequently ionic toxicity and oxidative stress. Salt stress causes osmosis stress by limiting the availability of water to plants. As a result, it leads to loss in turgor pressure of the plant due to decreased water potential that result in wilting that affect plant morphology and biomass production. Shabani *et al*. (2012) reported similar result in that tomato plant shoot fresh weight was highly reduced with increasing NaCl concentration. The similar results reported by Dheeba at al. (2015) who showed that salinity reduced fresh and dry weight of plants. The lower dry and fresh biomass at increased salinity level mainly be due to poor absorption of water from the growth medium due to osmotic effect salinity or physiological drought (Ramezani *et al*., 2019).

The reduction in shoot dry matter yield under higher salinity level could probably be due to physiological dryness of the plants as a result of exosmosis and decline in plant water potential. The reduction in shoot dry matter with increasing salinity levels could also be due to reduced number of branches and leaves, leaf size and stem diameter of tomato plants. It was observed that, variety Melka Shola was better than ARP tomato-d2 in salt tolerance in terms of shoot dry matter production and, thus, salinity threshold level. Daliakopoulos *et al*. (2016) found that shoot fresh and dry weight decreased as salinity level increases from control to the highest concentration.

The restriction in root growth may affect the whole processes when the plant grows under stress condition. Pérez-Alfocea *et al*. (2010) reported that root is very important in hormonal regulation of source–sink relations during the osmotic phase of salinity stress in tomato. They also reported that root senses the effect of soil salinity and influences root-to-shoot signaling to control shoot growth and physiology via hormonal signals, such as cytokines, ABA and auxin IAA, thus coordinating assimilate production and usage in competing sinks. Smolik *et al*. (2011) found that salt stress leads to changes in growth, morphology and

physiology of the roots that will, in turn, change water and ion uptake and the production of signals (hormones) that can transfer information to the shoot, affecting the whole plant when the roots are growing in a salty medium.

The reduction in root dry and fresh weights under higher salinity levels could be probably due to the adverse effects of salinity on tomato root development like root length, number and diameter as result of exosmosis and lower water potential in the roots. Daliakopoulos *et al*. (2016) found that root fresh and dry weight decreased as salinity level increases from control to the highest. Furthermore, they reported that tomato plant root was more affected as compared to the shoot part. However, less reduction in root growth as compared to the shoot part in the present study mainly be due to higher salt concentration which reduces water potential of the plant which results in the preferential allocation of biomass to roots.

Root to shoot ratio increased with increasing salt concentrations, indicating that, tomato root was less affected by the salinity stress than did the shoot part. This is due to the preferential allocation of assimilates to root due to osmotic stress. This result was in line with the findings of Hamed *et al*. (2011) who reported the root growth in tomato appears to be less affected, whereas, shoot was affected drastically, so that, the dry weight ratio was higher in plant grown under salt stress than in control environment. According to Chookhampaeng *et al*. (2007) and Amir *et al*. (2011), the root/shoot dry weight ratio in tomato increased under higher salt concentration. This could be due to changes in allocation of assimilates between root and shoot. In such cases the greater proportion of assimilates allocated for root as compared with shoot. Danait (2018) reported that, root dry weight is positively correlated but, shoot dry weight is negatively correlated to salinity. In contrast, Akram *et al*. (2010) reported that the phenomenon of photosynthesis proceeds normally in salt tolerant genotypes. Because such genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf, they store them in their roots. That is an adaptation mechanisms of tolerant plant species to withstand the adverse conditions that sensitive species substantially lack.

The increasing salinity concentration causes the decrease in photosynthetic rate due to stomatal closure of the plant in response to salt stress and due to its effects on leaf gas exchange, particularly CO_2. This result was in agreement with the findings of Daliakopoulos *et al*. (2016), who reported that stomatal conductance determines photosynthetic rate, which plays important role in growth and development of any plant, and increasing salinity level decreased stomatal conductance and the reduction was greater at the highest level. Such reduction of stomatal conductance under salt stress conditions may result in lower photosynthetic rate that, in turn, leads to lower total yield of the crop. In line with

this Zhai *et al*. (2015) reported that irrigation water with excessive salinity has negative effects on the chlorophyll content of tomato, which directly influence photosynthetic rate of the plant.

Salt stress also negatively affects the physiological and biochemical processes going on in tomato Rivero *et al*. (2014) and Asad *et al*. (2018). Reduced plant water contents or water potential due to salt stress led to stomatal closure to safeguard further loss of water by transpiration Manan *et al*. (2016). In addition to reduced transpiration due to stomatal closure, net photosynthesis also reduced under salt stress by the production of ROS and decrease in chlorophyll contents and rubisco activity Zhang *et al*.(2009) and Zribi (2009). ROS decrease net photosynthesis, chlorophyll content and rubisco activity by increasing the osmotic stress causing, oxidative damage due to lack of dissipation of excessive excitation of energy resulting in loss of chlorophyll leading to decreased rubisco activity that finally cause reduction in photosynthesis. Physiological efficiency of tomato is also adversely affected by saline conditions, as salinity affects photosynthesis by decreasing CO_2 availability because of diffusion limitations Flexas *et al*. (2007) and a reduction in the contents of photosynthetic pigments (Ashraf and Harris, 2013).

At the salinity level of $5dSm^{-1}$ yield of tomato varieties decreased by almost 50% as compared to the control treatments. This could be probably attributed to reduced fruit number, fruit size and reduced dry matter accumulation in the fruits, which have direct contribution to lower fruit yields. This result was in agreement with the report of Ciobanu and Sumalan's (2009) that 50% tomato yield loss was occurred at moderate salinity level ($5dSm^{-1}$). Due to the harmful impact of salt stress on the tomato growth, lowering of plant water potential, disturbance in mineral uptake and enhancement of plant respiration; result in the reduction of tomato yield. Shao *et al*. (2013) and Hou *et al*. (2014)] reported that tomato yield was negatively affected by increasing salinity levels, as increasing irrigation water salinity levels resulted in a significant reduction in fruit yield.

Furthermore, it has been reported that high saline soil decreased the number of fruits/plants Khursheda *et al*. (2015). Babu *et al*. (2012) found that, NaCl stress resulted in decreased rate of fruit growth. The reduction of stomatal conductance under salt stress conditions may result in lower photosynthetic rate that, in turn, leads to lower total yield of the crop and the effects of reactive oxygen species under higher salinity may also the reason for reduced yield. In line with this, Zhai *et al*. (2015) reported that irrigation water with excessive salinity has negative effects on the chlorophyll content of tomato, which directly influence photosynthetic rate of the plant.

High salt concentration in the irrigation water affects the physiological and biochemical process in tomato such as enzymatic activities, reduced water potential and oxidative damage due to increased ROS. In line with this, Rivero *et al*. (2014); Asad *et al*. (2018) and Manan *et al*. (2016) reported that salt stress also down regulates the physiological and biochemical processes going on in tomato and reduced plant water contents or water potential due to salt stress lead to stomatal closure to safeguard further loss of water by transpiration. Zhang *et al*. (2009) and Zribi *et al*. (2009) reported that in addition to reduced transpiration due to stomatal closure, net photosynthesis reduced under salt stress by the production of ROS and decrease in chlorophyll contents and rubisco activity. ROS decrease net photosynthesis, chlorophyll content and rubisco activity by increasing the osmotic stress causing, oxidative damage due to lack of dissipation of excessive excitation of energy resulting in loss of chlorophyll leading to decreased rubisco activity that finally cause reduction in photosynthesis.

Compos *et al*. (2006) reported that both vegetative and fruit growth of tomato decrease markedly under saline conditions. That may be due to changes in a range of metabolic processes caused by salt stress. Protein contents and activities of ascorbate peroxidase and catalase decreased under saline conditions and it also causes an ionic imbalance and osmotic shock to tomato plants (Ciobanu and Sumalan 2009). The accumulation of Na^+ ions and changes in leaf hormone relations contribute to leaf senescence. This in turn results in limiting tomato productivity. Under saline conditions Ghanem *et al*. (2008). Flexas *et al*. (2007) reported that saline conditions adversely affected physiological efficiency of tomato due to effects of salinity on photosynthesis by decreasing CO_2 availability because of diffusion limitations. Similarly, Maggio *et al*. (2007), reported that physiological efficiency of tomato is adversely affected by saline conditions. However, yield was negatively highly associated with Na ion, indicating that tomato yield significantly decreased with increasing salinity stress.

Disorder in translocation and distribution of minerals specially K^+ could be probably the reason for the decreased uptake of K^+ at the highest salinity level due to substitution of K with Na at its usual binding sites. The difference between varieties for K concentration imply, difference in osmotic adjustment and thus, can be used as selection criteria for salt stress tolerance. In line with this, Khalafalla *et al*. (2010) has reported that increase in K^+ concentration in nutrient solution could ameliorate negative effects of salt condition and potassium can alleviate the negative effects of NaCl on vegetative growth and yield. Akram *et al*. (2010) reported that the phenomenon of photosynthesis proceeds normally in salt tolerant genotypes. Because such genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf, they store them in their roots. That is an adaptation mechanisms of tolerant plant species to withstand the adverse conditions that sensitive species substantially lack. In addition to this, Maggio *et*

al. (2007) found similar observations in tomato. This result was in agreement with the findings of Sadak and Abdelhamid (2015) who reported that increased concentration of sodium affects the entry of K^+ ions. Flowers *et al*. (2015) reported that sodium concentration increases in plants under salt stress and suppresses the potassium concentration.

The difference between the varieties for sodium and potassium content may be due to their genetic difference in ion uptake for osmotic adjustment. In line with this, Flowers (2004) and Dheeba *et al*. (2015) reported that salt tolerance is genetically controlled and the ability of plants to overcome the effects of salt depends on selective ion accumulation or exclusion or osmotic adjustment. Akram *et al*. (2010) stated that salt tolerant genotypes transport very small amount of toxic ions (Na^+) to the upper areas like leaf. Variety Melka Shola exhibited such potential and better accumulation of K as compared to the variety ARP tomato-d2. [34] Reported that sodium concentration increases in plants under salt stress and suppresses the concentration of potassium. Sadak and Abdelhamid (2015) reported that, at cellular level salinity brings about ionic toxicity by elevated Na^+ and Cl^- levels. According to results of Asik *et al*. (2009) increased Na+ level was found in plants grown under higher salinity concentration. This indicates that Na^+ affected the proper uptake of S and P nutrients. This result was in agreement with that of Munns *et al*. (2006) who reported that salinity has an antagonistic impact on the uptake of nutrients. In addition, Asik *et al*. (2009) illustrated that Na and K suppressed or reduced the uptake and transportation of Ca and Mg cations under salt stress conditions. In the present study, it was observed that sulfur had significant negative association with Na^+. Better nutrient uptake under saline condition may help the plant to counteract the nutrient imbalance occurring under saline environment. This finding was in line with the result of Jogendra *et al*. (2011), who reported that the lower value of Na^+/K^+ ratio, indicated more uptake of K^+ from soil/medium by plants and such types of plants are similar to non-salinized plant, i.e., salt tolerant.

Conclusion and Recommendation

The comparison within varieties indicated that Melka Shola was tolerant as compared to ARP tomato-d2. It can be concluded that the main effects of salt on tomato varieties were due to the osmotic effect, ion toxicity (specifically Na^+) and nutrient imbalance due to increased uptake of Na^+ that resulted in reduction of Sulfur and Phosphorus uptake by plants. Potassium also indicated significant reduction with the increased salinity level. However, both varieties showed sufficient K^+ uptake under salinity stress. Variety Melka Shola showed better tolerance as compared to ARP tomato d-2. Therefore, Melka Shola could be recommended for salt affected areas for farmers and other tomato producers in salinity affected areas for production and should be considered as potential

planting material that is useful to breeders of salt tolerant cultivars. However, since the experiment was conducted for one year and under controlled conditions, on farm verification of the varieties in salt affected areas should be done in order to draw sound conclusions and recommendation and the effect of salinity on tomato quality also deserves further study.

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Germination Response of Released Tomato (Solanum Lycopersicum L.) Varieties to Salt Stress

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Abstract

Tomato (Solanum lycopersicon L.) is one of the most important fruit vegetables in vast areas in the world including Ethiopia. Many crop plants including tomatoes are susceptible to high salinity and it is considered as among the major abiotic factors limiting its production and productivity in Ethiopia. High salt level of irrigation water may induce a reduction and delay of germination and other germination parameters. The present study was conducted to assess germination responses of 14 tomato varieties to six different salinity levels. The study was carried out at Melkassa Agricultural Research Center in laboratory in 2018. Each treatment was replicated three times and arranged in Randomized Complete Block Design in factorial arrangement. Germination percentage, germination index, germination speed and seedling vigor were measured. All the traits showed significant decrease ($P<0.0001$) with increased salt concentration. The result clearly revealed that the highest germination percentage (95%) was recorded from the control treatment for variety ARP, while the lowest germination percentage (11.67%) was recorded from the highest salt concentration (5dSm-1) for variety Eshet. The higher values of germination indices (107 and 101.8) were recorded at 1dSm-1 for Awash River and Gelilea varieties respectively, and 100% were recorded at the control treatment for most of the varieties. The highest salinity level (5dSm-1) resulted in lowest germination index (14.3%) for variety Challi. Highest values of seedling vigor index, (1225.5, 1231.17 and 1211.58) were resulted from the control treatment for varieties Gelilea, ARP tomato d-2 and Melka Shola, respectively. In contrast, the highest salinity level (5dSm-1NaCl) resulted in the lowest seedling vigor index (61.5) for variety Melka Salsa. The result clearly revealed that highest number of speeds of germination (10 and 9.91) was recorded at 1 dSm-1 and control treatments respectively for variety ARP tomato d-2. On the other hand, highest salinity concentration (5dSm-1) resulted in the lowest speed of germination (0.29 and 0.22) for varieties Melka Salsa and Eshet respectively. The findings of the study revealed that, Melka Shola, ARP tomato d-2, Gelilea and Awash River were found to be more salt tolerant as compared to other varieties on the basis of studied traits. Since the present experiment was conducted for one season and under controlled condition, it deserves further evaluation and verification under green house or field condition in salt affected areas and the effect of salinity on tomato quality deserves further investigation.

Keywords: Irrigation water salinity, tomato germination.

Introduction

Tomato (*Solanum lycopersicum* L.) is the major horticultural crop with an estimated global production of 164 million metric tons from 4.73 million ha of land (FAO, 2014). In Ethiopia, current tomato production is estimated to 277,74.538 tons from 5,235.19 hectare of land for the *Meher* (main season) (CSA, 2018) and it is an important food ingredient in daily diet of people in almost all regions of the country. It is an important cash-generating crop to small-scale farmers and provides employment in the production and processing industries (Selamawit *et al*., 2017).

Despite its importance, still the national average yield of tomato for the *Meher* (Main season) in Ethiopia is 5.31 ton/ha (CSA, 2018), which is quite incomparable with the average yield of other countries such as China, USA, Turkey, India, Egypt, Italy and Spain with average yield of 22.67, 80.61, 35.81, 18.61, 40.00 and 76.35 ton/ha, respectively (FAOSTAT, 2010). A number of constraints are contributing to lower yield and yield components of tomato under farmer's condition in developing countries like Ethiopia including lack of improved varieties that tolerate different stresses. Among them, salinity is the most contributing stress factors (Kassaye *et al*., 2013).

Salt affected soils are becoming one of the main problems in Ethiopia (Seid and Genanaw, 2013). The arid and semi-arid agro-ecologies, which account for nearly 50% of the country's land areas, are regarded as marginal environments for crop production mainly due to soil and water salinity (Asad *et al*., 2018). Salinity has threatened the productivity of irrigated lands, which is producing more than 40% of the total food requirement of the country (Mohammed *et al*., 2015).

Low levels of annual rainfall and high daily temperatures have led to high water evaporation rates and consequently contributed to high concentrations of soluble salts in these lowland areas (Sileshi *et al*., 2015). The soil salinity problem in Ethiopia also stems from use of poor-quality water coupled with intensive use of soils for irrigation, poor on-farm water management practices and lack of adequate drainage facilities (Gebremeskel *et al*., 2018). Chloride and sulfate salts of sodium and calcium (mainly NaCl and CaSO4) are assumed to be the major soluble salts contributing to the very high salinity level of these soils (Auge *et al*., 2018).

High levels of both Na^+ and Cl^- in plants are inhibitory to a number of metabolic and cellular processes (Ashraf and Athar, 2009). Salt stress in soils causes physiological drought to plants, which result in the reduction of osmotic potential of the plant, and excessive toxicity of Na and Cl ions to cells causing the disruption of cell organelles and their metabolism. High uptake of Na and Cl ions also result in nutrient imbalance in plants (Evelin *et al*., 2009). Consequently, it

affects plant growth and yield. In addition to this, salinity stress causes reactive oxygen species (ROS) to be produced, inducing oxidative stress in crop plants (Choudhury *et al*., 2017).

To overcome the effects of salt stress, plants produce antioxidants and osmo-protectants to bring about tolerance against oxidative stress and osmotic stress, respectively (Garrido *et al*., 2014). In line with this, great efforts have been devoted to understand the physiological aspects of tolerance to salinity in plants, as a basis for plant breeders to develop salinity tolerant genotypes (Rashed *et al*., 2016).

As correcting saline conditions in field and greenhouse would be expensive and temporary, selection and breeding for salt tolerance can be a wise solution to minimize salinity effects and improve production efficiency of crops. It has been suggested that great magnitude of genotypic variability in tomato cultivars (*S. lycopersicum* L.) was found for salt tolerance at the germination stage (Jogendra *et al*., 2011). This shows that breeding for tolerant cultivars of tomato is possible under saline conditions. Most of the export crops such as cotton, sugarcane, citrus, banana and vegetables are being produced in the Rift valley of Ethiopia. However, development of large-scale irrigation projects in the Rift valley area in the absence of proper drainage systems for salinity control has resulted in increasing severity and rapid expansion of soil salinity and sodicity problems leading to complete loss of land for crop cultivation in these areas (Asad *et al*., 2018). Nearly 20 tomato varieties have been released and registered by Ethiopian Agricultural Research System. However, the reaction of these varieties and genotypes to salt stress has not been assessed, except that very few varieties have been tested under low salt concentrations at germination and seedling stages (Personal Communication). Moreover, it has been suggested that more research is needed to identify the variety which will perform better at germination stage and give higher yield under high soil salinity condition (Kassaye *et al*., 2013). Thus, it was essential to screen released tomato varieties under different salinity levels to determine the effect of different salinity levels of irrigation water on seed germination of released tomato varieties and identify potential sources of salt tolerance for future breeding activities.

Materials and Methods

Descriptions of the study areas

The study was conducted at Melkassa Agricultural Research Center (MARC) in 2018/19 in the laboratory. Melkassa is located in the Central Rift Valley of Ethiopia at 8°24′N latitude, 39°21′E longitude, and at an altitude of 1,550 meter above sea level.

Experimental Materials

Table 6. List of released tomato varieties by MARC and hybrid cultivars used for the study

No.	Variety	Year of Release (E.C.)	Productivity (ton/ha)		Days to Maturity	Responsible/Source Organization/company
			Research field	Farmer field		
1	Melka-salsa	1990	45.0	-	100-110	MARC
2	Melka-shola	1990	43.0	-	100-120	MARC
3	Gelilema	2007	50.0	-	80-92	MARC
4	Chali	1999	43.0	-	80-90	MARC
5	Cochoro	1999	46.3	-	70-80	MARC
6	Eshet	1997	39.4	-	130-140	MARC
7	Fetan	1997	45.4	-	110-120	MARC
8	Metadel	1997	34.5	-	90-140	MARC
9	Bishola	1997	34.0	-	140-150	MARC
10	Miya	1999	47.1	-	75-80	MARC
11	ARP tomato d2	2004	43.5	-	80-90	MARC
12	Galilea	2003	66.6	65.9	70-75	Green Life Plc
13	Awash River	2007	50-75	40-70	75	Mekamba Plc
14	Venis	2007	75	55	75	Markos Plc

Source: MoA (1998-2014)

Treatments and experimental design

The study consisted of six levels of salt concentrations (Awash River water as control (0.15), 1, 2, 3, 4 and 5dSm^{-1})) and fourteen released tomato varieties (Melka Salsa, Melka Shola, Gelilema, Chali, Cochoro, Eshet, Fetan, Metadel, Bishola, Miya, ARP tomato d2, Galilea, Awash River and Venis). The total number of treatment combinations was 84 (six different salinity levels in combination with fourteen tomato varieties). Thus, the experiment consisted of a total of 252 experimental units. A Randomized Complete Block Design in factorial arrangement was used and the treatments were replicated three times.

Experimental procedures

The varieties were screened for salt tolerance using six levels of salinity treatments at germination stage on Petri dishes in the laboratory at Melkassa Agricultural Research Center. The electrical conductivity (EC) and total dissolved salts (TDS) of the Awash River water were tested by using the conductivity meter 4310 JENWAY and pocket TDS scan 20 respectively.

Then, the levels of salt solutions were prepared using NaCl salt (pure 99.5% assay) to get the desired electrical conductivity of the solution (treatment) in separate containers. The amount of NaCl salt added per unit of irrigation water

was calculated using formula indicating relationship between the electrical conductivity (dSm^{-1}) and TDS (mg/L) of the solutions as TDS (g/L) = 0.64g x EC, where EC is the desired electrical conductivity of solution (Ali *et al*., 2012). Accordingly, 0.64 gram of NaCl was used per a liter of water to get the electrical conductivity of 1 dSm^{-1} and calculated for all treatments following the same formula.

Tomato seeds were sterilized by soaking in a 5% alcohol solution for 5 minutes. After the treatment, the seeds were washed several times with distilled water to remove the alcohol from the seed surface. Petri dishes were also sterilized with alcohol and thoroughly washed before use with clean water. Petri dishes were layered with filter papers (9 cm diameter) and 40 seeds were put in each Petri dish on the filter paper moistened with the respective treatment solutions in three replications. Five milliliters of saline treatments were added to each Petri dish containing seeds as described in the previous works (Jogendra *et al*., 2013). The Petri dishes were covered to prevent the loss of moisture by evaporation and put in the laboratory for 14 days. Seeds that produced full radicle were considered as germinated seeds. The initial germination counts were started at 4^{th} day and final germination counts were made at 14^{th} day after treatment application, and the result was expressed as percentage.

Data Collection

In the laboratory experiment germination process was recorded using the procedures described by (ISTA, 1996) and (Kandil *et al*., 2012). Three parameters of germination were recorded:

1. Standard germination percentage: Standard germination count was made at 14^{th} day after treatment application and expressed in percentage using the following equation (ISTA 1996 and (Kandil *et al*., 2012).

$$SG= \frac{\text{Number of normal seedlings}}{\text{Number of total seeds sown}} \text{ x } 100$$

2. Germination index (GI): GI was calculated according to the following equation (Karim *et al*., 1992).

$$GI = \frac{Germination\ Percentage\ in\ each\ reatment}{Germination\ Percentage\ in\ control\ treatment} \text{ x } 100$$

3. Seedling Vigor Index (SVI): was calculated according to the following equation as described by Abdul-Baki and Anderson (1970).

SVI = [(Root length (cm) + shoot length (cm) x Germination %]

4. Speed of germination (SPG): Speed of germination was measured by the following formula (ISTA, 1996).

$$SPG = \frac{No.of\ germinated\ seeds}{Days\ to\ first\ count} + \ldots + \frac{No.of\ germinated\ seeds}{Days\ to\ final\ count}$$

Data Analysis

Data was subjected to Analysis of variance (ANOVA) was performed using SAS PROC CORR (SAS Institute, 2008) version 9.0. Treatment means were separated by using Duncan's multiple range test at 5% probability level for all the parameters recorded.

Results and Discussion

Standard germination percentage

The effects of salt concentrations, varieties and their interactions on standard germination percentage showed significant difference ($P<0.0001$). The result revealed that the highest germination percentage (95%) was recorded for the control treatment for variety ARP tomato d-2. On the other hand, the highest salinity level ($5dSm^{-1}$) resulted in the lowest germination percentage (11.67%) for variety Eshet (Table 2). Increasing salinity levels from 1 to $5dSm^{-1}$ significantly reduced the standard germination percentages compared with the control treatment. At the final germination count, the applied moisture (treatment solution) was totally absorbed by the seeds of all varieties in the control plot.

In contrast, the moisture remained unabsorbed in the treatments with the higher salt concentrations, except for few varieties (ARP tomato-d2, Melka Shola and Gelilea) that showed better water uptake and germination percentage. This indicates that, in the higher salt concentrations the seed could not absorb water due to higher osmotic pressure of the solution or the lower water potential of the solution, while there was high water absorption by seeds in the control and lower salt concentrations. Since seed germination is a function of hydrolysis that helps the breakdown of starch to simple sugars and oxidizing of resulting sugar to energy, salt may have effect on hydrolysis (i.e. synthesis of enzyme amylase) and metabolic impairment. The reason why seeds of some varieties absorbed more water and showed higher germination percentage in concentrated salt solution may due to the ability of osmotic adjustment and tolerance to salinity stress. This result was in agreement with the findings of Croser *et al*. (2001) and Essa and Al-Ani (2001) who reported the effect of external salinity on seed germination may be partially osmotic or ion toxicity, which can alter physiological processes such as enzyme activities.

Among the different varieties treated with different NaCl concentration, ARP tomato-d2, Melka Shola and Gelilea gave higher standard germination percentage (Table 2). Varieties Eshet, Challi, Metadel and Melka Salsa, on the other hand, gave lower standard germination percentage. For any seed to germinate there

should be uptake of water by the process of imbibition then a general activation of seed metabolism follows. The water imbibition is followed by the diffusion of GA to the cytoplasm that is responsible for the production of amylase enzyme used for the breakdown of starch to simple sugars that facilitate germination. However, under higher salt conditions the process was delayed due to osmotic pressure. This result was in line with the findings of Jogendra *et al*. (2013) who reported that germination of tomato seeds drastically reduced with increasing salinity level. The genotypes which are least affected may be potential source of salinity tolerance for tomato breeding (Amir *et al*., 2011; Hamed *et al*., 2011). Seed germination is usually the most critical stage in seedling establishment, determining successful crop and seed quality (Khaje, 2003).

Table 7. Standard germination percentage as affected by the interaction of salinity level and variety

Salt (dSm-1)	Variety													
	Bishola	Fetan	Eshet	Challi	Metadel	Melka Salsa	Melka Shola	ARP	Gelilema	Venise	Gelilea	Awash River	Cochoro	Miya
RW (0.15)	65n-q	85b-h	65n-q	86.67a-h	59.17qr	73.33i-n	94.17ab	95a	69.17l-p	90.83a-d	91.67a-c	73.33i-n	85.83a-h	72.50i-n
1	71.67j-o	72.50i-n	19.17za-d	62.50o-r	28.33w-y	35vw	90a-e	90.83a-d	55rs	79.17f-k	93.33a-c	78.33g-l	78.33g-l	70.83l-o
2	50st	66.67m-	23.33yzab	17.50a-d	25x-za	25x-za	88.33a-f	87.5a-g	39.17uv	75i-m	87.5a-g	71.67j-o	60qr	47.50stu
3	31.67v-y	45tu	16.67a-d	19.17za-	22.5yza-	18.33a-	87.5a-g	84.17c-h	19.17za-	73.33i-n	80.83e-j	64.17n-	45.83tu	45tu
4	23.33yzab	33.33v-x	11.67d	15a-d	15.83a-d	13.33cd	80.83e-j	81.67d-i	15.83a-d	72.5i-n	77.5h-k	61.67p-r'	40uv	30w-y
5	27.5w-z	31.67v-y	11.67d	12.5d	15.83a-d	10.83d	67.5m-q	78.33g-l	16.67a-d	39.17uv	70l-p	35.83vw	33.33v-x	29.17w-y
CR	9.98													
CV	8.89													
Grand mean	53.59													

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range, RW= river water used as control

Germination index (GI)

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) with respect to germination index. The highest germination index was recorded for the control treatment. The highest salinity concentration of $5dSm^{-1}$resulted in the lowest average germination index (Table 3). Hence, germination index decreased as the salinity level increases from the control to the highest level. This could be probably due to toxic effect of salt ions on seed. This result was in line with the findings of Khayantnezhad and Gholamin (2011) who reported that, an increased germination index is indicative of decreased phytotoxicity and thus of a more mature germinated seed.

The higher values of germination indices (107 and 101.8) were recorded in the $1dSm^{-1}$ for the Awash River and Gelilea varieties respectively. In contrast, the highest salinity level ($5dSm^{-1}$) resulted in the lowest germination index (14.3%) for variety Challi. Among the different varieties treated with different salt concentration levels, ARP tomato-d2, Melka Shola, Gelilea and Awash River gave highest germination index. Varieties Eshet, Challi and Melka Salsa on the other hand, had lower germination index. This indicated that Eshet, Challi and Melka Salsa were the most affected varieties due to the toxic effects of salinity as compared to the other varieties. This experiment had been further evaluated under greenhouse condition to identify tolerant varieties and Melka shola and ARP tomato d-2 were found better.

Table 8 Germination index (%) as affected by the interaction of salinity level and variety

Salt (dS m^{-1})	Variety													
	Bishola	Fetan	Eshet	Challi	Metadel	Melka Salsa	Melka Shola	ARP	Gelilema	Venise	Gelilea	Awash River	Cochoro	Miya
RW	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1	96.	85.	29.5	72.2	48^{p-}	47.	95.	95.	79.9	87.	101.	107	91.	97.
2	77.	78.	36.8	20.3	42.	34.	93.	92^{b-}	56.7	82.	95.6	97.	70.	65.
3	48.	53^{o-}	25.8	22^{bc}	37.	24.	92.	88.	27.8	80.	88.3	87.	53.	62.
4	36.	39.	18.1	17.2	26.	18.	85.	86^{d-}	22.8	79.	84.8	84.	46.	41.
5	42.	37.	18.4	14.3	26.	14.	71.	82.	24.2	42.	76.4^{i}	49.	38.	40.
CR	13.41													
CV	9.69													
Grand	65.97													

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range, RW= river water used as control

Seedling vigor index

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) for seedling vigor index. The highest seedling vigor index was recorded in the control treatment, while the highest salinity level (5dSm^{-1}NaCl) resulted in the lowest value (Table 4). Hence, seedling vigor index decreased as the salinity level increased from the control to the highest. This could be probably due to osmotic and toxic effect of salt ions on seedling growth. This result was in line with the findings of Zaheer *et al*. (2017), indicating that seedling vigor index decreased with increasing NaCl level. Increased seedling vigor index is an indicative of increased uniformity and good performance of the seedlings. Highest values of seedling vigor index, 1225.5, 1231.17 and 1211.58 were resulted from the control treatment for varieties Gelilea, ARP tomato d-2 and Melka Shola, respectively.

In contrast, the highest salinity level (5dSm^{-1}NaCl) resulted in the lowest seedling vigor index (61.5) for variety Melka Salsa (Table 4). Similarly, varieties Eshet, Challi, Melka Salsa and Metadel showed lower values of seedling vigor index. This indicated that varieties Eshet, Challi, Melka Salsa and Metadel were the more affected due to higher salinity level as compared to the other varieties. Platten *et al*. (2013) reported that plant vigor is one of the major determinants of salt tolerance in plants. Similar report by Kumar *et al*. (2013) showed that growth vigor is such a mechanism which can avoid the toxic effects of salinity and vigor

is an avoidance mechanism rather than tolerance mechanism which works as far as the productivity is concerned.

Table 9 Seedling vigor index as affected by the interaction of salinity level and variety

Salt (dSm^{-1})	Variety													
	Bisho-la	Fetan	Eshet	Challi	Metadel	Melka Salsa	Melka Shola	ARP	Gelilema	Venise	Gelilea	Awash River	Cochoro	Miya
RW	751	975.	637.	948.	547.	724.	1211	1231.	792.	1141.	1225.	863.	1000.	846^{i-}
1	789	769.	164.	613.	247.	320.	1074	1110.	573^{qr}	912^{f-j}	1178.	816.	856^{i-m}	752.
2	579	758.	248^{x-}	192.	229.	248.	897.	924.8	462.	931.8	1019.	841.	754.5	514.
3	306	412.	120.	161.	172.	117.	871.	888.5	166.	707.9	901.5	551.	428^{tu}	413.
4	209	276^{x}	75.4	108.	114^{c-}	82^{f-h}	638.	766.5	126.	656^{o-q}	814.7	515.	321.2	243.
5	195.83^{y}	234.83^{x-}	67.67^{h}	77.17^{gh}	101.58^{e-h}	61.5^{h}	418.25^{t-v}	619.17^{p-r}	129.17^{a-h}	314.67^{v-x}	622.17^{p-r}	255.33^{x-z}	248^{x-z}	218.08^{x-}
CR						124.1								
CV						10.71								
Grand mean						552.54								

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range, RW= river water used as control

Speed of germination

Significant difference was observed between salinity level, varieties and their interactions ($p<0.0001$) with respect to speed of germination. The result clearly revealed that highest speeds of germination (10 and 9.91) was recorded in the 1 dSm^{-1} and control treatments respectively for the variety ARP tomato d-2. On the other hand, highest salinity concentration ($5dSm^{-1}$) resulted in the lowest speed of germination (0.29 and 0.22) for varieties Melka Salsa and Eshet respectively (Table 5). The highest salinity concentration of $5dSm^{-1}$ recorded the lowest averages of this trait. This result concluded that, increasing salinity levels from 1 to $5dSm^{-1}$ significantly reduced speed of germination compared with the control treatment. The result also indicated that, salinity highly affected speed of germination of different tomato varieties and lengthened the time needed to complete germination. The speed of germination was reduced, meaning that it

took more days to complete the germination under salinity as compared with the control treatment for all of the evaluated tomato varieties. This result is in agreement with the result that reported by (Amir *et al*., 2011).

The seedlings that were grown under high salinity level ($5dSm^{-1}$) showed lower speed of germination compared to others. Since higher salinity limited water absorption, it prevents the activation and early completion of germination process, as a result, speed of germination declined with increased salinity concentration. This result accords with the results reported by Groot and Karssen (1992) and Groot *et al*. (1988) that the stimulation of germination and days required for its completion depend upon Gibbrelic Acid (GA) content in seed. A low level of GA in seed in saline medium was unable to break the mechanical resistance of endosperm against imbibitions of water by seed and this leads to the reduction in speed of germination. Since the higher salt concentration limited the water absorption, it slows down the germination speed. Delayed germination causes increased irrigation cost, irregular and weak seedling growth in the establishment of crops (Tsegay and Gebreslassie, 2014). Amir *et al*. (2011) and Hamid *et al*. (2011) [19] reported that genotypes that germinate earlier at higher salinity concentrations are supposed to be more vigorous and might be used as parents or potential donors in salinity tolerance crop breeding programs.

Table 5. Speed of germination as affected by the interaction of salinity level and variety

Salt (dSm^{-1})	Variety													
	Bishola	Fetan	Eshet	Challi	Metadel	Melka Salsa	Melka Shola	ARP	Gelilema	Venise	Gelilea	Awash River	Cochoro	Miya
RW	4.56^{i-v}	6.71^{d-j}	4.47^{k-v}	4.84^{h-t}	4.80^{h-t}	5.54^{f-q}	9.64^{ab}	9.91^{a}	5.26^{g-r}	6.38^{e-k}	9.48^{ab}	6.71^{d-j}	7.57^{b-f}	5.6^{f-p}
1	4.49^{i-v}	5.77^{f-o}	0.66$^{b-e'}$	6.74^{d-i}	2.59$^{u-zabcd'}$	2.62$^{u-zabcd}$	8.60^{a-d}	10^{a}	3.35^{q-y}	2.88$^{s-zab'}$	8.53^{a-e}	7.10^{c-g}	6.60^{d-j}	6.56^{d-k}
2	3.46^{q-w}	6.19^{f-m}	1.03$^{za-e'}$	0.55$^{c-e'}$	1.25^{yza-e}	1.25^{yza-e}	6.81^{d-h}	8.53^{a-e}	2.90^{s-}	6.68^{d-j}	5.28^{g-r}	6.83^{d-h}	5.49^{f-q}	2.64^{t-}
3	1.52$^{xyza-e'}$	3.98^{m-v}	0.46$^{c-e'}$	0.85^{za-e}	1.03^{za-e}	0.57$^{c-e'}$	7.62^{b-f}	5.52^{f-q}	0.75$^{a-e'}$	2.71^{t-}	6.09^{f-n}	3.87^{o-w}	3.93^{n-w}	3.65^{o-w}
4	1.28$^{yza-e'}$	2.40$^{w-zabcde'}$	0.38$^{de'}$	0.58$^{c-e'}$	0.48$^{c-e'}$	0.37$^{de'}$	6.59^{d-k}	6.28^{f-l}	0.42$^{c-e'}$	3.02$^{s-za'}$	9.16^{abc}	4.13^{l-v}	1.93$^{xyza-e'}$	1.31$^{yza-e'}$
5	1.40$^{yza-e'}$	2.10$^{w-zabcde'}$	0.22$^{e'}$	0.68$^{b-e'}$	0.67$^{b-e'}$	0.29$^{de'}$	5.045^{g-s}	3.19^{r-z}	0.61$^{c-e'}$	0.98$^{za-e'}$	4.37^{k-v}	2.06$^{w-za-e'}$	1.57$^{xyza-e'}$	1.28$^{yza-e'}$
CR							2.33							
CV							28							

Means with the same letters with columns and rows are not significantly different at 5% probability level, CV = Coefficient of Variation, CR =Critical range, RW= river water used as control

Conclusion and Recommendation

Salinity is one of the major abiotic factors limiting production and productivity of tomato in Ethiopia. An experiment was conducted to assess germination responses of tomato varieties to different salinity levels under laboratory condition. Salinity induced in the form of NaCl solution had a pronounced effect on tomato varieties resulting in a considerable decrease in germination percentage, germination speed, germination index and seedling vigor index.

With increase in salt concentration, all the germination parameters were signific antly redu-ced and the reductions were higher at $5dSm^{-1}$. In conclusion, variety Melka Shola and ARP tomato d-2 showed better tolerance as compared to others. Therefore, based on laboratory and greenhouse results, these verities could be recommended for salt affected areas for farmers and other tomato producers in salinity affected areas for production and should be considered as potential planting material that is useful to breeders of salt tolerant cultivars. However, since the experiment was conducted under laboratory condition at early stage and greenhouse, the effect of salinity on tomato plants at the field condition should be done in order to draw sound conclusions and recommendation.

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Evaluation of Early Maturing Cassava (*Manihot Esculenta* Crantz) Varieties in Mid and Low Land Areas of Ethiopia

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Abstract

The importance of cassava for food security and income generation in resource poor areas is remarkable. In Ethiopia, five cassava varieties namely Melko 106, Kello, Qulle, Hawassa-4, and Chichu were nationally released. Despite high quality and yield of the varieties, all of them are late maturing that take more than 18 months for harvesting. Thus, there is a need of early maturing varieties with desirable traits. Hence, Hawassa Agricultural Research Center in collaboration with Areka and Arba Minch Agricultural Research Centers conducted trials and came up with cassava clones that comparatively mature earlier than the released varieties and have high yielding potentials. The trial was conducted for two years (2019 and 2020) at Hawassa (Wondo Tika), Dilla, Areka, Gofa and Arba Minch by using six varieties including the standard checks. The materials were arranged in a randomized complete block design with three replications. The result of the experiment indicated that the clone TB/1038 gave the highest marketable and total storage root yields in 10 months of maturity period which was eight months earlier than previously released varieties. Therefore, the clone TB/1038 can be recommended for wider production after verifying its performance at farmers' fields under their management conditions.

Keywords: Cultivar, storage root, marketable, early maturing

Introduction

Cassava (*Manihot esculenta* Crantz) is a major staple tuber crop in many tropical and subtropical developing countries, especially in West Africa. Grown in more than 90 countries, it ranks as the 4th supplier of energy after rice, sugar, and corn/maize (Heuberger, 2005). Cassava is a nutritionally strategic famine crop and could support food security in areas of low rainfall. Mature tubers are able to survive for a long time without water and still retain nutritional value. Storage roots are also valuable source of calories, whereas cassava leaves are valuable source of protein, minerals, and vitamins (Dufour and Wilson, 2002).

The importance of cassava for food security and income generation in resource poor areas is remarkable. For instance, cassava played significant role to poverty reduction in China (Huang *et al.*, 2006). Also, cassava is in Thailand's second most important food crop and third largest agricultural export crop (FAOSTAT,

2009). Uniquely in Thailand, cassava is grown as an industrial rather than a staple crop. The Thai cassava industry is very export oriented, with up to two-third of total production exported in 2008 (TTSA, 2009). It consists of two value chains: the dried cassava and the starch value chain from the sale they can generate a large household income (Tijaja, 2010).

Cassava has been grown and used as food for about a century in different regions of Ethiopia. In the Southern Ethiopia, particularly in Amaro-kello area (Gedeo Zone), Cassava is almost used as a staple food. In Wolaita area (North Omo Zone), cassava roots are widely consumed after washing and boiling or in the form of bread and 'injera' after mixing its flour with that of some cereal crops such as maize, sorghum, or tef (Taye, 1994).

In Ethiopia, nationally four cassava varieties namely Kello, Qulle, Hawassa-4, and Chichu were released in 2006 and 2016 (MoA, 2006; 2016). Recently Jima Agricultural Research Center released one variety for home consumption and one for industrial raw material. Despite high quality and yield of the varieties, all of them are late maturing that take more than 18 months for harvesting. Thus, there is a need of early maturing varieties with desirable traits. Hence, Hawassa Agricultural Research Center in collaboration with Areka and Arba Minch Agricultural Research Centers conducted trials and came up with cassava clones that comparatively mature earlier than the previously released varieties and have high yielding potentials. Therefore, this paper was aimed at presenting the performance of early maturing cassava varieties across different agro-climatic conditions.

Materials and Methods

Study areas

The study was conducted at five locations: Hawassa (Wondo Tika), Dilla, Areka, Gofa and Arba Minch for two consecutive seasons (2019 and 2020). The description of the study areas is presented in Table 1.

Table 1. Description of the study areas

Study area	Altitude (masl)	Latitude	Longitude
Arba Minch	1200	6°6'55" N	37°35'51" E
Areka	1752	7°04'10.98" N	37°41'43" E
Gofa	1252	6°36'43.48" N	37°09'57.91" E
Wondo Tika	1750	7°04'01.77" N	38°29'59.59" E
Dilla	1518	6°24'49.08" N	38°18'00.22" E

Treatments

The experiment was conducted by using six advanced cassava clones with different agronomic and genetic variability. They were MM96/5208, TB 1038, BAJAK-8, AWC-3, Kore original-4 and Local/farmer variety.

Experimental design and procedure

The treatments were arranged in a randomized complete block design (RCBD) with three replications with plant and raw spacing of 1.0m. Gross plot size where the experiment assigned was $24m^2$ while the net plot size was $8m^2$. The experiment was conducted for two consecutive seasons (2019 and 2020) for 10 months each. Data on marketable yield, unmarketable yield, total yield, stand count, number of storage roots (marketable, unmarketable, total), plant height and other traits were recorded. Data on marketable and total storage root yield in tons per hectare was analyzed by using SAS statistical software version 9.2 and mean separation was carried out by using the least significant differences (LSD).

Results and Discussion

The results of combined analysis over years and locations indicated that there were significant differences among clones for marketable and total root yields. Among the tested clones TB/1038 recorded the highest value at all locations and years for both marketable and total storage root yields except at Dilla where MM96/5208 clone surpassed all other clones (Tables 2, 3, and 4). The mean marketable yields of 67.1, 13.3, 37.1 and 36.3 t ha^{-1} were obtained at Arba Minch, Areka, Hawassa and Gofa from the clone TB/1038 whereas the smallest value (7.7 t ha^{-1}) for the same clone was obtained at Dilla. However, at Dilla the clone MM96/5208 did thrive the best marketable yield (26.5 t ha^{-1}).

Similarly, the average total storage yields of 73.4, 16.5, 42.9, and 40.6 t/ha were obtained at Arba Minch, Areka, Gofa and Hawassa locations from the clone TB/1038, respectively. However, at Dilla the total storage root yield (32.5 t ha^{-1}) obtained from the clone MM96/5208 was the highest compared to other clones although it was not statistically different from the values obtained from the clones BAJK-8 and Kore original (Tables 2, 3, and 4).

Table 2. Early maturing cassava varieties storage root yield (t ha^{-1}) in 2019 and 2020 cropping seasons at Arba Minch and Dilla

TRT	Arba Minch						Dilla					
	2019		2020		Mean		2019		2020		Mean	
	MRY	TRY	MRY	TRY	MRY	TRY	MRY	TRY	MRY	TRY	MRY	TRY
MM96/5208	70.6	79.2	51.1	58.8	60.8	69.0	23.0	26.0	30.0	39.0	26.5	32.5
TB/1038	77.3	82.4	57.0	64.4	67.1	73.4	13.0	16.0	7.7	11.0	10.4	13.5
BAJK-8	63.2	63.2	52.7	54.7	57.9	59.0	9.2	13.0	26.0	34.0	17.6	23.5
AWC-3	57.4	59	37.3	47.8	47.3	53.4	17.0	20.0	13.0	18.0	15.0	19.0
Kore Original	63.4	63.4	52.0	52.9	57.7	58.1	15.0	18.0	27.0	33.0	21.0	25.5
Local	50.2	54.1	59.3	41.9	54.8	48.0	12.0	15.0	11.0	20.0	11.5	17.5
LSD	28.2^{NS}	26.3*	23.5^{NS}	16.2*	15.3*	16.3*	7.8*	8.1*	16.0	20.0	9.5	15.0
CV(%)	24.3	21.6	24.3	17.1	22.4	23.2	30.0	25.0	31.0	42.0	37.0	46.0

Legend: NS=non-significant, *=Significant at P<0.01; TRT=treatments; MRY=Marketable root yield; TRY=Total root yield

Table 3. Early maturing cassava varieties storage root yield (t ha^{-1}) in 2019 and 2020 cropping seasons at Areka and Gofa

Treatment	Marketable root yield (2019)			Total root yield (2019)		
	Areka	Gofa	Average	Areka	Gofa	Average
MM96/5208	8.92	21.7	15.3	15.96	28.3	22.2
TB/1038	13.13	36.3	24.7	16.46	42.9	29.7
BAJK-8	6.92	21.3	14.1	11.83	27.1	19.5
AWC-3	3.50	15.8	9.7	7.96	20.0	14.0
Kore Original	6.79	17.5	12.2	12.25	28.3	20.3
Local	6.25	16.7	11.5	10.88	20.8	15.9
LSD	1.93	19.5	8.8	4.26	18.97	8.9
CV (%)	14.0	49.8	50.8	19.0	37.4	37.1

Table 4. Early maturing cassava varieties storage root yield (t ha^{-1}) in 2020 cropping season at Hawassa

Treatment	Marketable root yield (t ha^{-1})	Total root yield (t ha^{-1})
MM96/5208	23.65	26.54
TB/1038	37.14	40.60
BAJK-8	24.79	27.01
AWC-3	31.27	34.38
Kore Original	33.61	38.00
Local	55.79	63.71
LSD^{NS}	35.85	40.78
CV	57.32	58.42

The combined result over the locations and years indicated that the marketable and total yields of the clone TB/1038 was the highest compared to others. Although the total storage root yield of the clone MM96/5208 surpassed TB/1038, the later gave 35.65 and 37.8 t ha^{-1} average marketable and total storage root yields

within 10 months of growth period after planting which was eight months earlier than the previously released varieties (Table 5).

The result obtained from the current experiment is comparable to the values reported by Cock (1976) who identified varieties with 66 t ha^{-1} and 32 t ha^{-1} with 6-12 months after planting. Similarly, Olasanmi *et al.* (2014) found extra early cassava varieties which matured within 12 months after planting for long dry season experienced in most parts of cassava growing areas.

Table 5. Early maturing cassava varieties storage root yield (t ha^{-1}) in 2019 and 2020 cropping seasons across locations

Treatments	2019		2020		Mean of all locations	
	MRY	TRY	MRY	TRY	MRY	TRY
MM96/5208	31.1	37.4	37.5	38.9	34.3	38.15
TB/1038	34.9	39.4	36.4	36.2	35.65	37.8
BAJK-8	25.2	28.8	34.5	38.6	29.85	33.7
AWC-3	23.4	26.7	30.7	29.9	27.05	28.3
Kore Original	25.7	30.5	37.8	41	31.75	35.75
Local	21.3	25.2	36.2	47.7	28.75	36.45

Conclusion and Recommendation

Cassava varieties released so far are late maturing that take more than 18 months for harvesting. The current study found relatively early maturing type and TB/1038 gave the highest marketable and total storage root yields in 10 months of maturity period which was eight months earlier than previously released varieties. Therefore, TB/1038 variety can be recommended for wider production after verification of its performance at farmers' fields under their management conditions.

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Participatory Variety Selection of Improved Orange-Fleshed Sweetpotato (*Ipomoea Batatas*) Varieties at Gedeb District of Gedeo Zone, Southern Ethiopia

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Abstract

Orange-fleshed sweetpotato (OFSP) is a special type of bio-fortified crop that provides an incredible source of beta-carotene for combating the problems related with vitamin-A deficiency. There is an increasing demand by farmers for production and consumption of improved OFSP varieties in the study areas. In order to respond to the demand of farmers, participatory variety selection experiment was conducted in 2019 and 2020 across three sites in Gedeb district of Gedeo zone to select superior OFSP varieties with farmer preferred traits. Six varieties including one old variety as a check were tested in a mother trial using each site as a replication. For a baby trial, one new along with one old variety was given to 30 model farmers in each site. Data were collected on agronomic traits from mother trial and analysis of variance was conducted. The combined analysis showed the presence of significant differences (P≤ 0.05) among tested genotypes for observed traits. The highest root yield was recorded for Dilla (23.11 t ha-1), Alamura (22.57 t ha-1) and Kabode (18.66 t ha-1), whereas NASPOT-13 produced the lowest root yield (12.10 t ha-1) as compared to the others. Three improved varieties, namely Dilla, Alamura and Kabode produced relatively good root yields sequentially with yield advantages of 43.72%, 40.36% and 16.04 % over the check variety (Kulfo). Demonstrations of various sweetpotato based foods were made and 18 farmers (13 male and 5 female) were invited for variety assessment and selection. These farmers set sensorial attributes like flavor, taste, texture, and hardness of the cooked roots for taste-tests. Based on root yield, above ground biomass, resistance to virus disease and taste, they selected three varieties, namely Dilla, Alamura and Kabode as the first, second and third choices, respectively. Moreover, the farmers agreed that variety Dilla should be scaled-up for further dissemination for production and consumption by smallholder farmers of the area.

Keywords: Baby trial, mother trial, orange-fleshed sweetpotato, participatory variety selection

Introduction

Sweetpotato (*Ipomoea batatas* L. (Lam)) plays an immense role in human diet and it is mainly produced by smallholder farmers in Ethiopia. Orange-fleshed sweetpotato (OFSP) is known to provide considerable health benefits for nutrition-endangered low-income populations (Ginting 2013; Grüneberg *et al*., 2015; Mohammad *et al*., 2016; Bowser *et al*., 2017). The problem of vitamin A

deficiency is on the wheel of great public health concern of the poorer section in nutritional victimization across the globe (Ritchie and Roser, 2017; FAO, 2018). For this matter, there is a great possibility of OSFP for being adopted as systematic diet of the consumers through food-based approach for the resource poor densely populated farmers in the era of extensive population growth and nutritional crisis (Rodrigues *et al*., 2016).

The increasing importance of sweetpotato can be attributed to its potential to nutrition and food security in developing countries including Ethiopia (Bililign *et al*., 2021). According to previous reports (Tumwegamire *et al*., 2004; Tairo *et al*., 2004; Van Jaarsveld *et al*., 2005) they indicated that high yielding OFSP with a small plot of 500 square meters can meet the daily requirements of a family of five for resource poor farming communities. However, all the farmers in the study areas grew the dominant old white fleshed variety (Awassa-83) and to a lesser extent an old variety Kulfo. Variety Awassa-83 does not contain beta carotene while Kulfo has low dry matter content that its acceptance by farmers remained very low (Fekadu *et al*., 2015). To solve this problem, a breeding program aimed at improving the root dry matter contents and beta carotene of orange-fleshed sweetpotato varieties to replace existed old OFSP was designed by Hawassa Agricultural Research Center in 2013 (Fekadu, 2019) and has developed and officially released three improved orange-fleshed sweetpotato varieties in 2020. So far, these improved varieties have not been disseminated for farming communities in Gedeb district of Gedeo Zone. For this reason, once the potential varieties that meet the desires of farmers are developed through various methods, they have to be tested in the farmers' fields for their suitability to meet the preferences of farmers and to assess their acceptability by the farmers. Thus, participatory variety selection (PVS) is a more rapid and cost-effective approach in identifying farmers' preferred varieties than the conventional method which assures the access to good quality planting materials of most preferred variety by large number of farmers within a short period of time (Ceccarelli *et al*., 2009; Tefera *et al*. 2013). Furthermore, in the study area farmers demanded for improved OFSP varieties to incorporate in their farming systems. Based on the demand of famers, this study was designed to select superior OFSP varieties with farmer preferred traits in Gedeb districts of Gedeo zone.

Materials and Methods

Description of the study area

The participatory variety selection experiment was conducted during 2019 and 2020 main rainy seasons under rain-fed condition. The experiment was tested at three sites and these sites are characterized by well drained loamy soil type and altitudes ranging from 1990-1996 meters above sea level. According to the Agriculture Office of Gedeb district, the major crops grown in the areas are maize,

coffee, enset, khat, sweetpotato and other root crops that are locally available. However, nearly all famers in these areas grow old white- and orange-fleshed sweetpotatoes.

Experimental materials and design

Six orange-fleshed sweetpotato varieties and one local variety were used in this study; of which three were recently released varieties with high dry matter, beta-carotene and high root yield (Table 1). The experiment was employed using the mother and baby design approach (Suwarno *et al*., 2002) using farmers in each site as a replication.

Experimental procedure

The three sites (villages) were selected to conduct mother trial and a total of 30 farmers in each site were selected based on their consent and ability to provide land for the baby trial in collaboration with the development agents of the Kebeles. In the mother trial, all the six varieties were planted on a single farmer's field as a single replication across the three sites. A plot size was $10.8m^2$ (contains six rows) with 3.6m wide and 3m long for each genotype was used in the mother trial. Planting materials of one new variety and one old variety as check were given to 30 farmers around each site as a baby trial. All plots received the recommended cultural practices uniformly and no fertilizer was applied (Hawassa ARC, 2015). Replanting was done to substitute the dead vine after one week of planting. Earthening up was done after four weeks of planting and all plots were kept weed free manually by farmers.

Data collection

Data were collected from mother trial on root yield, above ground biomass and sweetpotato virus diseases. Besides, famers were invited to participate for variety evaluation at harvesting and after harvesting. At harvesting, variety evaluation was made based on agronomic performances of each variety while after harvest taste-tests for organoleptic properties were conducted in collaboration with the food science research team. The agronomic performance of the crop includes diseases resistance/tolerance, earliness to maturity, vine length and above ground biomass. Moreover, the taste of all varieties was evaluated by preparing roasted and boiled roots, which are some of common ways of consumption of sweetpotato by farmers in the study district. Consequently, the tested varieties were evaluated for root yield and its component traits using analysis of variances across sites over seasons.

Data analysis

Collected data on root yield and its components were subjected to analysis of variance using SAS package (SAS 9.0). Data were checked for homogeneity of error variance for two growing years using F-ma and it was non-significant. Then, data was combined over years. Least significance differences (LSD) was

employed to compare treatments following the procedure developed by Gomez and Gomez (1984). Data for taste-tests from farmers' perception was analyzed using SPSS software.

Table 1. List of the orange-fleshed sweetpotato varieties used for the study

No	Name of variety	Root flesh color	Dry matter content (%)
1	Alamura	Deep orange	31.8
2	Dilla	Deep orange	32.4
3	Vita	Intermediate orange	29.6
4	Kabode	Intermediate orange	30.3
5	NASPOT-13	Deep orange	26.8
6	Kulfo	Pale orange	22.5

Results and Discussion

Performance of genotypes for root yield and yield-related traits across sites

The combined analysis showed the presence of significant differences ($P \leq 0.05$) among tested genotypes for observed traits (Table 2). The three newly released varieties, namely Alamura, Dilla and Kabode had higher root yield over the check variety Kulfo (Table 2). The root yields of six tested varieties across three sites ranged from 12.10 t ha^{-1} to 23.11 t ha^{-1} with an overall mean of 18.02 t ha^{-1}. In addition, significantly highest above ground biomass was obtained from varieties Dilla, Alamura and Kabode with yields of 32.62, 29.90 and 25.88 t ha^{-1} as compared to the check variety Kulfo (17.15 t ha^{-1}), in that order across sites and over seasons. This suggests that these three varieties could be the potential varieties to be used as dual purpose (Low *et al*., 2009). All the genotypes showed resistance/tolerance to sweetpotato virus diseases with low score of < 2.0 (Shiferaw *et al*., 2014).

There was no significant difference for the interaction between genotypes and sites over seasons for all traits except for reaction to sweetpotato virus diseases (Table 2). In general, the three newly released improved varieties (Dilla, Alamura and Kabode) performed better than the check variety. Moreover, these three varieties were preferred by farmers as their first, second and third choices, respectively (Table 3). Highly significant differences were observed among the three sites ($p<0.01$) which shows the existence of varying effects among the sites. The genotype by site interaction was not significant for all traits except for virus diseases, which implies that all varieties consistently performed across the three sites (Table 2).

Table 2. Combined mean performance of orange fleshed sweetpotato varieties for yield and its components across three sites over two seasons (2019 and 2020)

Variety	Characters				
	Root yield (t ha^{-1})	Above ground biomass (t ha^{-1})	Harvest Index (%)	SPVD score (1-5)	Yield advantage over check (%)
Alamura	22.57	29.90	0.47	1.33	40.36
Dilla	23.11	32.62	0.56	1.67	43.72
Vita	15.18	23.38	0.36	1.33	-5.60
Kabode	18.66	26.88	0.41	1.00	16.04
NASPOT-13	12.10	20.68	0.35	1.33	-24.75
Kulfo (Check)	16.08	17.15	0.31	1.67	-
Mean	18.02	25.83	0.43	1.38	
LSD (0.05)	2.20	3.03	0.07	0.30	
CV (%)	17.37	19.23	13.96	20.80	
Mean squares					
Genotype (G)	**	**	**	**	
Site (S)	**	**	NS	**	
GXS	NS	NS	NS	*	

Where,*, ** significant at 5%, 1% and NS= non-significant difference

Farmers' preferences of orange fleshed sweetpotato varieties

About 18 farmers (13 male and 5 female) were involved in variety assessment and selection (Table 3). At harvesting, discussion was made with invited farmers on plant characters used by local farmers for sweetpotato variety selection and then, the farmers did provide their opinions on the preferred attributes and identified the traits such as vine length and thickness, above ground biomass (foliage vigor), diseases resistance/tolerance, earliness to maturity and root yield. They mentioned the above listed attributes as farmers' preferred traits for sweet potato selection at Gedeb district of Gedeo zone.

With respect to organoleptic tests of the sweetpotato genotypes, boiled roots were prepared from each variety and the attributes considered most important by farmers were flavor, taste, texture, powder and color (boiled roots). These characteristics were ranked by panelists using ranking scale (Table 3). The term flavor appeared to be subjective. The finding is consistent with previous works reported by Shikuku *et al*. (2019) and Kikulwe *et al*. (2011) who found that taste was an important consumption attribute with a strong influence on adoption of improved sweetpotato varieties. Root texture in terms of fiber content was another important trait used by farmers in selecting sweetpotato varieties. A variety with roots with no or low fiber content was mentioned by famers as preferred variety. Since firmness is an indication of high dry matter content, panelists tasted boiled roots of each tested variety for hardiness/firmness and they selected varieties with very firm roots and noticed as this trait was more preferable by local farmers in selecting sweetpotato varieties. Farmers identified their best varieties based on flesh color of boiled roots. The deep orange-flesh-colored boiled roots were

preferred by most of the farmers. Considering the overall ranking of six parameters, varieties Dilla, Alamura, and Kabode were selected as the first, second and third choices in a given order by farmers based on taste-tests (Tables 3 and 4).

Table 3. Farmers' preference scores and ranking on sensorial attributes of the boiled roots of the six OFSP sweetpotato varieties evaluated in 2020

Genotypes	Attribute (N=18)						
	Flavor	Taste	Texture	Powder (high dry matter)	Color (boiled roots)	Total scores	Rank
Alamura	4.0	4.3	4.4	5.0	4.6	22.2	2
Dilla	5.0	4.6	4.6	5.0	5.0	24.2	1
Vita	3.3	3.2	2.6	3.6	3.6	16.3	5
Kabode	3.6	4.0	4.0	4.3	4.0	19.9	3
Naspot-13	3.3	3.0	3.2	4.0	3.3	16.8	4
Kulfo	2.3	2.0	2.3	2.0	2.3	10.9	6

Where, N= Number of farmers who participated in the assessment; Farmer's preference ranking using subjective scale (1-5); 1=bad and 5=excellent

Table 4. Pair-wise ranking of six orange-fleshed sweetpotato varieties by farmers for different organoleptic properties in Gedeb district in 2020

Genotypes	Alamura	Dilla	Vita	Kabode	NASPOT-13	Kulfo	Points	Rank
Alamura		Dilla	Alamura	Alamura	Alamura	Alamura	4	2
Dilla			Dilla	Dilla	Dilla	Dilla	5	1
Vita				Kabode	NASPOT-13	Vita	1	5
Kabode					Kabode	Kabode	3	3
NASPOT-13						NASPOT-13	2	4
Kulfo							0	6

Conclusion and Recommendation

The study showed that the most desirable attributes preferred by the participant farmers were root yield, above ground biomass and resistance to virus diseases. Organoleptic attributes such as flavor, taste, texture, and hardiness of the cooked roots of the tested varieties were also considered as selection criteria of farmers to select their best varieties. Based on both agronomic and farmers' perception tests, three varieties namely, Dilla, Alamura and Kabode were selected and ranked as the first, second, and third choices. The results of this study imply that variety improvement need to be given with due attention and a comprehensive test of

agronomic traits and the involvement of farmers for the selection and dissemination of improved technologies are very crucial.

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Evaluation of Improved White and Orange-Fleshed Sweetpotato (*Ipomoea Batatas L.*) Varieties in Gamo Zone, Southern Ethiopia

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Abstract

Sweetpotato plays a significant role as a food security crop in southern Ethiopia especially in Gamo and Wolayta zones. However, the productivity of the crop remained low (19.57 t ha-1) for a long time and the production of the crop has been declining various factors such as recurrent drought, lack of planting materials, shortage of farmer preferred varieties, poor extension system, market and postharvest related problems. An experiment was conducted with two sets of twelve sweetpotato varieties (white- and orange-fleshed) were tested in Gamo zone during 2019 and 2020 to evaluate their root yield potential and demonstrate best performing varieties. The experiment was laid out in a randomized complete block design with four replications. For white-fleshed set the combined analysis of variance showed highly significant differences among genotypes on growth, root yield and yield components. The highest number of marketable roots per plot was recorded on Hawassa-09 (70.25) whereas the least number of roots per plot was obtained on ADU. The highest root yield was obtained from Hawassa-09 (62.16 t ha-1) followed by Tola ((53.99 t ha-1) and Berkume (52.85 t ha-1). The least root yield was recorded from ADU (5.21 t ha-1). For orange-fleshed set the combined analysis of variance showed highly significant differences among genotypes on growth, root yield and yield components. The maximum number of marketable roots per plot was recorded on RW11-4743 (59.13) followed by Kyoyabwerer (57.00) and Kulfo (53.63); while the minimum number of roots per plot was recorded on Mayai. The highest root yields were obtained from Kyoyabwerer (53.23 t ha-1) and RW11-4743 (52.64 t ha-1) followed by Kulfo (48.42 t ha-1). Conversely, the least root yield was recorded from Carrot-C (37.84 t ha-1). Based on the results of this study, among white-fleshed sweetpotato varieties Hawassa-09 was recommended for pre-extension demonstration in different areas of the Gamo zone with similar agro-ecological conditions. Among orange-fleshed sweetpotato varieties Kyoyabwerer, RW11-4743 and Kulfo gave the highest yields; however, the first two varieties have not been registered in the country. Therefore, Kulfo can be recommended for pre-extension demonstration in the Gamo zone. We suggest further evaluation of Kyoyabwerer and RW11-4743 by including other genotypes at different locations for registration.

Keywords: Sweetpotato, white-fleshed, orange-fleshed, root number, root yield

Introduction

Sweetpotato (*Ipomoea batatas*L.) is one of the globally important crops ranking seventh and fifth in production in the world and in Africa, respectively (Low *et al*., 2015). It is mainly grown for human food and animal feed. It produces storage roots which are rich in carbohydrate, vitamins such as A, B complex, C, E and minerals such as potassium, calcium and iron. Central America is considered as the primary center of diversity of sweetpotato based on molecular markers study and most likely the center of origin since the highest diversity was found in this region (Zhang *et al*. 2000 and Gichuki *et al.* 2003). Globally China is the leading sweetpotato producing country with production of 70,963,630 metric tons (MT), followed by Nigeria (3,478,270 MT), Tanzania (3,345,170 MT) and Ethiopia (2,701,599 MT). China contributes annually more than half of the world's total sweetpotato production (Fekadu, 2019).

In Ethiopia, sweetpotato is widely grown in south, southwestern and eastern parts by small-scale farmers with limited land, labor and capital. Sweetpotato occupied about 62,116.56 ha of land with a total annual production of 1.6 million tons during the main growing season (CSA, 2021). However, the productivity of the crop remained low (25.74 t ha^{-1}) for a long time and the production of the crop is also declining due to many factors including recurrent drought, lack of planting materials, shortage of farmer preferred varieties, poor extension system that does not encourage production of root crops, market and postharvest related problems (Fekadu *et al*., 2015). Sweetpotato viruses, weevil and butterfly are the major sweetpotato production constraints in Ethiopia. Furthermore, low root dry matter content (RDMC) in the orange-fleshed sweetpotato (OFSP) varieties and lack of knowledge on postharvest storage and processing are some of the prevailing constraints (Tesfaye, 2006; Assefa *et al*., 2007; Fekadu *et al*., 2015).

Sweetpotato plays a significant role as a food security crop in southern Ethiopia especially in Gamo and Wolayta zones. However, the farmers in the study areas still use old released white-fleshed sweetpotato varieties that are susceptible to diseases and have no beta carotene. Nowadays, many improved sweetpotato varieties have been released by research centers and universities for production. The improved sweetpotato varieties together with improved crop management practices proved to give three-to-four-fold yield advantage and nutrient composition as compared to old released white-fleshed sweetpotato varieties with traditional production and management practices. Therefore, this study was conducted to evaluate and select the best high yielding sweetpotato varieties and to demonstrate the well adaptable sweetpotato varieties in the Gamo zone of Ethiopia.

Materials and Methods

Description of the study area

The experiment was conducted at Arba Minch Zuria district of Gamo zone, SNNPRS during 2019 and 2020 growing seasons. The site is located at 37°35'51" E longitude, 6°6'55" N latitude and altitude of 1220 m.a.s.l. The mean annual rainfall is 1050mm and the soil textural class of the experimental site is clay loam.

Experimental materials and design

Two sets (white- and orange-fleshed) of twelve sweetpotato varieties were used. The list of varieties is presented in Table 1. The experiment was laid out in RCBD with four replications. Each plot area was 3m x 2.4m = 7.2 m^2 wide consisting of four rows, which accommodated 10 plants per row and thus 40 plants per plot. The spacing between plots and blocks were 1m and 1.5 m, respectively. Healthy looking and young sweetpotato vines were planted at a spacing of 60cm and 30cm between rows and plants, in that orded. Cultural practices such as weeding, cultivation and ridging were practiced as per the recommendation. To reduce border effect, data were recorded from the two central rows of each plot.

Table 1. Sweetpotato varieties used for the study

No.	Varieties	Set (flesh color)	Source[1]	Year of release
1	ADU (Cuba-2)	White	HU	2007
2	Awassa–83	White	AwARC/SARI	1997/98
3	Berkume (TIS 8250-2)	White	HU	2007
4	Beletech (192026 II)	White	AwARC/ SARI	2004
5	Hawassa –09 (TIS-8250-1)	White	AwARC/ SARI	2017
6	Tola (TIS 844-40)	White	BARC	2012
7	RW11-4743	Orange	AwARC/ SARI	Introduced and not released
8	Kyoyabwerer	Orange	AwARC/ SARI	Introduced and not released
9	Carrot-C	Orange	AwARC/ SARI	Introduced and not released
10	Mayai (TIS 70357-5)	Orange	WARC/EIAR	2010
11	Kulfo (Lo-323)	Orange	AwARC/ SARI	2005
12	Vita	Orange		Introduced and not released

[1]HU = Haramaya University, AwARC/SARI=Awassa Agricultural Research Center/ Southern Agricultural Research Institute, WARC/EIAR=Werer Agricultural Research Center/ Ethiopian Institute of Agricultural Research and BARC= Bako Agricultural Research Center

Data collected

The following data were collected from the two central rows and used for analysis. Stand count at harvest, yield of top green parts per plot (fresh weight in kg), vein and internode length at maturity (cm), number of marketable roots per plot, weight of marketable roots per plot (kg), average marketable root length (cm), average marketable root girth (cm), number of unmarketable roots per plot, weight of

unmarketable roots per plot (kg), number of marketable roots per hectare, weight of marketable roots per hectare (t ha^{-1}), number of unmarketable roots per hectare, weight of unmarketable roots per hectare (t ha^{-1}), total number of roots per hectare, total weight of roots per hectare (t ha^{-1})were collected and analyzed.

Statistical analysis

Analysis of variance for each year was done for tuber yield and other traits using the SAS software version 9.0 (SAS systems, 2002). For factors showing significant effects, mean comparisons were made using the least significant difference (LSD) at 5% level of significance.

Results and Discussion

White-fleshed sweetpotato varieties (Set 1)

The results of combined ANOVA showed that there were highly significant variations ($P < 0.01$) among varieties for yield and yield related parameters except stand count at harvest (Table 2).

Maximum number of roots per plot was obtained on Hawassa-09 (70.25). In addition, the highest root yield was obtained from Hawassa-09 (62.16 t ha^{-1}) followed by Tola (53.99 t ha^{-1}) and Berkume (52.85 t ha^{-1}). Conversely, minimum number of roots per plot (11.00) and the least root yield (5.21 t ha^{-1}) were recorded from variety ADU (Table 3). The result of this study was in line with Mohammed (2018) and Tesfaye *et al*. (2011) who reported the presence of significant variations among sweetpotato varieties for yield and yield related parameters. Variety ADU gave the highest yield of top green parts per plot (21.25 kg), and the least number (11) and weight (1.18 kg) of marketable roots per plot (Table 3). This indicates that variety ADU can be produced for animal feed rather than human food.

Orange-fleshed sweetpotato varieties (Set 2)

The results of combined ANOVA showed that there were significant variations ($p < 0.05$) among varieties for stand count at harvest and yield of top green parts per plot (fresh weight in kg) while highly significant variations ($p<0.01$) among varieties for yield and yield related parameters (Table 4). The highest number of roots per plot was obtained from variety RW11-4743 (59.13) followed by variety Kyoyabwerer (57.00) whereas the lowest number of roots per plot was recorded from variety Mayai (45.25). The highest root yield was obtained from varieties Kyoyabwerer (53.23 t ha^{-1}) and RW11-4743(52.64 t ha^{-1}) followed by Kulfo (48.42 t ha^{-1}) whereas the least root yield was recorded from variety Carrot-C (37.84 t ha^{-1}) (Table 5). The result of the current study was similar to the findings by Fekadu *et al*. (2017) who reported the presence of high significant variations

among sweetpotato varieties for root dry matter content, β-carotene content and fresh root yield.

Table 2. Combined ANOVA for mean squares of growth, yield and yield related parameters for six white-fleshed sweetpotato genotypes grown at Arba Minch Zuria district in Southern Ethiopia during 2019 and 2020 cropping seasons

Source of variation	DF	SCAH	YTGPPP (kg)	VINLAM (cm)	NMRPP	WMRPP	AMRL (cm)	AMRG (cm)	NUMRPP
Yr	1	12.00^{ns}	78.21**	3996.75**	7178.52**	606.34**	22.55*	35.11*	2268.75**
Yr(Rep)	6	4.21^{ns}	11.76^{ns}	111.94^{ns}	27.74^{ns}	2.97^{ns}	3.05^{ns}	9.67^{ns}	86.88*
Trt	5	8.63^{ns}	182.39**	4051.30**	3482.92**	357.27**	53.45**	283.34**	1035.13**
Yr*Trt	5	6.65^{ns}	22.06*	343.78^{ns}	368.02**	27.17**	3.08^{ns}	18.02*	1347.85**
Error	30	4.61	5.97	140.12	34.96	4.83	4.44	5.93	35.66
Mean		14.71	12.43	155.43	51.10	13.05	19.57	23.63	38.17
CV (%)		14.60	19.66	7.62	11.57	16.84	10.77	10.30	15.65

Table 2. Continued.

Source of variation	DF	WUMRPP (kg)	NMRPH	WMRPH (t ha^{-1})	NUM RPH	WUMRPH (t ha^{-1})	TNRPH	TWRPH (t ha^{-1})
Yr	1	55.86**	55389820867**	4678.58**	17505788310**	430.92**	148766081536**	7949.28**
Yr(Rep)	6	0.15*	214066786.61^{ns}	22.95^{ns}	670331834*	1.15*	1435507203.20^{ns}	19.71^{ns}
Trt	5	5.26**	26874389764**	2756.56**	7987139983**	40.61**	63566229016**	3354.75**
Yr*Trt	5	3.369**	2839667020.3**	209.63**	10400077381**	25.98**	14416151448**	313.83**
Error	30	0.06	269750953.38	37.27	275141468.42	0.43	694894419.50	39.64
Mean		2.19	141956	36.25	106018.5	6.07	245370.4	42.33
CV (%)		10.83	11.57	16.84	15.65	10.81	10.74	14.88

DF=Degree of freedom, SCAH=Stand count at harvest, YTGPPP=Yield of top green parts per plot (fresh weight in kg), VINLAM=Vein and internode length at maturity (cm), NMRPP=Number of marketable rootsper plot, WMRPP=Weight of marketable rootsper plot (kg), AMRL=Average marketable Root length (cm), AMRG=Average marketable Root girth (cm), NUMRPP=Number of unmarketable rootsper plot, WUMRPP=Weight of unmarketable rootsper plot (kg), NMRPH=Number of marketable rootsper hectare, WMRPH=Weight of marketable roots (t ha^{-1}), NUMRPH=Number of unmarketable roots per hectare, WUMRPH=Weight of unmarketable roots (t ha^{-1}), TNRPH=Total number ofroots per hectare, TWR=Total weight of roots (t ha^{-1}).

Table 3. Mean values of growth, yield and yield related traits of six white-fleshed sweetpotato genotypes grown at Arba Minch Zuria district in Southern Ethiopia during 2019 and 2020 cropping seasons

Genotypes	SCAH	YTGPPP (kg)	VINLAM (cm)	NMRPP	WMRPP (kg)	AMRL (cm)	AMRG (cm)	NUMRPP
ADU	16.50a	21.25a	162.45b	11.00d	1.18e	17.76c	12.16c	25.38d
Awassa -83	15.38ab	9.71cd	124.38d	64.13b	14.48c	19.53bc	23.58b	35.38c
Berkume	13.88b	10.94c	164.43b	51.00c	16.63bc	22.43a	28.58a	28.50d
Beletech	14.00b	14.06b	190.08a	55.25c	9.62d	15.50d	23.75b	45.88b
Hawassa -09	14.50 ab	10.81c	150.33c	70.25a	19.34a	21.73a	26.68a	56.13a
Tola	14.00b	7.81d	140.90c	55.00c	17.06b	20.45ab	27.05a	37.75c
Mean	14.71	12.43	155.43	51.10	13.05	19.57	23.63	38.17
LSD	2.19	2.495	12.09	6.04	2.24	2.15	2.49	6.10

Table 3. Continued.

Genotypes	WUMRP (kg)	NMR (/ha)	WMR (t ha^{-1})	NUMR (/ha)	WUMR (t ha^{-1})	TNR (/ha)	TWR (t ha^{-1})
ADU	0.70e	30556d	3.28e	70486d	1.93e	85417d	5.21e
Awassa -83	1.96d	178125b	40.21c	98264c	5.44d	276389b	45.64c
Berkume	2.40c	141667c	46.18bc	79167d	6.67c	220833c	52.85b
Beletech	2.66b	153472c	26.72d	127431b	7.38b	280903b	34.10d
Hawassa -09	3.03a	195139a	53.75a	155903a	8.41a	351042a	62.16a
Tola	2.38c	152778c	47.40b	104861c	6.60c	257639b	53.99b
Mean	2.19	141956	36.25	106018.5	6.07	245370.4	42.33
LSD	0.24	16771	6.23	16938	0.67	26918	6.43

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

SCAH=Stand count at harvest, YTGPPP=Yield of top green parts per plot (fresh weight in kg), VINLAM=Vein and internode length at maturity (cm), NMRPP=Number of marketable rootsper plot, WMRPP=Weight of marketable rootsper plot (kg), AMRL=Average marketable root length (cm), AMRG=Average marketable root girth (cm), NUMRPP=Number of unmarketable rootsper plot, WUMRPP=Weight of unmarketable roots per plot (kg), NMR=Number of marketable roots per hectare, WMR=Weight of marketable roots (t ha^{-1}), NUMR=Number of unmarketable roots per hectare, WUMR=Weight of unmarketable roots (t ha^{-1}), TNR=Total number ofroots per hectare, TWR=Total weight of roots (t ha^{-1}).

Table 4. Combined ANOVA for mean squares of growth, yield and yield related parameters for six oranges fleshed sweetpotato genotypes grown at Arba Minch Zuria district in Southern Ethiopia during 2019 and 2020 cropping seasons.

Source of variation	DF	SCAH	YTGPPP (kg)	VINLAM (cm)	NMRPP	WMRPP (kg)	AMRL (cm)	AMRG (cm)	NUMRPP
Yr	1	54.19**	712.48**	83842.44**	13233.52**	1076.74**	124.16**	3.19^{ns}	5985.33**
Yr(Rep)	6	2.77^{ns}	3.67^{ns}	489.96^{ns}	21.35^{ns}	7.63^{ns}	3.62*	12.43^{ns}	13.82^{ns}
Trt	5	8.37*	20.78*	7799.28**	209.27**	47.33**	43.4**	100.80**	1653.98**
Yr*Trt	5	10.04*	26.81**	1541.30^{ns}	596.67**	18.83**	4.05*	34.77**	419.83**
Error	30	2.77	6.19	688.40	19.20	3.52	1.19	8.90	17.55
Mean		15.15	15.80	179.24	52.73	13.97	21.88	23.19	44.54
CV (%)		10.99	15.75	14.64	8.31	13.43	4.99	12.87	9.41

Table 4. Continued.

Source of variation	DF	WUMRPP (kg)	NMRPH	WMRPH (t ha-1)	NUM RPH	WUMRPH (t ha-1)	TNRPH	TWRPH (t ha-1)
Yr	1	59.07**	102623620829.00**	8321.07**	46183131984**	455.84**	28563673671**	12735.85**
Yr(Rep)	6	0.46 ns	156839378.56ns	58.60ns	106631470 ns	3.62 ns	229498884.60 ns	67.28 ns
Trt	5	3.85**	1620917136.30**	364.49**	12762217172**	29.69**	20031410852**	371.03**
Yr*Trt	5	1.79**	4627860709.00**	144.95**	3239454881**	13.78**	11647923032**	189.21**
Error	30	0.23	145393936.99	27.35	135438091.68	1.77	412112075.60	30.18
Mean		2.68	146585.6	38.79	123726.9	7.45	270196.8	46.18
CV (%)		17.86	8.23	13.48	9.41	17.86	7.51	11.90

DF=Degree of freedom, SCAH=Stand count at harvest, YTGPPP=Yield of top green parts per plot (fresh weight in kg), VINLAM=Vein and internode length at maturity (cm), NMRPP=Number of marketable roots per

plot, WMRPP=Weight of marketable roots per plot (kg), AMRL=Average marketable root length (cm), AMRG=Average marketable root girth (cm), NUMRPP=Number of unmarketable rootsper plot, WUMRPP=Weight of unmarketable roots per plot (kg), NMRPH=Number of marketable roots (t ha^{-1}), WMRPH=Weight of marketable roots (t ha^{-1}), NUMRPH=Number of unmarketable roots per hectare, WUMRPH=Weight of unmarketable roots (t ha^{-1}), TNRPH=Total number of roots, TWR=Total weight of roots (t ha^{-1}).

Table 5. Mean values of growth, yield and yield related traits of six orange fleshed sweetpotato genotypes grown at Arba Minch Zuria district in Southern Ethiopia during 2019 and 2020 cropping seasons

Genotypes	SCAH	YTGPPP (kg)	VINLAM (cm)	NMRPP	WMRPP (kg)	AMRL (cm)	AMRG (cm)	NUMRPP
RW11-4743	17.13a	17.65a	170.83b	59.13a	15.28ab	21.35c	21.13b	68.88a
Kyoyabwerer	14.38b	13.69d	241.20a	57.00ab	16.66a	19.23d	28.80a	36.88c
Carrot-C	14.63b	14.57cd	153.50b	52.50cd	10.72c	20.55c	20.08b	46.25b
Mayai	15.25b	17.19ab	173.10b	45.25e	11.21c	24.10b	20.38b	40.38c
Kulfo	14.50b	16.76abc	172.21b	53.63bc	14.50b	20.75c	26.23a	48.88b
Vita	15.00b	14.94bcd	164.58b	48.88de	15.44ab	25.33a	28.80a	26.00d
Mean	15.15	15.80	179.24	52.73	13.97	21.88	23.19	44.54
LSD	1.70	2.54	26.79	4.48	1.92	1.12	3.05	4.28

Table 5. Continued.

Genotypes	WUMRP (kg)	NMR (/ha)	WMR (t ha^{-1})	NUMR /ha	WUMR (t ha^{-1})	TNR (/ha)	TWR (t ha^{-1})
RW11-4743	3.68a	164236a	42.43ab	191319a	10.21a	355556a	52.64a
Kyoyabwerer	2.50b	158333ab	46.29a	102431c	6.94b	260764c	53.23a
Carrot-C	2.91b	145833cd	29.77c	128472b	8.07b	274306bc	37.84c
Mayai	2.53b	125694e	31.15c	112153c	7.02b	237847d	38.09c
Kulfo	2.93b	149653bc	40.29b	135764b	8.13b	284722b	48.42ab
Vita	1.56c	135764de	42.82ab	72222d	4.34c	207986e	46.85b
Mean	2.68	146585.6	38.79	123726.9	7.45	270196.8	46.18
LSD	0.49	12313	5.34	11884	1.36	20730	5.61

Means in the same column followed by the same letters are not significantly different at 5% level of significance. SCAH=Stand count at harvest, YTGPPP=Yield of top green parts per plot (fresh weight in kg), VINLAM=Vein and internode length at maturity (cm), NMRPP=Number of marketable roots per plot, WMRPP=Weight of marketable roots per plot (kg), AMR=Average marketable root length (cm), AMRG=Average marketable root girth (cm), NUMRPP=Number of unmarketable roots per plot, WUMRPP=Weight of unmarketable roots per plot (kg), NMR=Number of marketable roots per hectare, WMR=Weight of marketable roots (t ha^{-1}), NUMR=Number of unmarketable roots per hectare, WUMR=Weight of unmarketable roots (t ha^{-1}), TNR=Total number of roots per hectare, TWR=Total weight of roots (t ha^{-1}).

Conclusion and Recommendation

Among the tested white-fleshed sweetpotato varieties Hawassa-09, Tolla, and Berkume gave better yields than locally well-known and largely cultivated variety (Awassa-83). Therefore, these varieties can be recommended for participatory evaluation and demonstration in the Gamo Zone. From the evaluated orange-fleshed genotypes, Kyoyabwerer, RW11-4743, Kulfo and Vita provided better yields. Variety Kulfo can be recommended for participatory evaluation and demonstration in the Gamo zone. However, the other three varieties have not been registered in the country. We therefore suggest further evaluation of Kyoyabwerer, RW11-4743 and Vita genotypes in different locations for registration.

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Participatory Variety Selection of Orange Fleshed Sweetpotato (*Ipomoea Batatas* L.) Varieties at Wondo Genet and Koka Areas

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Abstract

Orange fleshed sweetpotato (OFSP) is considered as an important staple food crop showing a huge potential as a critical component of strategic interventions aimed at combating vitamin A deficiency and food insecurity. An experiment was conducted during the 2019 and 2020 at Wondo Genet and Koka to evaluate and select the best adaptable and high yielding variety. Five OFSP varieties were tested in a randomized complete block design with three replications using the mother-baby trial approach. Data were collected from the mother trial and analyzed. The combined analysis of variance showed the presence of significant differences among the tested varieties for plant height, root diameter, root yield, and root dry matter content. The highest root yield was obtained from Kulfo (33.9 t ha-1), which was statistically similar with Kabode (31.64 t ha-1), followed by Alamura (23.0 t ha-1). On the contrary, variety Vitae gave the lowest root yield of 10.8 t ha-1. The participated farmers ranked the traits used for selection and evaluated the varieties using their selection criteria such as root yield, uniformity, taste, flavor and texture. Although the Kulfo variety gave the highest yield, farmers rejected it due to its taste after boiling. Consequently, they selected Kabode, Alamura, and Dilla varieties as their first, second, and third choices. Therefore, scaling up of these selected varieties could be done in the study areas and other locations with similar agro-ecologies to enable producers to access the varieties for production and use them in overcoming the nutritional deficiency and food insecurity.

Keywords: Farmer preferences, mother trial, baby trial, root yield, selection

Introduction

Sweetpotato (*Ipomoea batatas* L.) is a dicotyledonous plant belonging to the family Convolvulaceae (Torto *et al*., 2010). Globally, sweetpotato is the seventh most important food crop after wheat, rice, maize, potato, barley, and cassava (FAO, 2020). More than 140 million tons was produced globally. The world average storage root yield was estimated to be 14.8 t ha^{-1} (FAO, 2020). Asia is the world's largest producing continent (129 million tons per annum) and China is the leading country (121 million tons per annum) which is 86% of world production of sweetpotato (FAOSTAT, 2020). In Asia, it is primarily used for human consumption and animal feed. In Africa, sweetpotato is the second most

important root crop after cassava and its production is concentrated in the East and the Great Lakes Region of African countries (Ndole *et al.*, 2001; Dantata *et al.*, 2010). Sweetpotato is the third root and tuber crop after Irish potato and cassava in per capita consumption in tropical Africa (Laban *et al*., 2015). Sweetpotato yields are high per unit area (Nwankwo *et al*., 2012) and per unit of time (Nedunchezhiyan *et al*., 2012). Due to its higher productivity and drought tolerance, the crop can play a vital role in achieving food self-sufficiency in the region (Amare *et al*., 2014). This makes it an ideal sustainable crop for production in developing countries, where population growth has decreased the size of arable land and increased the use of marginal land for food production (Woolfe, 1992). Sweetpotato provides household food security as the crop can be harvested within 3-6 months (Anyaegbunam *et al*., 2008). Furthermore, it can remain in the ground for "piece meal" harvesting, a common sweetpotato "storage" practice in the tropics (Laban *et al*., 2015).

In Ethiopia, sweetpotato ranks first in productivity (33.5 t ha^{-1}) and third in area coverage next to Irish potato and taro among root and tuber crops cultivated (CSA, 2021). Sweetpotato is one of the most important sources of carbohydrates for smallholder farmers in the country (Amare *et al*., 2014). Its root is used as food usually consumed after boiling. It is one of the cheapest sources of vitamin A and its leaf and vine are used as feed for livestock. Sweetpotato is tolerant to adverse conditions like drought, hardy, and can grow in marginal areas, thereby contributing to improved food security. It is considered as an attractive food crop among growers because it requires less care and input (CIP, 1995). Despite the growing of different sweetpotato varieties in different potential areas of Ethiopia, the OFSP has not been widely grown and less popular in the study areas. Orange-fleshed sweetpotato is one of the bio-fortified crops that contain high levels of beta-carotene to prevent vitamin A deficiency (Low *et al*., 2017). In addition, it is one of the starchy staple crops that contain ascorbic acid, the amino acid lysine which is deficient in cereal-based diets such as rice, and appreciable amount of β-carotene. Moreover, it contains soluble fiber which helps in reducing cholesterol concentration and anti-oxidant nutrients which can inhibit the development of coronary heart disease (Kays and Kays, 1998). As a result, it is crucial to evaluate improved OFSP varieties by involving farmers in their fields using their selection criteria. When farmers select a variety by their selection criteria the newly generated technology will be familiar to their farming activity and increases technology utilization. Hence, participatory variety selection (PVS) was necessary to identify farmers' selection criteria and acceptable varieties to adapt and assimilate into the production system in the study areas.

Participatory variety selection can effectively be used to identify farmer-acceptable varieties and thereby overcome the constraints that cause farmers to grow old or obsolete varieties (Witcombe *et al.*, 1996). Moreover, participatory

research complements the formal breeding system (Belay *et al*., 2006), increases the job efficiency of the researchers (Bellon, 2001) and improves farmers' knowledge that enables to be retained effectively from year to year (Grisley and Shamambo, 1993). Furthermore, PVS is a more rapid and cost-effective way of identifying farmer-preferred varieties if a suitable choice of varieties exists (Witcombe *et al*., 1996). In many parts of Ethiopia particularly at Wondo Genet in Sidama region, and Koka in Oromia region, OFSP varieties have not been reached farmers; however, farmers have been demanding better yielding and disease resistant varieties of sweetpotato. Therefore, PVS was proposed to evaluate and select the best adaptable and high yielder varieties of OFSP through farmer's selection preferences to diversify and popularize them in the study areas.

Materials and Methods

Description of experimental sites

The experiment was conducted at Wondo Genet in Sidama region and Koka in Oromia region. Experimental sites are described in Table 1.

Table 1. Description of the study areas

Locations	Latitude	Longitude	Altitude (m.a.s.l.)	Rainfall (mm)	Temperature (°C)		Soil type	Soil pH
					Min	Max		
Wondo Genet	7°19' N	38°38' E	1876	1000	12.02	26.72	Sandy clay loam	6.4
Koka	8°26' N	39°1' E	1604	830.9	13.68	28.30	Loam	8.01

Experimental materials and design

The experiment consisted of five orange-fleshed sweet potato varieties (Kabode, Alamura, Dilla, Kulfo, and Vitae) that were released by Hawassa Agricultural Research Center. The experiment was carried out as Mother and Baby trials. The mother trial was arranged in a randomized complete block design (RCBD) with three replications. The treatments were randomly allotted to each plot. The experimental plot had an area of $9m^2$ (3m length x 3m width). The space between replications and plots was 1.5m and 1m, respectively. The space between rows and plants was 60cm and 30cm, in that order. Five plants from the three middle rows (out of the five rows) of each plot were used for sampling and data analysis.

Farmers' preferences for variety evaluation

Participatory variety selection was used in this research to identify farmers' selection criteria and acceptable varieties to adapt and assimilate into the production system. The selection of varieties was done in research stations at Wondo Genet and Koka. Researchers, experts from the Woreda and Kebele Agricultural Development Offices, and farmers in both areas were participated in

the selection of sweetpotato varieties. A total of 36 participants including 26 farmers (7 female and 19 male), 4 development agents (2 female and 2 male), and 6 agricultural experts (1 female and 5 male) were engaged. Prior to the evaluation, discussions on plant characters were made with invited participants and the farmers provided their opinions on the preferred attributes and identified the traits such as root size, root color, root uniformity, diseases resistance/tolerance, earliness to maturity, root yield, and taste. Two phases of selections were conducted. The first selection was made at the vegetative stage while the second selection was performed after harvesting the root yields from each variety based on farmers' preferences or criteria (Figure 1). Agronomic data and farmers' preference criteria like disease resistant, high yielder, larger root size, good color, high number of roots, and good taste were used for variety selection by farmers.

Figure 1. Evaluation of orange-fleshed sweetpotato varieties with integration of Researchers, Farmers and Agricultural Experts at the vegetative and harvesting stages in both areas

Data analysis

Data were subjected to analysis of variance using SAS package (SAS 9.4). The least significance differences (LSD) were used to compare the treatment means

following the procedures of Gomez and Gomez (1984). Farmers' perception data were analyzed using SPSS software.

Results and Discussion

Performance of orange-fleshed sweetpotato varieties for growth and yield traits

The analysis of variance (ANOVA) revealed significant differences ($P \leq 0.01$) among the varieties for agronomic and yield traits (Tables 2 and 3). This indicated the presence of sufficient variability, which could be attributed to the genetic potential of the varieties for the traits under consideration. The result is in agreement with previous findings on sweetpotato (Mekonnen, 2021) and potato (Zewdu *et al*., 2017) varieties tested in different areas.

Variety Alamura was the tallest (228.43cm) which was statistically similar to variety Dilla (213.48cm) while the shortest plants were recorded for Kabode (107.38cm), statistically similar to Vita (107.38cm). The tested sweetpotato varieties had no significant differences in root length and root number. The maximum root diameter (8.19cm) was obtained from variety Kulfo which was statistically similar to the value obtained from variety Kabode while the lowest (5.75cm) was from variety Dilla, statistically similar with the rest two varieties (Table 2). The maximum number of roots per plant was recorded from Kabode and the lowest was obtained from Alamura; however, this was statistically similar with all the tested varieties. The significant differences in plant height, and root diameter among sweetpotato varieties might be due to the inherent characters of the varieties and the differences in the environment between the study areas. The present results are in agreement with the findings obtained by Mekonnen (2021).

Table 2. Combined mean values for different growth traits of the tested orange-fleshed sweetpotato varieties at Wondo Genet and Koka in 2019/20 main cropping season

Varieties	Plant height (cm)	Root length (cm)	Root diameter (cm)	Root number per plant
Alamura	228.43[a]	21.73	5.97[b]	3.28
Dilla	213.48[a]	23.19	5.75[b]	3.75
Kabode	105.10[c]	22.30	7.14a[b]	5.43
Kulfo	1440.08[b]	14.17	8.19[a]	3.48
Vita	107.38[c]	22.47	6.04[b]	3.68
CV	11.13	12.97	13.55	18.33
LSD	18.23	NS	0.88	NS

The highest root weight per plant was harvested from Kulfo (2.81kg) which was statistically similar with Kabode (2.73kg); however, Vita gave the lowest which was statistically similar with the rest two varieties (Table 3). Variety Kulfo gave the highest root yield per hectare (33.90 t ha^{-1}) which had no statistical difference with the yield obtained from Kabode (31.64 t ha^{-1}) while the lowest (10.28 t ha^{-1})

was recorded from Vita (Table 3). Furthermore, variety Kabode gave the highest root dry matter content (34.82), followed by Dilla (30.16), whereas the lowest (23.31) was obtained from Kulfo, statistically similar with Vitae (Table 3). The presence of highly significant differences among sweetpotato varieties in terms of yield traits might be due to the presence of genetic differences among them. In line with the present results, Mekonnen (2021) reported that the tested sweetpotato varieties had a significance difference with respect to root and related traits. Moreover, Habtamu *et al*. (2016) reported a similar finding and stated that significance differences among potato varieties were found probably due to their genetic variability presented.

Table 3. Combined mean values for different yield traits of the tested sweetpotato varieties at Wondo Genet and Koka in 2019/20 main cropping season

Varieties	Root weight (Kg per plant)	Root yield (t ha^{-1})	Root dry matter content (%)
Alamura	2.10^{b}	23.00^{b}	29.87^{b}
Dilla	2.25^{b}	16.81^{c}	30.16^{b}
Kabode	2.73^{a}	31.64^{a}	34.82^{a}
Kulfo	2.81^{a}	33.90^{a}	23.31^{c}
Vita	1.99^{bc}	10.28^{c}	27.51b^{c}
CV	14.83	14.83	10.26
LSD	0.79	5.36	3.07

Farmers' preferences of orange-fleshed sweetpotato varieties

Root yield and quality play an important role in the successful production and marketing of sweetpotato. Traditionally, high yielding ability alone has been the most important factor to the producer; however, there have to be other additional traits that should be considered in variety evaluation. For instance, at the two sites, Wondo Genet and Koka, the highest yielder, disease-resistant and best-tasting quality scored high percent response rate and was ranked first (Table 4). However, as shown in Table 3 above, though Kulfo gave the highest yield, it was not selected by farmers due to its poor taste quality after boiling. Therefore, the participated farmers ranked the traits used for selection and evaluated the varieties using their selection criteria. Based on their preferences Kabode, Alamura and Dilla varieties were selected as the first, second, and third choices (Table 5) while the other varieties were low yielder and had poor-taste quality, thus they were not selected by the farmers in both study areas.

Table 4. Pair-wise ranking matrix for traits of sweetpotato varieties at Wondo Genet and Koka sites in 2019/2020 cropping season

Traits	RN	DR	RY	RS	RC	RU	TA	Total	Rank
RN		DR	RY	RN	RN	RN	TA	3	4
DR			DR	DR	DR	DR	TA	5	2
RY				RY	RY	RY	TA	4	3
RS					RS	RS	TA	2	5
RC						RU	TA	0	7
RU							TA	1	6
TA								6	1

RN=Root number, DR=Disease resistant, RY=Root yield, RS=Root size, RC=Root color, RU=Root uniformity, TA=Taste

Table 5. Farmers' preferences for orange-fleshed sweetpotato varieties at Wondo Genet and Koka locations in 2019/2020 cropping season

Preference Criteria	Ranking				
	Alamura	Dilla	Kabode	Kulfo	Vita
Earliness	3.6	3.0	3.5	3.2	2.4
Disease resistance	4.0	3.4	5.0	1.0	3.5
Number of roots per plant	3.5	3.2	4.0	4.0	2.5
Root size	2.4	3.0	3.5	3.5	2.0
Root color	2.0	2.0	4.2	2.0	2.8
Root uniformity	3.6	3.0	5.0	2.8	3.0
Taste	4.0	3.0	4.0	1.0	2.0
Summation	23.1	20.6	29.2	17.5	18.2
Overall rank	2	3	1	5	4

Ranking scales: 1=poor, 2= satisfactory, 3=good, 4= very good, 5= excellent

Conclusion and Recommendation

Participatory variety selection trial was conducted with the objective of selecting superior OFSP varieties with farmer's preferred traits. The participated farmers ranked the traits used for selection and evaluated the varieties using their own selection criteria. Despite the highest yielding potential of Kulfo, farmers did not select it due to its poor taste after boiling. Based on their preferences, Kabode, Alamura and Dilla varieties were selected as the first, the second and the third choices. Therefore, scaling up of these selected varieties could be done in the study areas and other locations with similar agro-ecologies to overcome the nutritional deficiency and food insecurity.

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Evaluation of Orange Fleshed Sweet Potato (*Ipomoea Batatas* (L) Lam) Genotypes in Different Agro-Ecologies of South West and West of Ethiopia

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Abstract

The study was conducted in major sweet potato growing areas of South west Ethiopia during 2019-2020 growing seasons. Nine Orange fleshed sweet potato varieties were evaluated to identify stable and adaptable sweet potato varieties for production and release. The varieties were tested in four representative locations (Jimma, Agaro, Metu and Haru) by using a randomized complete block design with three replications. Data from yield and yield related traits were collected and analyzed using the additive main effect and multiplicative interaction and genotype main effect plus genotype by environment interaction bi-plot analyses. The combined ANOVA for total storage root yield showed significant effects of the genotypes, environments and their interaction. The average total storage root yield of the genotypes across the eight environments was 45.45 tha-1. Genotypes NASPOT-12, NASPOT-13 and Koka-12 outperformed the rest; 55.88 tha-1, 47.55 tha-1 and 45.55 tha-1 yield, respectively; while genotype Kulfo was the lowest performed genotype and produced 42.39 tha-1. Additive main effect and multiplicative interaction bi-plot and genotype x environment interaction bi-plot revealed that NASPOT-12 was the most stable sweet potato genotype, but Kulfo, Guntutei and VITA were unstable genotypes. Furthermore, the genotype main effects and GGE bi-plot showed Metu-1 and Agaro-1 as the most discriminating and representative environments. The GGE bi-plot also identified three different sweet potato growing environments. The first environment containing Jimma-1, Agaro-1, Agaro-2, Haru-1 and Haru-2 with the wining genotype NASPOT-12, the second environment included Jimma-2 and Metu-2 areas with wining genotype of Guntutei and the third environment encompassing Metu-1, with wining genotype of Kabode.

Keywords: AMMI analysis, Genotype, GGE-bi-plot, Environment, Sweet potato

Introduction

Sweet potato [*Ipomoea batatas* (L) Lam] is an important tuberous root crop belonging to the family *Convolvulaceae*. It is originated from tropical Americas and was first cultivated at least 5,000 years ago (Ahn, 1993). They spread very early throughout the region including the Caribbean now known as southeastern United States (Zhang *et al.*, 1998). They were brought to Europe by Spanish and Portuguese explorers and sweet potato cultivation quickly spread throughout much of the Old World up to Africa (Woolf, 1992). Currently, it is cultivated in

different areas of tropical and sub-tropical areas of the world (Fekadu *et al*., 2017; Getachew *et al.,* 2020). In sub-Saharan Africa, sweet potato plays a significant role as a food security crop and economical uses. Similarly, as compared to other root crops, sweet potato has the advantages of a high yield potential and adaptability to a wide range of agro-ecologies including drought affected environments (Manrique and Hermann, 2000). Further, the crop is a source of vitamin A that serves in prevention of vitamin A deficiency related health problems (Getachew *et al.,* 2020).

In Ethiopia, sweet potato is the second most important root crop after enset [*Ensete ventricosum* (Welw.) Cheesman] (CSA, 2022). It is widely grown in different areas of the country; mainly in Southern and Oromia region for food, feed and economic uses (Fekadu *et al.* 2015; Getachew *et al.,* 2020). Sweet potato genotypes are evaluated for yield in multi-location trials, and wide differences are frequently observed in yield performances of the genotypes over the growing environments. This wide agro-ecological variability is due to the high genotype x environment interaction (GEI) effect (Manrique and Hermann, 2000). This is the major challenge to produce single variety across ecology but it has an opportunity to have the diversified sweet potato varieties.

In the last decades, several studies have been conducted on GEI and stability of white fleshed sweet potato germplasm under various environmental conditions. Report on GEI and stability of orange flashed sweet potato genotypes under southwest Ethiopian condition is very limited (Getachew *et al.,* 2020). Information on GEI and stability of orange flashed sweet potato genotypes across environments in southwest Ethiopia would therefore provide a scientific basis to select specifically adapted variety (ties) and to develop future breeding strategies that target the development of orange flashed sweet potato varieties for release (register). Further, study on GEI also support sweet potato breeders to develop strategies for testing and selecting genotypes more adapted to the target environments under which the genotypes will be grown. Therefore, this study was designed to assess the nature and magnitude of GxE interactions and advance insights into mega-environments for orange flashed sweet potato in southwest Ethiopia.

Materials and Methods

Descriptions of the experimental locations

A field experiment was conducted in four testing locations namely; Jimma, Agaro, Metu and Haru Agricultural research center and sub- sub-centers which are considered as the representative sweet potato growing areas of southwest Ethiopia. The experiment was conducted for two cropping seasons/years (2019-2020). This made a total of eight environments considering one location and one

cropping season as one environment. The description of agro-ecological and climate conditions of the study sites is summarized in Table 1.

Table 1. The summary of agro-ecological and climatic description of the study areas

Location	Altitude (m.a.s.l.)	Latitude	Longitude	Rainfall (mm)	Temperature (^{0}C)	
					Maximum	Minimum
Jimma	1753	7^o 40.00' N	36^o 47'.00' E	1521.1	26.2	12.1
Agaro	1560	7°51' .00' N	36°51' 35' E	1520	23.35	12.6
Metu	1550	8°18' .00' N	35°35' .00' E	1520	28.0	12.2
Haru	1750	8^{o}58'00' N	38^{0}48'00' E	1727	21.5	12.2

Source: Anonymous (2010)

Experimental design

The experiment was laid out in randomized completely block design (RCBD) with three replications.

Descriptions of the experimental materials

A total of nine orange fleshed sweet potato varieties were evaluated for their yield performances and yield stability under rain fed condition at the above-mentioned testing sites.

Table 2. List of tested varieties

T.N	Varieties	Origin
1	Alamura	Ethiopia
2	Dilla	Ethiopia
3	Guntutei	Ethiopia
4	Kabode	Uganda
5	Koka-12	Ethiopia
6	Kulfo	Ethiopia
7	NASPOT-12	Uganda
8	NASPOT-13	Uganda
9	VITA	Uganda

Source: Fekadu (2019)

Experimental Management

Land was ploughed twice during the dry season to avoid weed and insect pest infestation before planting in all tested locations. During planting land was harrowed, mowed, softened and ridges were prepared and the planting materials /cutting/ were placed on the ridge. Recommended intra and inter-row spacing of 30 cm and 60 cm were used. The gross plot size for each treatment was 3.6m^2 (1.5 m x 2.4 m), and it accommodated 25 plants per plot. Vines of the same size and age were used as planting material. One month after planting, seedlings were earthed up followed by frequent weeding. All other agronomic practices were followed according to the recommendations.

Data collection

Data were collected from nine plants from each plot and the average values were used for data analysis. The characters that were used for data collection were: vine length (cm), marketable storage root number, storage root length (cm) storage root girth (cm), weight of above ground biomass (t ha^{-1}), total storage root weight (t ha^{-1}) and harvest index (%).

Data analysis

A number of statistical tools available were used to analyze G x E interaction and to quantify the magnitude of the varieties. Among these, Additive Main effect and Multiplicative Interaction (AMMI) (Gauch and Zobel 1996; Gauch, 2013) and Genotype plus Genotype by Environment Interaction (GGE bi-plot) (Yan *et al*. 2000; Yan *et al*. 2001; Yan, 2002) were the most commonly used statistical methods for analyzing multi-environment data of the varieties.

Homogeneity of the residual variance was tested prior to combined analysis over locations in each year as well as over locations and years (for the combined data) using Bartlet's test (Steel and Torrie, 1980). Accordingly, the data collected indicated homogenous variance. Normality test was also conducted and all data showed normal distribution. A combined analysis of variance was performed using GenStat 14th edition (Payne *et al*. 2011) and SAS version 9.0 (SAS, 2000) statistical soft wares. Treatment means was separated by using the Fisher's protected least significant difference (LSD) test at 1% and 5% probability. The model employed in the analysis was;

$$Y_{ijk}=\mu+G_i+E_j+B_k+GE_{ij}+\varepsilon_{ijk}$$

Where: Y_{ijk} is the observed mean of the ith genotype (G_i) in the jth environment (E_j), in the Kth block (B_k); μ is the overall mean; G_i is effect of the ith genotype; E_j is effect of the jth environment; B_k is block effect of the ith genotype in the jth environment; GE_{ij} is the interaction effects of the i$^{th\ genotype}$ and the jth environment; and ε_{ijk} is the error term.

AMMI and AMMI bi-plot analysis, showing the genotype and environment means against Interaction Principal Component Analysis one (IPCA-1), and Interaction Principal Component Analysis one (IPCA-1) against Interaction Principal Component Analysis two (IPCA-2) were also performed using Meta-analysis procedure-I using the same statistical software. GGE bi-plot was also executed using the Meta-analysis of GenStat 14 th edition.).

Results and Discussion

Combined Analysis of variance and estimation of variance component

The results acquired from the combined analysis of variance of all the evaluated traits and genotype is illustrated in Table 3. The genotypes, environment and genotype x environment interaction (GEI) variance were analyzed to deliver the overall performance of the genotypes and evaluated traits. Accordingly, the genotypes, the environments and their interaction showed highly significant variation ($p<0.001$) for all evaluated traits of sweet potato.

On top of the genetic variability, the ANOVA (Table 3) also revealed that the environments (both locations and growing years) on which the experiments were conducted were different from one another in treating the tested sweet potato genotypes. Likewise, it also indicates that the response of the genotypes was unstable and fluctuated in their trait expression with change in the environments. These evidently established the presence of GEI in this study.

Table 3. Mean squares for yield and related traits of Orange fleshed sweet potato genotypes across locations.

Sources of variation	DF	Mean square						
		TSRW	VL	SRL	SRG	MSRN	WAGB	HI
Block	16	118	1378.0	12.02	126.8	0.38	163.0	93.1
Genotype (G)	8	426***	14612.0***	56.06***	537.4***	3.26***	1462.0***	149.9***
Environment (E)	7	11632***	18549.0***	154.2***	4057.1***	11.08***	7747.0***	1443.6***
G*E	56	154***	1169.0***	8.72*	125.0***	0.84***	618.0***	136.2***
Residual	30	78	598.0	4.73	58.4	0.41	254	53.0

, **, * significant at 0.05, and 0.001 % of probability level, DF= Degree of freedom, TSRW= Total storage root weight (t ha^{-1}), VL= Vine length (cm), SRL= Storage root length (cm), SRG= Storage root girth (cm), MSRN= Marketable storage root number, WAGB= weight of above ground bio mass (t ha^{-1}), and HI= Harvest Index (%)*

With regard to contribution to the variability concerned, most of the traits contribution to environmental variance was higher (ranging from 36.87 % for vine length to 83.35% for total storage root yield) followed by genotype x environment interaction and genotype, respectively (Table 4). Similar results were reported by (Baye *et al*., 2019; Fekadu *et al*., 2019) on Irish potato and sweet potato. With respect to vine length, the greatest source of variance was mainly the inherent genetic component meaning genotypic effect (33.19 %) (Table 4), which is similar to the results reported by Fekadu *et al.* (2015).

Table 4. Combined sum of squares for yield and related traits of Orange fleshed sweet potato genotypes evaluated during 2019-2020 cropping season

Sources of Variation	DF	TSRW	VL	SRL	SRG	MSRN	WAGB	HI
Block	16	1888(1.93)	22048(6.26)	192.32(8.18)	2028.8(4.67)	6.08(3.6)	2608(2.35)	1489.6(6.77)
Genotype (G)	8	3408(3.49)	116896(33.19)	448.48(19.08)	4299.2(9.89)	26.08(15.43)	11696(10.56)	1199.2(5.45)
Environment (E)	7	81424(83.3)	129843(36.87)	1079.4(45.92)	28399.7(65.32)	77.56(45.88)	54229(48.96)	10105.2(45.91)
Gen*Env	56	8624(8.83)	65464(18.59)	488.32(20.78)	7000(16.10)	47.04(27.82)	34608(31.25)	7627.2(34.65)
Residual	30	2340(2.40)	17940(5.09)	141.9(6.04)	1752(4.03)	12.3(7.28)	7620(6.88)	1590(7.22)
Total	117	97684	352191	2350.42	43479.7	169.06	110761	22011.2

Note: *Number inside and outside parenthesis are SS and % of SS of traits, respectively. DF= Degree of freedom, Gen= Genotype, Env= Environment, TSRW= Total storage root weight (t ha $^{-1}$), VL= Vine length (cm), SRL= Storage root length (cm), SRG= Storage root girth (cm), MSRN= Marketable storage root number, WAGB= weight of above ground bio mass (t ha^{-1}) and HI= Harvest Index (%)*

Performance of Sweet potato genotypes

The average total storage root yield of the tested sweet potato genotypes over the eight environments was 45.45 tha^{-1}. NASPOT-12 had the highest average total storage root yield (55.88 tha^{-1}), followed by NASPOT-13 (47.55tha^{-1}) while, Kulfo was the lowest yielding genotype (42.39 tha^{-1}) (Table 5).

Similarly, NASPOT-12 had the highest average storage root girth (71.53cm), marketable storage root number (2.93) and weight of above ground biomass (61.50 tha^{-1}). While, Alamura, Kabode and Kulfo produced the lowest storage girth, marketable storage roots number and weight of above ground biomass, respectively.

Table 5. Combined mean yield and yield related traits of Orange fleshed sweet potato genotypes across all tested environments

Genotypes	TSRW	VL	SRL	SRG	MSRN	WAGB	HI
Alamura	43.91bc	147.02b	18.82ab	58.80b	2.95a	50.66b	0.46c
Dilla	44.31bc	167.02a	18.98ab	60.29b	2.89a	47.96bc	0.48cb
Guntutei	43.04bc	108.3cd	20.12a	59.41b	2.31bc	43.11bcd	0.49bc
Kabode	42.90bc	103.1d	19.22ab	62.11b	2.01c	38.58d	0.51ab
Koka-12	45.55bc	156.95ab	17.99bc	62.08b	**2.29bc**	**50.3b**	**0.46c**
Kulfo	42.39c	121.4c	14.75d	69.61a	2.46b	36.18d	0.53a
NASPOT-12	**55.88a**	122.07c	17.17c	71.53a	2.93a	61.50a	0.48bc
NASPOT-13	47.55b	100.36d	18.25bc	59.71b	2.96a	50.15b	0.48bc
VITA	43.53bc	109.87cd	18.67b	59.22b	2.31bc	40.62cd	0.52ab
Mean	**45.45**	**126.24**	**18.22**	**62.53**	**2.57**	**46.56**	**0.49**
LSD	**5.02**	**15.07**	**1.45**	**4.92**	**0.37**	**8.26**	**0.04**
CV(%)	**19.40**	**20.9**	**13.94**	**13.78**	**25.51**	**31.09**	**14.43**

Means followed by the same letter are not statistically different from each other DF= Degree of freedom, TSRW= Total storage root weight (t ha^{-1}), VL= Vine length (cm), SRL= Storage root length (cm), SRG= Storage root girth (cm), MSRN= Marketable storage root number, WAGB= weight of above ground bio mass (t ha^{-1}) and HI= Harvest Index (%)

Variance estimate for total storage root yield and related traits of sweet potato genotypes

The combined ANOVA for total storage root yield and related traits revealed that there was highly significant variation ($p<0.01$) among the genotypes, environments (year, location, year x location) and genotype by environment interaction (genotype x year, genotype x location and genotype x year x location) (Table 6). These significant variations of the genotypes, environments and the GEI indicated that the response of the genotypes were unstable and varied in their total storage root yield with change in environment and these phenomena clearly declared the presence of GEI in this study.

The storage root yield of the nine sweet potato genotypes was highly variable over the eight environments, showing highest storage root yield cross-over interaction from environment to environment. Among the environments the highest total storage root yield (55.88 t ha^{-1}) was observed from genotype NASPOT-12and Agaro-1 was the best environment. While, the lowest root yield (42.4 tha^{-1}) was recorded from genotype Kulfo and Agaro-2is the least suitable environment for sweet potato production (Table 7).

Table 6. Combined Analysis of Variance for mean total storage root yield (t ha^{-1}) and yield related traits of Orange fleshed sweet potato genotypes

Sources of variation	DF	Mean square						
		VL	SRL	SRG	MSRN	WAGB	TSRW	HI
Environment (E)	3	11896.8***	29.44**	4050.3***	7.02***	1724.4***	2477.6***	0.16***
Genotype (G)	8	14611.7***	56.05***	537.3***	3.26***	1462.3***	426.0***	0.015**
Year (Y)	1	6647.5***	15.39	2995.8***	3.01***	9273.7***	5.86	0.08***
Y*E	3	29168***	325.38***	4417.6***	17.65***	13259.9***	24395.7***	0.14***
G*E	24	1137.0**	11.19**	136.2**	1.08***	723.7***	143.3**	0.01***
G*Y	8	816.4	5.71	109.7	0.55	462.0*	169.3**	0.01**
G*Y*E	24	1318.6**	7.24	118.8*	0.68*	564.9***	160.6***	0.01***
Error	142	687.8	6.45	4.3	0.43	209.57	77.38	0.005

, **, * significant at 0.05, and 0.001 % of probability level, DF= Degree of freedom, VL= Vine length (cm), SRL= Storage root length (cm), SRG= Storage root girth (cm), MSRN= Marketable storage and HI= Harvest Index (%)*

Table 7. Mean total storage root yield (t ha^{-1}) performance of nine orange fleshed sweet potato genotypes tested across eight environments.

Genotypes	Environments								Over all mean
	Jimma-1	Agaro -1	Metu -1	Haru-1	Jimma-2	Agaro-2	Metu -2	Haru-2	
Alamura	26.59	65.24	40.07	33.02	79.77	17.97	43.62	45.07	43.92
Dilla	27.19	66.10	34.53	29.71	68.38	20.18	42.33	66.11	44.32
Guntutei	25.37	66.10	36.50	30.24	75.32	16.34	37.01	57.47	43.04
Kabode	25.72	64.44	35.62	29.86	71.86	18.06	41.81	55.88	42.91
Koka-12	28.93	66.47	31.38	28.38	59.49	24.0	46.28	79.47	45.55
Kulfo	24.67	65.96	34.15	28.48	71.73	15.83	34.67	63.70	42.40
NASPOT-12	37.84	80.10	49.61	43.08	90.10	27.86	46.06	72.37	**55.88**
NASPOT-13	28.37	75.91	40.15	33.48	84.27	15.70	24.24	78.29	**47.55**
VITA	25.94	65.77	39.85	32.60	80.78	16.58	40.27	46.52	43.54
Mean	**27.85**	**68.45**	**37.98**	**32.09**	**75.74**	**19.17**	**39.59**	**62.76**	**45.46**

AMMI analysis

In addition to the usual ANOVA the ANOVA from the AMMI model for total storage root yield also detected significant variation ($p<0.001$) for both the main and interaction effects indicating the existence of a wide range of variation between the genotypes, years (seasons), locations and their interactions.

AMMI 1 biplot analysis:

The AMMI bi-plot analysis provides a graphical representation to condense information on main effect and interaction effects of both genotypes and environments simultaneously. The AMMI1 bi-plot containing the genotype and environment means against interaction principal component analysis one (IPCA1) scores is illustrated in Figure.1. As indicated in the figure the displacement along the abscissa reflected differences in main effects, whereas displacement along the ordinate exhibited differences in interaction effects. Genotypes and environments with IPCA-1 greater than zero classified as high yielding genotypes and favorable environments, whereas those with IPCA-1 lower than zero classified as low yielding genotypes and unfavorable environments (Manrique and Hermann, 2000; Yan and Thinker, 2006).

Consequently, genotypes NASPOT-12 and NASPOT-13were the genotypes with above average mean total storage root yield as they laid-down on the right side of the vertical line (grand mean of the genotypes and environments). Conversely, genotypes Guntutei, Alamura, VITA and Dilla had yield below the grand mean because of they laid down to the left side of the vertical line. Exceptionally, Koka-12 laid very close to the vertical line, indicating the mean yield of this genotype was similar to the overall environment mean. NASPOT-12 followed by NASPOT-13 had higher mean total root yield in the favorable environments, whereas Kulfo and Kabode had lower mean total root yield in the unfavorable environments. Regardless of their contribution for the interaction, Guntutei and Kulfo fall on the same vertical line (ideal) showing their similarity in their mean yield. NASPOT-12 and Kabode which laid on the same horizontal line had similar

contribution in the interaction component despite of their yield performance. With regard the environments, Jimma-2, and Agaro-1 had root yield above the grand mean and were considered as favorable environments. In the other hand, Jimma-1, and Agaro-2, Haru-1 and Mrtu-2 had below average total storage root yield and were considered as unfavorable environments. Metu-1 laid very close to grand mean line indicating that genotypic yield in Metu-1 represents the overall genotypic mean across all environments.

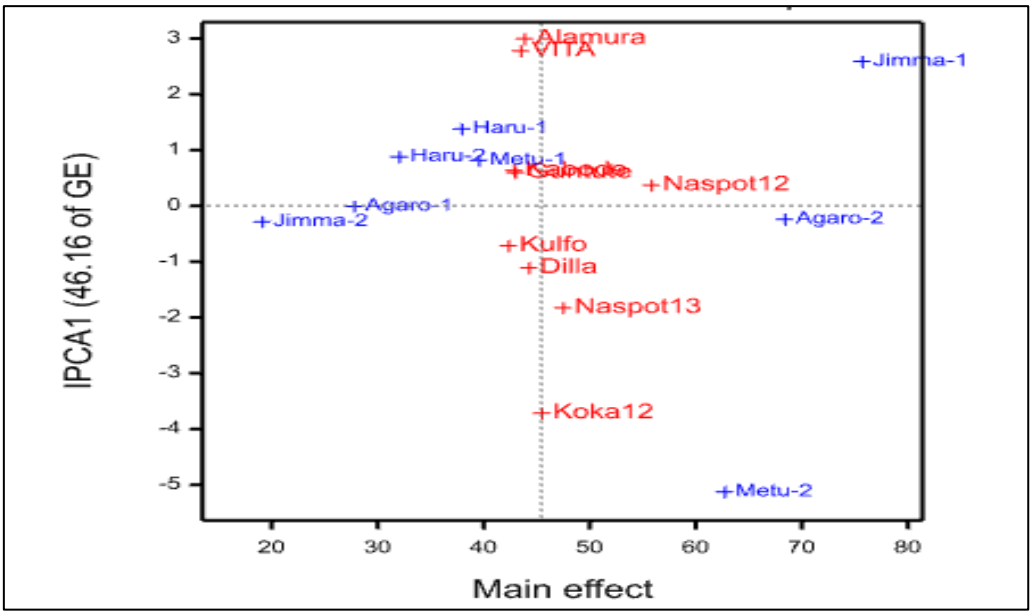

Figure 1. AMMI1 bi-plot showing Genotype and Environmental means against IPCA-1.

AMMI 2 biplot:

The AMMI2 bi-plot with IPCA-1 in the X-axis and IPCA-2 in the Y-axis is plotted in Figure 2. The first interaction principal component (IPC1 or PC1) explained 46.16 % and the second interaction principal component (IPC2 or PC2) about 26.61% of the sum of squares of the genotype by environment interaction. The two interaction principal components cumulatively explained about 72.77% of the sum of squares of the genotype by environment interaction (Figure2). Yan *et al*., (2007) stated that the closer the genotypes to the origin are the more stable they are and the furthest the genotypes from the origin are the more unstable they are. In addition, the closer the genotypes to the given vector of any environment are the more adaptive to that specific environment and the farthest the genotypes to the given vector of any environment are the less adaptive to that specific environment. Accordingly, genotypes Koka-12, NASPOT-13, Alamura, and VITA are far apart from the bi-plot origin indicating these genotypes as the more responsive and contributed largely to the interaction component and considered as specifically adapted genotypes. On the other hand, Kulfo, NASPOT-12, Guntutei, Kabode and Dilla were the genotypes with least contribution to the

interaction component as they located near to the bi-plot origin indicating their wider adaptability (Figure.2). Regarding to the adaptability of the genotypes in the environments; genotypes Kulfo and NASPOT-12 were adaptive to Agaro-2, Haru-1 and Haru-2, and genotypes Kabode and Dilla were adaptive to environments Jimma-1, Agaro-1, respectively.

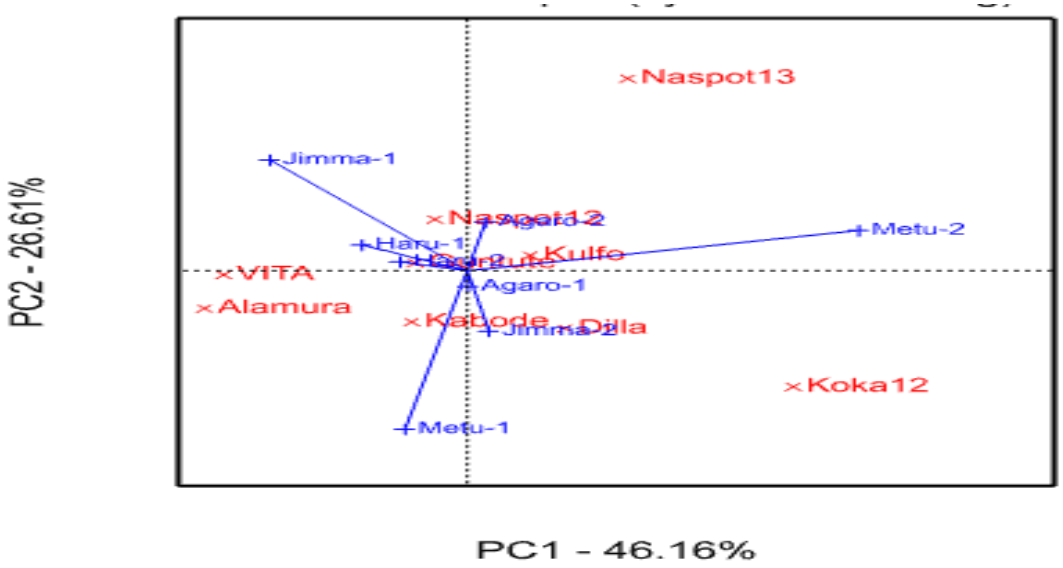

Figure 2. AMMI2 bi-plot showing PC1 versus PC2 indicating the stability of the genotypes.

GGE Biplot

The first two principal components in the GGE bi-plot of this study constituted 69.25% of total variance of as indicated by Yan and Thinker, (2006), the similarity between two environments as well as genotypes is determined by both the length of their vectors and the cosine of the angle between them and the relations is illustrating in figure 3. The angle betweenJimma-1 andMetu-2 is about 90^0 indicating there was no correlation between these environments and produce different information about the tested genotypes (Figure 3). The rest of the environments had vectors with less than 90^0 indicating that, these environments were positively correlated to each other. Agaro-2 had longest vector and small IPCA-2 and that was relatively the most representative and discriminating environment and considered as the ideal environment for widely adapted genotypes. Hence, Genotype with above average yield in this environment had above average yield all environments. Jimma-1and Metu-2 were the most discriminating but least representative environments which were with little information of the genotypes and favorable for specifically adapted genotypes. Exclusively, Metu-1 was neither discriminating nor representative environment. To clearly display graphically, the 'which -won-where' pattern of a polygon view

of GGE bi- plot is exhibited in Figure 4. The polygon was formed by connecting the vertex genotypes that were furthest away from the bi-plot origin such that all other genotypes were included in the polygon. The polygon view of bi-plot analysis (Figure 4) showed there were three different sweet potato growing environments. The one environment including the high yielding environments which were in the Jimma-1, Agaro-1, Agaro-2, Haru-1 and Haru-2 areas with winning genotypes NASPOT-12 and NASPOT-13; the second environment included the low to medium yielding environments, which were under Jimma-2 and Metu-2 areas with a vertex genotype Guntutei. The third environment included Metu-1 with winning genotype Kabode. The other vertex genotypes (Alamura, Koka-12 and Dilla) without any environment in their sectors were not the highest yielding genotypes at any environment rather they were poorest genotypes at all or some environments.

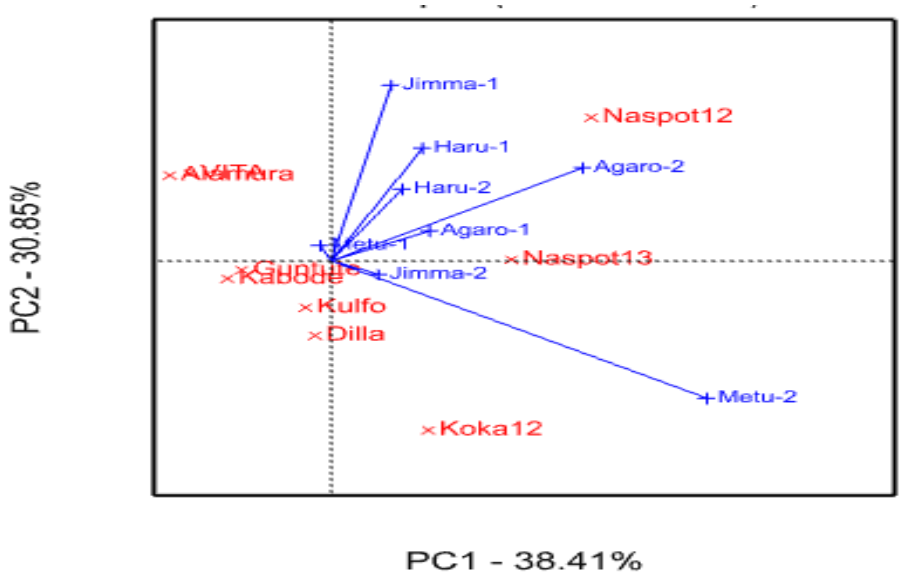

Figure 3. The environment vector view of the GGE bi-plot to show similarities among test environments

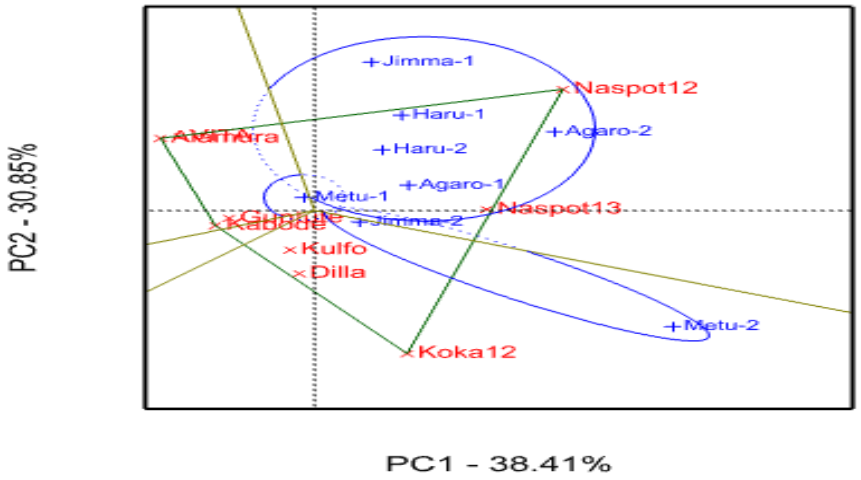

Figure 4. The which-won-where view of the GGE biplot

Conclusion and Recommendation

The combined Analysis of Variance showed significant differences among Orange fleshed sweet potato genotypes in this study for mean storage root yield across environments. The result also showed that the environments were highly variable with respect to climatic/edaphic factors. This GEI in turn indicated that the performance or ranking of the genotypes was variable across environments and it was difficult to identify superior genotypes for all tested locations. The GGE bi-plot identified three sweet potato growing environments; Jimma-1, Agaro-1, Agaro-2, Haru-1 and Haru-2 areas with NASPOT-12 a winning genotype, the second environment included Jimma-2 and Metu-2 areas with a vertex genotype Guntutei and the other environments encompassing Metu-1, with Kabode; as a winning genotype. The AMMI bi-plot and GGE bi-plot analysis identified NASPOT-12 and NASPOT-13 as the most stable and widely adapted genotypes for total storage root yield while, Kaka-12 was specifically adapted in the environment.

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Evaluation of Taro (*Colocasia Esculenta* (L.) Schott) Genotypes in Southwest Ethiopia

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Abstract

A study was conducted at four locations (Jimma, Agaro, Gera and Metu) for two cropping seasons (2019/20 and 2020/21). Nine taro genotypes and one standard check were evaluated to identify high yielding and stable genotypes for breeding. The materials were established by using a randomized complete block design with three replications. Data for yield and yield related traits were collected and analyzed using the additive main effect and multiplicative interaction (AMMI) and genotype main effect as well as genotype by environment interaction (GEI) bi-plot analyses. The result of the combined analysis of variance revealed significant differences ($p<0.01$) for genotype, environment, and genotype by environment interaction effects for all the traits considered except for root length. The average total storage root yield of the taro genotypes across the eight environments was 25.69 t ha-1. Genotypes 053, 133 and Kiyaq outclassed the rest; 29.17 t ha-1, 26.36 t ha-1and 25.99 t ha-1 root yield, respectively. Whereas, genotype 165 was the least performed and produced average storage root yield of 24.1 t ha-1. The AMMI and GEI bi-plots revealed that genotypes 053 and 133 were ideal genotypes with high yield and wider adaptability that could potentially be released for production in the region. However, genotypes 165, 130, 023 and 032 were unstable. The genotype main effects and GGE bi-plot exhibited Agaro-2 and Gera-2 were the most discriminating and representative environments for the evaluation of taro genotypes for yield and yield components. Moreover, the GGE bi-plot identified four mega-environments (MGE) for taro breeding; where Agaro-2, Gera-2 and Gera-1 combined into MGE-1; Metu-1 and Jimma-1 clustered into a separate MGE-2; Jimma-2 and Agaro-1 pooled into MGE-3; and Metu-2 separated in to MGE-4.

Keywords: AMMI, genotype by environment interaction, GGE bi-plot, taro, yield

Introduction

Taro (*Colocasia esculenta* (L.) Schott) is one of the oldest cultivated crops in the world serving as food for mankind for over 9000 years (Adelekan, 2012; Esther *et al.*, 2020). It is an important root crop and potentially produced for reasonable yield under conditions where most crops will fail making it a food security crop (Singh *et al*. 2008; Tewodros and Getachew, 2013; Yared *et al*., 2014). In most producing areas, taro production is usually carried out by smallholder farmers with little reliance on external support and plays important economic and nutritional roles in the livelihood of many poor farmers in developing countries (Singh *et al*., 2012; Singh *et al*., 2012; Banjaw, 2017). Furthermore, the leaves

and petioles of taro serve as a rich source of protein, carbohydrate, fiber minerals, vitamins and micronutrients, and consumed as vegetables in Africa (Esther *et al*., 2020).

In Ethiopia, taro is cultivated as subsistence level due to the unavailability of high yielding varieties which are stable and adaptable to different environments (Tewodros and Getachew. 2013; Yared *et al*., 2014; Asfaw *et al.*, 2020). The most effective way of producing more stable and high yielding varieties is through evaluation of genotypes in multi-location trials (Fan *et al*., 2007; Esther *et al*., 2020). The success of genetic enhancement programme hinges on identification of best genotypes adapted to specific growing season with stable performance for harnessing maximum gains from the selection. The yield of each genotype in each test environment is a measure of an environment main effect (E), a genotype main effect (G), and the genotype by environment interaction (GEI) (Yan and Tinker, 2006). Typically, environmental effect elucidates 80% or higher of the total yield variation in many crops; however, it is genotype and GEI that are relevant to genotype evaluation (Yan and Rajcan, 2002).

The GEI has been studied by different researchers extensively on taro, and several methods have been proposed to analyze it. For instances, Sing *et al*. (2006) reported evaluation of multi-location trial on taro genotypes collected from New Zealand; and Asfaw *et al.* (2020) described the AMMI, genotype and genotype by environment (GGE) bi-plot study of taro from Southern Ethiopia. Further, Eze *et al.* (2016) reported the evaluation of taro genotypes based on AMMI and GGE from Nigeria. Esther *et al.* (2020) reported the estimation of genotype by environment and the yield stability performance of taro genotypes from Ghana. Frequently, a large number of genotypes are tested across a number of environments, seasons and years, and it is often difficult to determine the pattern of genotypic response across locations or seasons without the help of graphical display of the data (Yan *et al.*, 2001). Bi-plot analysis provides solution to the aforementioned problem as it displays the two-way data and allows visualization of the interrelationship among environments, genotypes, and interactions between genotypes and environments (Owusu *et al.*, 2018). Two types of bi-plots, the AMMI bi-plot (Gauch, 1988; Gauch and Zobel, 1997) and the GGE bi-plot (Yan and Rajcan, 2002; Aina *et al*., 2007) have been used widely to visualize genotype by environment interaction.

AMMI is a statistical model that combines analysis of variance with principal component analysis to adjust the main effects and GEI effects (Gauch and Zobel, 1996; Aian *et al*., 2007; Gauch, 2013). The GGE bi-plot analysis was developed by Yan *et al*. (2000) to determine the relationship between genotypes and test environments graphically. These models are providing valuable insights in assessing the extent of GEI in multiple environments and to classify the

environments of taro (Badu-Apraku and Oyekunle, 2012). Understanding the nature and magnitude of genotype by environment are important to identify the most discriminating and representative environments for taro production in Ethiopia. The objectives of the study therefore were (i) to determine the effect of GEI on yield and yield related traits of taro genotypes in major growing areas of southwest Ethiopia, (ii) to select stable and high yielding taro genotypes for the yield and yield related traits for release, and (iii) to determine the most discriminating and representative environment for the root yield and yield related traits of taro.

Materials and Methods

Study areas

Field experiments were conducted at Jimma, Agaro, Gera and Metu, which are considered as the representative taro growing areas of southwest Ethiopia. The experiment was conducted for two cropping seasons (2019/20 and 2020/21) at all the four locations. This made a total of eight environments considering one location and one cropping season as one environment. The detail descriptions of all tested sites are presented in Table 1.

Table 1. The geographical description of the study sites

Location	Altitude (m.a.s.l.)	Latitude	Longitude	Rainfall (mm)	Temperature (°C)	
					Maximum	Minimum
Jimma	1753	7° 40.00' N	36°47'.00' E	1521	26.2	12.1
Agaro	1560	7°51'.00' N	36°51' 35' E	1520	23.3	12.6
Gera	1970	7° 31.60' N	36°15'.00' E	1877	18.6	12.0
Metu	1550	8°18'.00' N	35°35'.00' E	1520	28.0	12.2

Source: JARC (2010)

Plant materials, experimental design and management

Nine taro genotypes which were collected from major growing areas of Southwest Ethiopia and one released variety (Kiyaq) were used for this study. The genotypes were evaluated using a randomized complete block design with three replications. The gross plot size for each treatment was $9m^2$ (3m x 3m), using inter-row spacing of 0.75m and intra-row spacing of 0.5m. Corms of the same size and age were used as planting material. One month after planting, seedlings were earthed up followed by frequent weeding. All other agronomic practices were applied according to the recommendations.

Data collection

Data were collected from eight middle plants from each plot and the average values were used for data analysis. The traits used for data collection were: number of verticals per plant, storage root length (cm), storage root diameter (cm), number of marketable storage roots per plant (marketable or saleable roots

represent the roots that were more than or equal to 100g or roots with diameters at the widest point >25mm) (Levette, 1993), total number of storage roots per plant, weight of marketable storage roots (t ha^{-1}), and weight of total storage roots (t ha^{-1}).

Data analysis

Homogeneity of residual variance was tested prior to combined analysis over locations in each year as well as over locations and years (for the combined data) using Bartlet's test (Steel and Torrie, 1980). Accordingly, the data collected indicated homogenous variance. In addition, normality test was conducted and all data showed normal distribution. Data were subjected to analysis of variance (ANOVA) for each location and combined over environments following the standard procedure using SAS (SAS, 2000) and GenStat (Payne *et al*., 2011) software. Treatment means were separated by using the Fisher's protected least significant difference (LSD) test at 1% and 5% probability levels.

AMMI analysis

The total root yield was subjected to the combined analysis of variance and additive main effects and multiplicative interactions (AMMI) analysis, which is a combination of analysis of variance and multiplication effect analysis. The analysis of variance was used to partition variance into three components: genotype, environment, and genotype by environment deviations from the grand mean. Subsequently, multiplication effect analysis was used to partition genotype by environment deviations into different interaction principal component axes (IPCA), which were tested for statistical significance through ANOVA. To determine the GEI for yield parameters, AMMI and GGE bi-plot analyses were performed. The following AMMI model was used (Gauch, 2013). Genotypic stability for each genotype was computed using GenStat software, as prescribed by Malhotra *et al*. (2007). The AMMI statistical model reported by Gauch and Zobel (1996) was used to analyze yield data to obtain AMMI analysis of variance and AMMI mean estimates as follow:

$$Y_{ger} = \mu + \alpha_g + \beta_e + \sum \lambda_n y_{gn} \delta_{en} + \rho_{ge} + E_{ger}$$

Where: Y_{ger} = yield of genotype g in environment e for replicate r, μ = grand mean, α_g = genotype mean deviation (genotype means minus grand mean), β_e = environment mean deviation, n = number of principal component analysis (PCA) axes retained in the model, λ_n singular value for PCA axis n,y_{gn} = genotype eigenvector values for PCA axis n δ_{en} = environment eigenvector values for PCA axis n, ρ_{ge} = residuals, E_{ger} = error term.

Another important point reported by Yan*et al*. (2007) was genotype and genotype-by-environment effects considered simultaneously to make a meaningful decision

in selection. Significant GEI was also analyzed by a GGE bi-plot which was useful in ranking genotypes based on their average performance and stability for best traits in taro. The GGE bi-plot model was used to determine the influence of GEI on total storage root yield, storage root length and number of marketable storage roots per plant across the test environments. The model for the GGE bi-plot based on singular value decomposition (SVD) of first two principal components was calculated by using the model (Yan *et al.*, 2007):

$$Y_{ij}-\mu-\beta_j=\lambda_1\xi_{i1}\eta_{j1}+\lambda_2\xi_{i2}\eta_{j2}+\varepsilon_{ij}$$

Where: Y_{ij}= measured mean of genotype i in environment j, μ= grand mean, β_j = main effects of environment j, $\mu + \beta_j$ = the mean yield across all genotypes in environment j, λ_1 and λ_2= are the singular values (SV) for the first and second principle components (PCA-1 and PCA-2) respectively.ξ_{i1}andξ_{i2} = are eigenvectors of genotype i for PCA-1 and PCA-2, respectively, η_{j1} andη_{j2} = eigenvectors for environment j for PCA-1 and PCA-2, respectively.ε_{ij}= residual associated with genotype i in environment j.

Results and Discussion

Analysis of variance for the storage root yield and yield related traits of taro genotypes

The results from the combined analysis of variance revealed that the genotype and environment components showed highly significant variations ($p<0.01$) for all agronomic traits. Except storage root length and girth, the other traits showed significant variations ($p<0.01$) for GEI (Table 2). From the genetic variability points of view, the analysis of variance revealed that the environments (both locations and growing seasons) at which the experiments were conducted were different from one trait to another in the tested genotypes (Table 2). The results further revealed that the response of the genotypes was varied and inconsistent in their trait expression with change in the environments. These phenomena clearly confirm the existence of GEI.

Table 2. Mean squares for yield and related traits of taro genotypes across four tested locations and over two cropping seasons

Sources of variation	DF	Mean squares						
		TSRW	NVPH	SRL	SRG	NMSR	TNSR	MSRW
Block	16	13.12	17.39	3.43	3.51	4.94	19.11	12.72
Genotype (G)	9	30.34**	47.40***	1.97*	3.15***	19.77***	38.14***	43.98***
Environment (E)	7	81.88***	647.77***	32.37***	32.54***	116.74***	655.74***	154.04***
G*E	63	10.88*	17.14**	1.19	1.12	4.44***	19.92***	21.57*
Residual	35	6.43	6.04	0.50	0.66	1.21	6.39	6.98

*, **, *** significant at 0.05, 0.01 and 0.001% of probability levels. DF=Degree of freedom, TSRW=Total storage root weight (t ha^{-1}), NVPH=Number of verticals per hill, SRL=Storage root length (cm), SRG=Storage root girth (cm), NMSR= Number of marketable storage root, TNSR=Total number storage root and, MSRW=Marketable storage root weight (t ha^{-1})

For most of the traits the contribution of environment for the overall variance varied from 16.83% for total storage root weight to 57.74% for total number of storage roots followed by GEI and genotype, respectively (Table 3). Similar results were reported by (Sing *et al.*, 2006; Tewodros and Getachew, 2013). With respect to total storage root weight, the greatest source of variance was mainly the inherent genetic component meaning genotypic effect (8.02%) (Table 3), which is similar to the results reported by Asfaw *et al.*, (2020).

Table 3. Combined sum of squares for yield and related traits of taro genotypes evaluated during 2019-2020 cropping season

SV	DF	TSRW	NVPH	SRL	SRG	NMSR	TNSR	MSRW
Block	16	210 (6.17)	278 (3.5)	54.9 (10.47)	56.2 (10.62)	79.0 (4.75)	306 (3.85)	203 (4.85)
G	9	273.1 (8.02)	427 (5.37)	17.7 (3.38)	28.4 (5.37)	177.9 (10.69)	343 (4.31)	396 (9.46)
E	7	573.2 (16.83)	4534 (57.02)	226.6 (43.22)	227.8 (43.04)	817.2 (49.10)	4590 (57.74)	1078 (25.75)
G*E	63	685.5 (20.13)	1080 (13.58)	75.1 (14.32)	70.9 (13.40)	279.8 (16.81)	1255 (15.79)	729 (17.42)
Residual	35	224.9 (6.60)	212 (2.67)	17.8 (3.40)	23.1 (4.36)	42.5 (2.55)	224 (2.82)	244 (5.83)
Total	239	3405.8	7952	524.3	529.3	1664.2	7950	4186

Numbers inside and outside parentheses are SS and % of SS of traits, respectively. SV=Sources of variation, DF=Degree of freedom, G=Genotype, E=Environment, TSRW=Total storage root weight (t ha^{-1}), NVPH=Number of verticals per hill, SRL=Storage root length (cm), SRG=Storage root girth (cm), NMSR=Number of marketable storage roots, TNSR=Total number of storage roots and, MSRW=Marketable storage root weight (t ha^{-1})

Agronomic performance of taro genotypes

The average total storage root yield of the ten tested taro genotypes over eight environments was 25.69 t ha^{-1}. Genotype 053 had the highest average total root yield (29.17 t ha^{-1}), followed by genotypes 133 (26.36 t ha^{-1}) and Kiyaq (25.99 t ha^{-1}). Conversely, genotype 165 provided the least storage root yield (24.15 t ha^{-}

[1]) (Table 4). Similarly, genotype Kiyaq had the highest average storage root length (18.02cm), girth (33.02cm), number of marketable storage roots (6.65) and total number of storage roots (12.13). In the contrary, genotype 9/75 produced the lowest storage length (16.83cm) and girth (31.83cm) while genotype 183 produced the lowest number of marketable storage roots (3.74) and total number of storage roots (7.76) (Table 4).

Table 4. Combined mean yield and yield related traits of taro genotypes across environments

Genotypes	TSRW	NVPH	SRL	SRG	NMSR	TNSR	MSRW
44/75	24.63bc	6.55 bcd	17.34bc	32.34bc	4.13de	8.59de	20.7cde
133	26.36bc	5.93d	17.19bc	32.19bc	4.45cde	8.88cde	22.98b
Kiyaq	25.99bc	6.23 bcd	18.02a	33.02a	6.65a	12.13a	22.56bc
165	24.15c	6.87bc	17.07bc	32.07bc	4.98cd	10.35abcd	19.83e
130	25.92bc	6.88bc	16.90c	31.90c	5.17bc	11.45ab	22.18cde
023	24.64bc	7.03b	17.04bc	32.04bc	4.99cd	11.25ab	22.18bcd
9/75	24.99bc	8.04a	16.83c	31.83c	4.65cde	10.56abc	20.89cde
183	25.36bc	6.07cd	17.29bc	32.29bc	3.74e	7.76e	21.3bcde
032	25.65bc	6.75bc	17.03bc	32.03bc	4.47cde	10.08bcd	21.1bcde
053	29.17a	6.17cd	17.63ab	32.63ab	5.99ab	11.15ab	25.04a
Mean	25.69	6.65	17.23	32.23	4.92	10.22	21.70
LSD	1.91	0.81	0.63	0.63	0.97	1.97	2.00
CV(%)	13.06	21.53	6.50	3.47	34.63	33.80	16.20

Means followed by the same letter are not statistically different from each other. TSRW=Total storage root weight (t ha^{-1}), NVPH=Number of verticals per hill, SRL=Storage root length (cm), SRG=Storage root girth (cm), NMSR=Number of marketable storage roots TSRW=Total number of storage roots and, MSRW=Marketable storage root weight (t ha^{-1})

Variance estimate for total storage root yield and related traits of taro genotypes

The combined analyses of variance for the agronomic traits evaluated in eight environments revealed that there were highly significant variations ($p<0.01$) among the genotypes, environments (year, location, year by location) and genotype by environment interaction (Table 5). These significant variations of the genotypes, environments and the genotype by environment interactions indicated that the response of the genotypes varied for their total storage root yield with change in environment. These phenomena indicated the presence of GEI.

Table 5. Combined analysis of variance and significant tests for taro yield and related traits of ten genotypes tested in two years and four locations

Sources of variation	DF	Mean squares					
		TSRW	NVPH	SRL	MSRNP	TSRNP	MSRW
Environment (E)	3	47.85***	337.07***	45.80***	159.9***	501.8***	128.6***
Genotype (G)	9	47.48***	9.17***	3.15**	17.90***	47.4***	55.97***
Year (Y)	1	353.12***	161.04***	4.69*	71.38***	136.1***	563.6***
Y*E	3	4.53	15.23***	28.57***	82.91***	964.3***	24.0
G*E	27	20.14*	4.90***	1.09	2.55	12.63	21.65*
G*Y	9	9.15	1.14	0.29	2.36	34.83**	16.11
G*Y*E	27	14.05	1.50	1.43	4.44*	15.74	11.52
Error	158	11.26	2.05	1.25	2.91	11.94	12.38

*, **, *** significant at 0.05, 0.01 and 0.001% of probability levels.

The storage root yields of the ten taro genotypes were highly variable over the eight environments, showing highest storage root yield cross-over interaction from environment to environment. Among the environments the highest total storage root yield (25.04 t ha^{-1}) was obtained from genotype 053 while Metu-2 was the best environment. Conversely, the lowest root yield (19.83 t ha^{-1}) was recorded from genotype 165 while Agaro-1 and Jimma-1 were the least suitable environment for taro production (Table 6).

Table 6. Mean total storage root yield (t ha^{-1}) performance of ten taro genotypes tested across eight environments

Genotypes	Environments								Over all mean
	Jimma-1	Agaro -1	Gera-1	Metu -1	Jimma-2	Agaro-2	Gera-2	Metu -2	
44/75	17.50	15.33	18.09	22.95	22.11	20.73	22.81	26.22	20.72
133	22.35	20.33	22.54	24.57	24.44	23.04	22.98	23.59	22.98
Kiyaq	23.74	15.50	24.44	24.59	24.00	21.33	24.52	22.40	22.57
165	13.18	17.67	16.67	18.81	23.78	22.54	22.27	23.73	19.83
130	19.67	17.67	22.57	18.57	23.55	19.96	23.17	25.24	21.30
023	15.71	17.50	18.51	23.81	24.51	17.82	21.03	24.62	20.44
9/75	17.46	18.16	18.41	23.67	23.55	19.67	21.92	24.26	20.89
183	18.09	24.33	18.73	22.14	26.44	21.48	22.45	23.82	22.19
032	20.77	19.78	18.57	18.09	26.06	10.90	21.47	24.27	19.99
053	25.08	20.50	23.81	27.09	24.55	25.51	25.96	27.82	25.04
Mean	19.36	18.68	20.23	22.43	24.30	20.30	22.86	24.60	21.59
LSD	5.69	5.43	5.9	5.94	6.19	5.98	4.73	2.49	5.29
CV(%)	17.15	25.07	17.01	15.44	14.85	16.45	12.09	5.90	15.50

Table 7. Mean storage root length (cm) performance of ten taro genotypes tested across eight environments

Genotypes	Environments								Over all mean
	Jimma-1	Agaro -1	Gera-1	Metu - 1	Jimma-2	Agaro-2	Gera-2	Metu - 2	
44/75	19.1	19.5	16.9	17.8	14.8	17.7	18.1	14.9	17.3
133	18.8	18.1	16.7	18.1	16.2	17.6	17.0	16.0	17.3
Kiyaq	18.9	18.0	17.1	18.8	16.9	17.7	17.1	16.7	17.7
165	19.2	18.5	16.2	17.2	15.5	18.1	17.1	15.2	17.1
130	18.2	17.5	16.4	18.0	15.9	17.0	16.5	15.7	16.9
023	18.7	18.0	16.3	17.6	15.7	17.6	16.8	15.5	17.0
9/75	18.2	17.6	16.4	17.9	15.6	16.9	16.6	15.5	16.8
183	18.3	18.1	17.2	18.7	15.9	16.8	17.2	16.0	17.3
032	19.2	17.8	15.9	17.2	16.5	18.4	16.4	15.8	17.1
053	18.3	17.9	17.7	19.7	16.9	16.8	17.3	17.0	17.7
Mean	18.7	18.1	16.7	18.1	16.0	17.5	17.0	15.8	17.2
LSD	1.34	1.83	1.95	1.59	1.36	3.29	2.03	3.71	2.14
CV(%)	15.16	14.41	14.04	16.58	25.14	22.95	18.55	40.12	20.87

Table 8. Mean number of marketable roots per plant performance of ten taro genotypes tested across eight environments

Genotypes	Environments								Over all mean
	Jimma-1	Agaro -1	Gera-1	Metu -1	Jimma-2	Agaro-2	Gera-2	Metu -2	
44/75	3.8	5.0	7.3	4.5	3.2	2.0	4.2	3.1	4.1
133	3.6	5.5	8.9	4.5	3.5	1.9	4.5	3.2	4.5
Kiyaq	4.2	12.2	14.3	6.2	4.8	2.5	6.1	4.3	6.8
165	4.3	7.4	7.9	5.2	3.4	2.4	4.6	3.5	4.8
130	5.1	5.3	8.0	5.6	4.4	3.3	5.4	4.3	5.2
023	4.6	4.5	7.7	5.1	4.0	2.9	5.0	3.9	4.7
9/75	4.4	6.3	7.3	5.1	3.4	2.5	4.6	3.6	4.7
183	3.7	4.9	6.1	4.3	2.7	1.8	3.8	2.8	3.8
032	4.5	5.1	7.0	5.1	3.6	2.7	4.6	3.7	4.5
053	4.1	8.2	14.4	5.7	5.4	2.7	6.4	4.5	6.4
Mean	4.2	6.4	8.9	5.1	3.8	2.5	4.9	3.7	5.0
LSD	1.48	1.33	1.60	1.42	2.00	1.43	2.09	1.16	1.56
CV(%)	2.76	3.42	2.95	2.59	3.60	2.52	3.69	2.20	2.97

Additive main effect and multiplicative interaction (AMMI 2) bi-plot analysis

The performance of a genotype in an environment is considered better than the average performance in that environment if the angle between its vector and the environment is less than 90° (acute angle); near average if the angle is 90° (right angle) and below average if the angle is greater than 90° (obtuse angle) (Yan *et al.*, 2007). The AMMI-2 bi-plot analyses of total storage root weight (TSRW), storage root length (SRL) and number of marketable roots per plant (NMSRP) of the ten genotypes evaluated in eight environments are shown in Figures 1-3, respectively. For TSRW, the percentage of variation accounted by the IPCA-1 and IPCA-2 axes was 45.86% and 21.33%, respectively (Figure 1). Genotypes 2 (133),

1 (44/75), and 10 (053) had broad adaptability as they were located closer to the center of the bi-plot. Genotypes 9 (032), 8 (183), 3 (Kiyaq), 5 (130) and 4 (165) were placed furthest from the point of origin, showing specific adaptation to the environments within their proximity on the bi-plot.

Furthermore, genotypes 8 (183), 2(133), and 10 (053) had above average yields and were located on the acute angle of PC-1. Genotypes located on the right-hand side of the bi-plot were positively associated with the environments on the same side. Based on this analysis, environment Gera-1 was considered highly discriminating and had similar discriminating ability of the site since it had longer vector. Environments Gera-2 and Agaro-2 were highly positively correlated, indicating that genotypes ranked similarly with respect to total storage root weight in these environments. This suggested that these environments might form part of the same mega-environment.

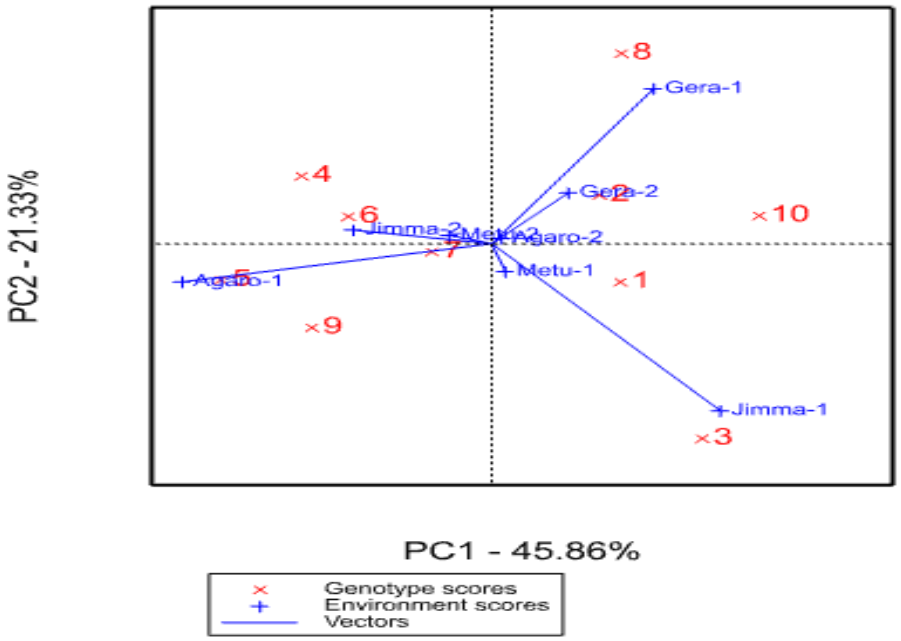


Figure 1. AMMI-2 bi-plot for IPCA-1 against IPCA-2 scores for 10 taro genotypes and eight environments on total storage root yield

In regarding to storage root length, the AMMI-2 bi-plot explained 76.34% of the total GEI (Figure 2). The percentage of variation accounted for by IPCA-1 and IPCA-2 was 51.53% and 24.81%, respectively. Genotypes 2 (133), 6 (023), 7 (9/75) and 5 (130) were close to the bi-plot origin; these genotypes had yields close to the overall mean yield. The following genotypes were positively correlated with environments closer to them: 032 (Jimma-2), 023 and 165 (Agaro-1), Kiyaq and 130 (Metu-2) and 053 (Gera-2). Genotypes located on the right-

hand side of the bi-plot were positively correlated with the environments found on that side. Thus, all environments had similar discriminating ability of the site at different right angles. Environments Gera-1 and Metu-2 had the shortest vector, suggesting poor genotype discriminating ability.

The percentage of variation of AMMI-2 bi-plot for the number of marketable storage roots accounted for by IPCA-1 and IPCA-2 was 68.17% and 12.29%, respectively (Figure 3). Genotypes 1 (44/75), 7 (9/75) and 8 (183) were much closer to the bi-plot center, showing broader adaptability across the environments and had positively correlated with environments located on the right-hand side of the bi-plot. Genotypes 1 (44/75), 7 (9/75) and 8 (183) were positively correlated with environment Gera-2, and genotypes 5 (130) and 9 (032) suggesting specific adaptation to this environment. In this investigation, except environments Gera-1, Agaro-2 and Agaro-1, all environments had shorter vectors, which implied the low discriminating ability of the sites. Most environments in this study had positive correlations. The positive correlation obtained between test environments also suggests that indirect selection for total storage root yields and related traits can be applied across the sites. Combining these environments into a single test environment can give similar genotypic responses, thus reducing unnecessary costs and improving breeding efficiency.

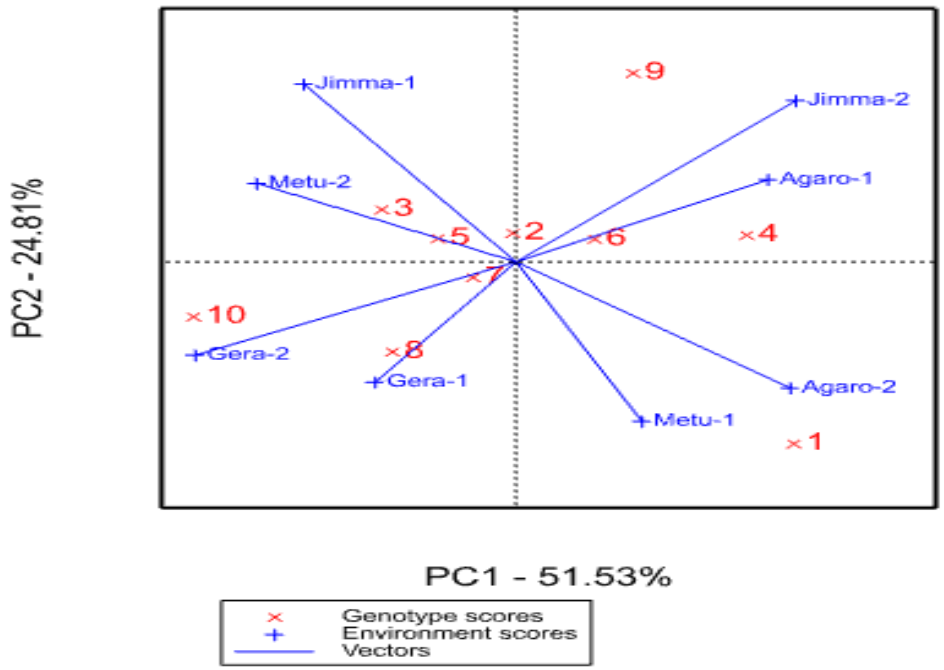


Figure 2. AMMI 2 bi-plot for IPCA-1 against IPCA-2 scores for 10 taro genotypes and eight environments on storage root length

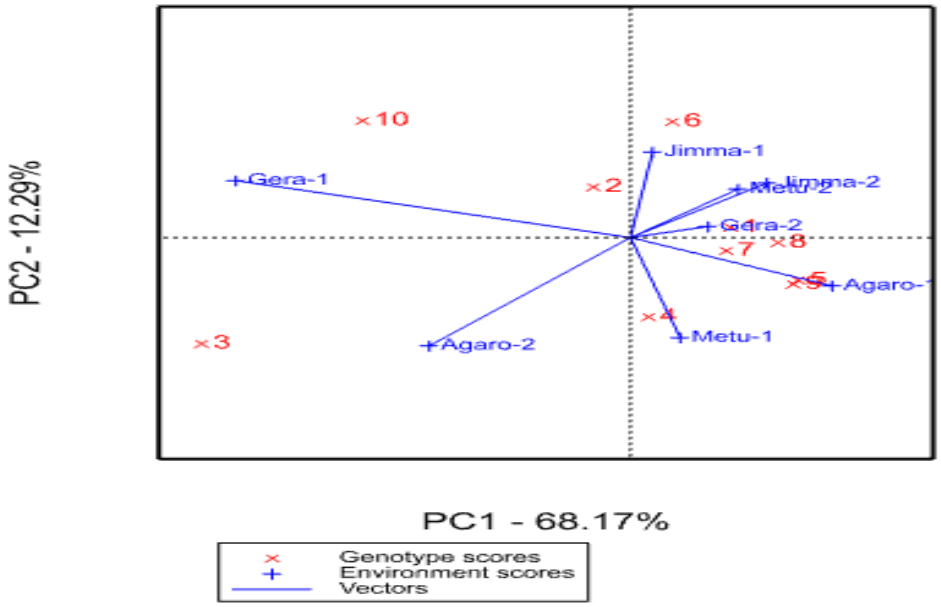


Figure 3. AMMI-2 bi-plot for IPCA-1 against IPCA-2 scores for 10 taro genotypes and eight environments on the number of marketable roots per plant

Mega-environments analysis using GGE bi-plots

The polygon views of the GGE bi-plot for total storage root yield, storage root length and number of marketable storage roots per plot are presented in Figures 4, 5 and 6, respectively. In each bi-plot, different mega environments (MGEs) were grouped into sectors. Environments within the same MGE were assumed to have a similar effect on genotype performance and were considered a homogeneous group. Similarly, genotypes within the same MGE were assumed to have a similar response to the environments located in the MGE sector. The genotype located at the vertex of the sector was considered the best-performing variety in the MGE.

For total storage root weight (Figure 4), principal component-1 (PC-1) explained 34.81% of the total variation, whereas PC-2 explained 29.50%, with both axes accounting for 64.31% of the total variation. Perpendicular lines were drawn to each side of the polygon, all lines starting from the bi-plot origin. In this analysis, four mega-environments were found, environments Agaro-2, Gera-2 and Gera-1 combined into MGE-1, environments Metu-1 and Jimma-1 were fell into a separate MGE-2 and environments Jimma-2 and Agaro-1 pooled into MGE-3, and Metu-2 separated in to MGE-4, respectively. Genotypes 3 (Kiyaq) and 10 (053) were the highest-yielding genotype in MGE-1. Genotype 5 (130) won in the MGE-2. Genotype 8 (183) was positively correlated with the environment Metu-2 site and was the winning genotype in MGE-4.

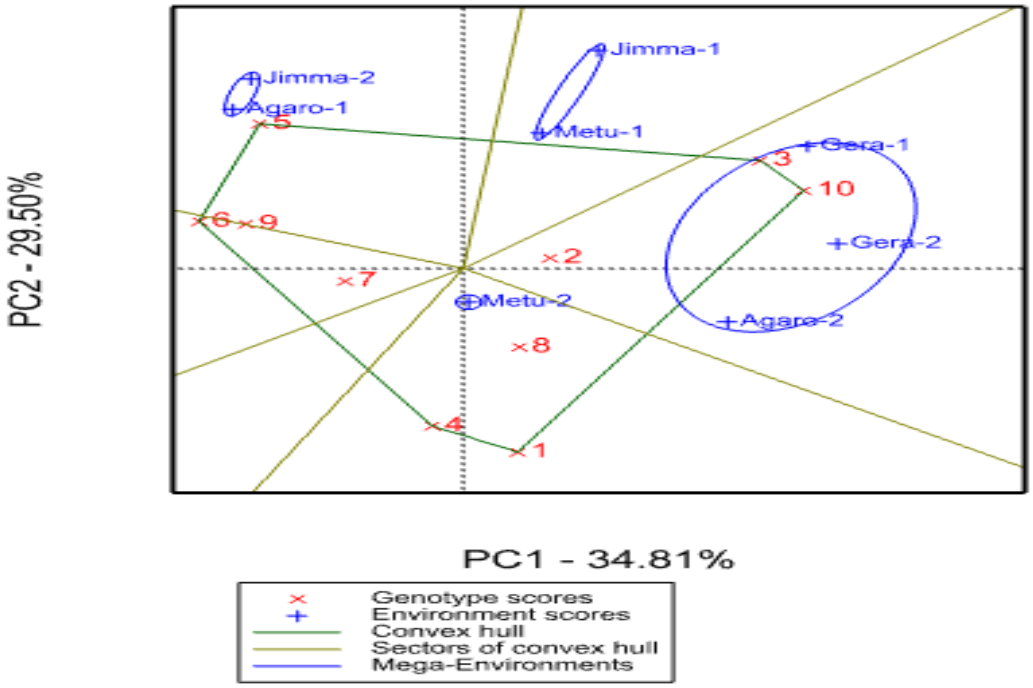


Figure 4. The "which-won-where" polygon view for total storage root yield of the GGE bi-plot analysis representing the performance of 10 taro genotypes tested across eight environments

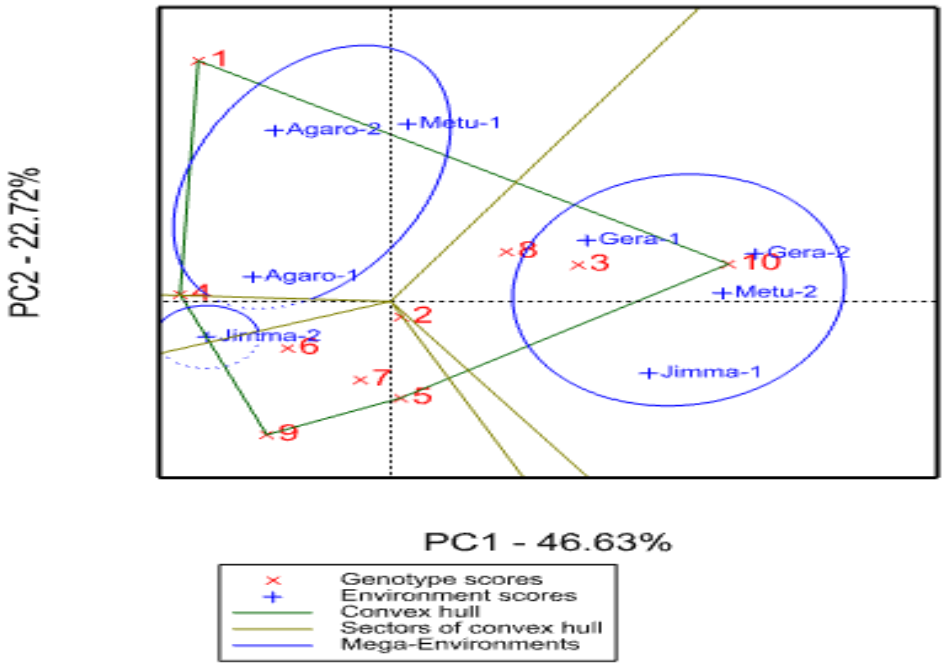


Figure 5. The "which-won-where" polygon view for storage root length of the GGE bi-plot analysis representing the performance of 10 taro genotypes tested across eight environments

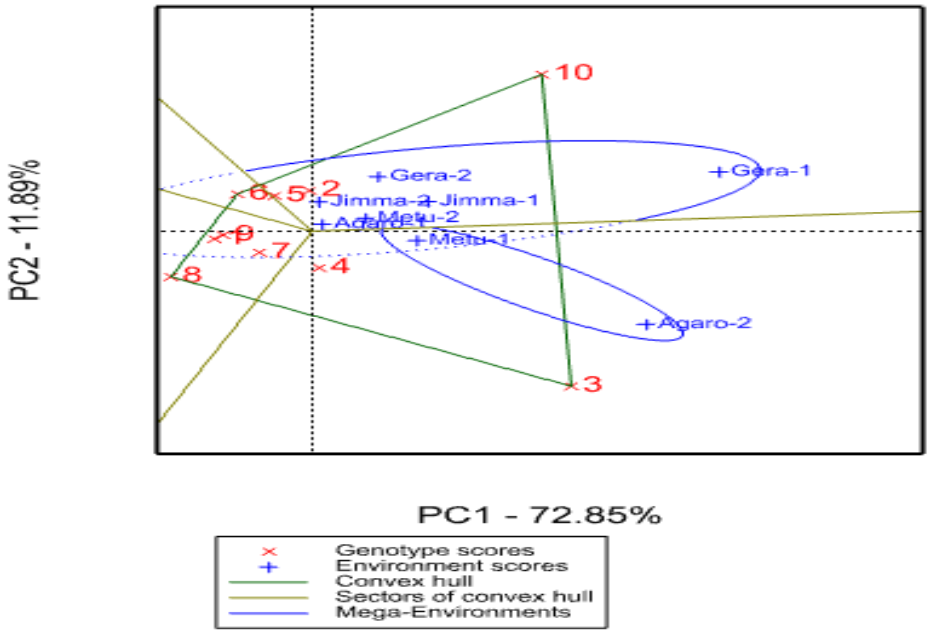


Figure 6. The "which-won-where" polygon view for the number of marketable storage roots of the GGE bi-plot analysis representing the performance of 10 taro genotypes tested across eight environments

Genotype yield and stability using GGE bi-plots

The average environment coordinate (AEC) view based on genotype-focused singular value partitioning (SVP = 1) can be referred as the "mean versus stability" view of GGE bi-plot (Yan *et al.*, 2007). The view facilitates genotype comparisons based on mean performance and stability across environments within a mega-environment. The genotype stability view of GGE bi-plot explained 88.24, 68.98 and 86.03% of genotypic and genotype by environment variation for the total storage root yield, storage root length and number of marketable roots per plant, respectively (Figure 7: Panels A, B, and C). The arrow shows on the AEC abscissa points in the direction of higher trait performance of genotypes and ranks the genotypes with respect to trait performance. Thus, genotype 10 (053) had the highest total storage root yield and marketable yield while genotype 1 (44/75) had the lowest (Figure 7: Panel A). Similarly, genotypes 3 (Kiyaq) and 10 (053) had the highest storage root length and marketable storage roots per plant, respectively. Conversely, genotype 9 (032) and 4 (165) had the shortest storage root length and genotype 8 (183) had the lowest marketable storage root count (Figure 7: Panels B and C).

The stability of each genotype was explored by its projection onto the AEC vertical axis. The most stable genotype was located almost on the AEC abscissa (horizontal axis) and had a near-zero projection onto the AEC (vertical axis). Thus, genotypes 10 (053) and 2 (133) were the most stable and 1 (44/75) and 4 (165) were the least stable for total storage root yield (Figure 7: Panel A).

According to Yan and Tinker (2006), stability is meaningful only when associated with high trait mean. Therefore, an ideal genotype has both high trait mean and stable performance. An ideal genotype is represented on the head of arrow on the AEC abscissa (horizontal axis) (Figure 7: Panels A, B and C). For storage root length, genotypes 3 (Kiyaq) and 10 (053) could be regarded as the best genotypes (Figure 7: Panel B). Similarly, for number of marketable storage roots per plant these genotypes were the best (Figure 7: Panel C).

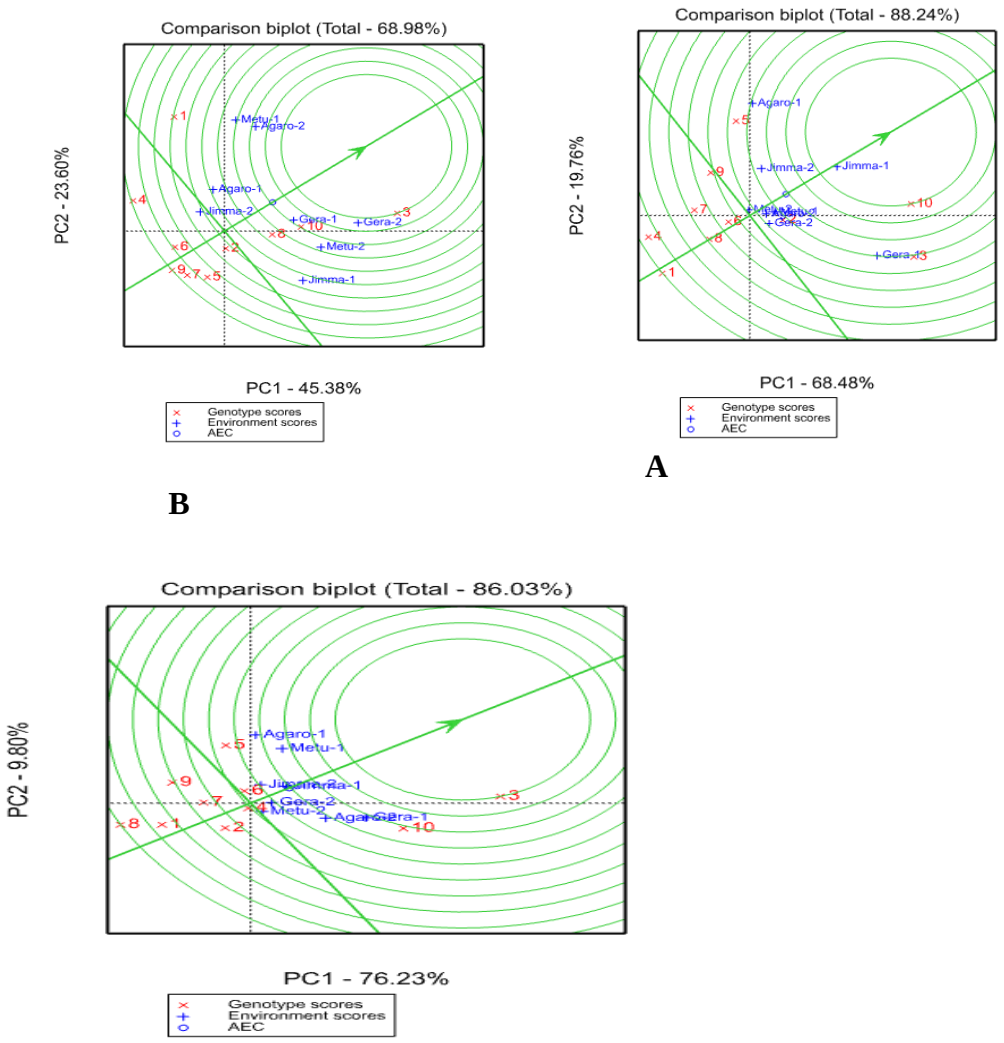
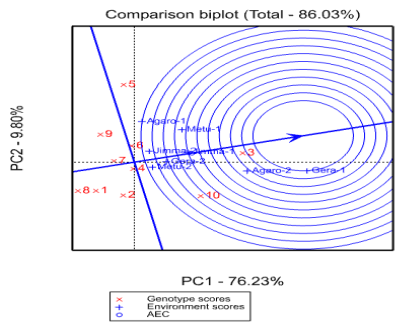


Figure 7A-C. The average environment coordination (AEC) view showing mean performance and stability of 10 taro genotypes tested in eight environments on (Panel A) total storage root yield, (Panel B) storage root length, and (Panel C) number of marketable roots per plant.

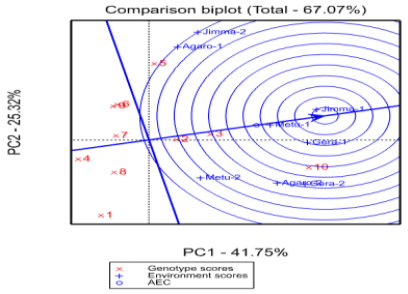
Environment discriminating ability and representativeness using GGE bi-plot

A similar analysis was applied for environment focused bi-plots for total storage root yield, storage root length and number of marketable roots per plant, which represented the ideal environment within a mega-environment (Figure 8A-C). Ideal environment must have high discriminating ability and representativeness. For total storage root yield, the ideal test environment was Jimma-1 followed by Metu-1 (Figure 8A); whereas for storage root length and number of marketable roots per plant, Gera-1 and Agaro-2 were the best environments, owing to their closeness to the ideal environment (Figure 8B and C). Test environments that had close proximity to the ideal environment on the AEC axis were positively correlated with genotypes closer to them.

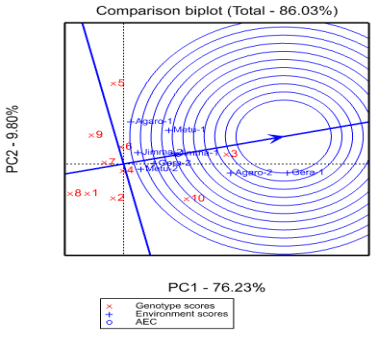
Environments that had less interaction with the genotypes were Agaro-2 and Gera-2 (for total storage root weight and root length) (Figure 8A and B) and Agaro-1 (for number of marketable roots per plant) (Figure 8C). The purpose of validation of test-environment is to identify idea environments that effectively identify superior genotypes for a mega-environment. The ideal test environment should be highly discriminating of the genotypes and representatives of the mega-environment. The result of this study showed that Jimma-1 and Metu-1 had a high discriminating ability and representativeness for taro genotype evaluation for total storage root yield while Gera-1 and Agaro-2 for storage root length and number of marketable roots per plant, respectively.



A



B



C

Figure 8A-C. The bi-plot for comparison of all environments with the ideal environment for (Panel A) total storage root yield, (Panel B) storage root length, and (Panel C) number of marketable roots per plant

The positive correlation existing between the genotypes and environments indicated that these genotypes possessed a specific adaptation. However, when test environment markers fall close to the bi-plot origin, as of their short vectors, it means that all genotypes performed similarly in those environments. This provides little or no information about the genotype differences, since the genotypes show broad adaptability. In this case, breeders find it difficult to select higher yielding and more stable taro genotypes.

Variation in the performance of genotypes in different environments is a great constraint to the breeding and selection of genotypes for narrow and wide adaptations (Owusu *et al.,* 2017). The significant differences ($p<0.01$) among the environments for all the traits considered reveals that the tested environments were distinctive. The environments had different influences on the performance of genotypes due to the different climatic conditions that prevailed at the experimental locations during the experiment period. This finding agrees with the reports of (Eze *et al*., 2016; Asfaw *et al*., 2020) who found significant differences among environments during their multi-environment trials. Understanding the effect of GEI on traits enables breeders to identify locations which are efficient in distinguishing ideal genotypes across sites as well as environments which are good representatives of target regions of interest (Lin *et al*., 1986). The significant GEI observed for all the traits except for storage root length and girth suggests that the expression of these traits by the genotypes was inconsistent across the eight environments. A genotype which performed better in one environment did perform poorly in another environment. A higher magnitude of the mean square for environment than for genotypes and GEI for all the traits suggests that environmental influence played a major role in the expression of the traits. This result in in harmony with previous reports (Purchase *et.al*, 2020; Asfaw *et.al*, 2020) who stated that the higher magnitude of the mean square of the environment reveals the diversity among the environments and large variation amongst the environments over genotypes. Furthermore, the genotype ranked differently at different environments suggests the existence of GEI and the environmental conditions were variable during the execution of the experiment. This suggests that environment-specific genotypes of taro should be selected for different agro ecological zones and environmental conditions as reported by (Waki *et al.,* 2018; Gerrano *et al*., 2019).

In the present study, the mean storage root yield showed highly significant differences ($p<0.01$) among the tested taro genotypes from southwest Ethiopia. This suggested the presence of high degree of genetic variability in the materials

evaluated and the existence of considerable genetic diversity among taro genotypes for selection. This result is similar with the finding of Tewodros and Yared (2014) who reported taro genotypes collected from southern Ethiopia had significant differences for storage tuber yield and related traits. Similarly, Yared *et.al*. (2014) also reported highly significant ($p<0.01$) differences among taro genotypes in south Ethiopia. The storage root length was also varied significantly ($p<0.01$) among tested taro genotypes. The longest root length was obtained from genotypes 053, Kiyaq and 44/75 with values of 17.68, 17.66 and 17.35cm, respectively. The length of tuber was highly affected by the soil texture where taro was grown. This result is supported by the finding of Tewodros and Yared (2014) who reported the storage tuber length of taro grown in clay soil and high moisture stress areas of southern Ethiopia were reduced significantly. Further, Esther *et al.* (2020) reported significantly different corm length among 25 taro genotypes grown in Dormah Ahenkro, Bunso and Tano Dumasi districts of Ghana. However, in this study the storage tuber length obtained from Jimma (48.90cm) and Metu (53.10cm) was higher than the report of Asfaw *et al.* (2020).

In this study, taro genotypes 053, 133 and Kiyaq produced the highest total storage root yields with values of 25.04, 22.98 and 22.57 t ha^{-1}, respectively. The result obtained from this study was lower than the finding of Esther *et al.* (2020) who reported the corm yield of taro ranged from 8.62-440 t ha^{-1} collected from different areas of Ghana. However, the result obtained from this study was higher than the finding of Tewodros and Getachew (2013) for taro genotypes collected from southwest Ethiopia. In the present study, the mean number of marketable storage roots of taro genotypes ranged from 2-14. The least number of marketable storage roots was obtained from genotype 183 at Agaro-2 while the highest mean number of marketable storage roots was collected from genotype Kiyaq at Gera-1. This result was similar with the finding of Tewodros and Yared (2015) who reported the number of marketable storage roots ranged from 3-22. Similarly, the starch content obtained was almost similar with the study of Tewodros and Getachew (2013) who found the number of marketable storage roots of taro genotypes from southwest Ethiopia ranged from 2-16. Furthermore, the GGE bi-plot identified four mega-environments for taro breeding: Agaro-1, Gera-2 and Gera-1 combined into MGE-1; Metu-1 and Jimma-1 were fell into a separate MGE-2; Jimma-2 and Agaro-1 pooled into MGE-3; and Metu-2 separated in to MGE-4.

Conclusion and Recommendation

The result of the study indicated that the storage root yield of taro was highly affected by genotype and location (environment). In addition, GEI contributed to the variation among the genotypes studied. This result further indicated that the yields and yield related traits studied were varied across the test environments.

Genotypes 053, 133 and Kiyaq were found to be widely adaptable and had yield stability across environments. They are therefore recommended for release to farmers in southwest Ethiopia for production.

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Evaluation of Fenugreek (*Trigonella Foenum-Graecum* L.) for Highland Environments in Ethiopia

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Abstract

This study was conducted to evaluate the performance of promising lines of fenugreek genotypes across locations for yield, quality and adaptability to release new variety for wider cultivation. Accordingly, 13 fenugreek genotypes (11 pipe lines and 2 standard checks) were used at five locations (Debre Zeit, Chefe Donsa, Akaki, Kulumsa and Haramaya) in 2018 and 2019 cropping seasons. The experiment was laid out in a randomized complete block design with three replications. The combined analysis over locations revealed the significant effects of genotypes for plant height, number of primary branches per plant, pod length, number of seed per pod and grain yield per hectare among the studied traits. Genotype FG-1 scored 12.26% yield advantage over the grand mean, 42.99% yield advantage over the standard check (Burka) and these genotypes scored 10.114% oleoresin content which was 4.73% advantage over the grand mean (9.65%) and 1.3% advantage over the standard check. FG-1 was the second widely adapted genotype among the tested genotypes across locations and over years based on stability value. FG-12 was the third high yielding genotype and scored 1027.7 kg ha-1 that is 7.1% and 32.86% yield advantage over the grand mean and the standard check, respectively. FG-12 scored 10.54% oleoresin content which was 9.2% and 5.62% advantage over the grand mean (9.65%) and the standard check in that order. Accordingly, the verification trial was undertaken with two candidate varieties (FG-1 and FG-12) and recently released variety Burka under diverse agro-ecologies. The variety release technical committee evaluated the performance of the candidate varieties and the recently released variety. The two candidates namely FG-1 ("Chafe") and FG-12 ("Turu") have been released for wider cultivation.

Keywords: Genotype, environment, interaction, yield, oleoresin

Introduction

Fenugreek (*Trigonella foenum-graecum* L.), wild or cultivated, is widely distributed throughout the world. It is indigenous to countries on the Eastern shores of the Mediterranean, but the crop is widely cultivated in India, Egypt, Ethiopia, and Morocco (Davoud *et al*., 2010). In Ethiopia, fenugreek is used for many purposes. As a rotation crop, it improves both the soil structure and fertility. In addition, it fetches high revenue for farmers and producers. Furthermore, its

flour is used as a flavoring of the traditional bread and maintains soft texture of "*tef-injera*" (Million *et al*., 2012). Ethiopia is rich in fenugreek genetic resource; however, it is cultivated by traditional methods of farming without optional improved varieties and production packages.

The wide gap of fenugreek yield under farmers' conditions (1.28 t ha^{-1}) and attainable yield (5.2 t ha^{-1}) is attributed to lack of advanced production packages and improved varieties for different agro-ecological zones of the country (Wojo *et al.,* 2016). The development of high yielding varieties of fenugreek for different agro-ecologies has been given less emphasis. Therefore, this research activity was initiated to develop new optional superior fenugreek variety from the locally collected 75 fenugreek accessions.

Materials and Methods

Description of study areas

The experiment was conducted at five locations, namely Debre Zeit, Chefe Donsa, Akaki, Kulumsa and Haramaya (Table 1) in 2018 and 2019 cropping seasons.

Table 1. Agro ecological description of the testing locations

Locations	Altitude (m.a.s.l)	Rainfall (mm)	Soil type	Global Position	
				Latitude	Longitude
Akaki	2200	1025	Vertisol	08°52' N	38°47' E
Chefe Donsa	2450	909	Vertisol	08°58' N	38°37' E
Debre Zeit	1900	851	Vertisol	08°44' N	38°58' E
Haramaya	1980	780	Alluvial	9°26' N	42°3' E
Kulumsa	2200	820	Luvisol	08°01'10" N	39°09'11" E

Experimental materials and procedure

Eleven pipeline genotypes and two released varieties were used for the study (Table 2). The effect of genotype, environment, and genotype by environment interaction (GEI) on yield and yield related traits of fenugreek genotypes was estimated. General analysis of variance for grain yield and yield components for each environment and across locations was analyzed. The analysis of variance (ANOVA) for each location was performed to assess the differences of performance among genotypes for yield and yield related traits following the standard procedure (Gomez and Gomez, 1984). Bartlett's test was used to assess the homogeneity of error variances prior to combine analysis over environments (Bartlett, 1947). Combined analysis over environments was analyzed using GenStat (16th edition) statistical software. Duncan Multiple Range Test (DMRT) at 5% probability was used for means comparison of the tested genotypes (Gomez and Gomez, 1984). The interaction principal component axis (IPCA) scores for each genotype were calculated as stability parameters of AMMI model. In addition, Additive Main Effect and Multiplicative Interaction (AMMI) stability

value (ASV) for each genotype was calculated to identify stable genotypes (Purchase, 2000).

Table 2. List of experimental materials

No.	Treatments	Genotypes	Status
1	FG-1	FG-202120	Pipe line
2	FG-2	FG-216830	Pipe line
3	FG-3	FG-202171	Pipe line
4	FG-4	FG-53008	Pipe line
5	FG-5	FG-202228	Pipe line
6	FG-6	FG-53105	Pipe line
7	FG-7	FG-212878	Pipe line
8	FG-8	FG-207379	Pipe line
9	FG-11	FG-202137	Pipe line
10	FG-12	FG-53063	Pipe line
11	FG-9	Chala	Check
12	FG-13	Burka	Check
13	FG-10	FG-227379	Pipe line

Results and Discussion

The analysis of variance conducted for each location showed a significant ($P<0.05$) and highly significant ($P<0.01$) differences among genotypes for yield across locations and over years except Kulumsa in 2018 (Tables 3 and 4). In addition, the combined analysis of variance over environments showed significance difference for mean squares of environment, genotype and the interaction of genotype by environment (GEI) for grain yield (Table 5). Furthermore, the fenugreek genotypes exhibited signficant differenceces for different vegetative traits and oleoresin content at different locations (Table 6 and 7). The signficant effect of environment and GEI on the studied traits was an indication of the differential response of genotypes across the test locations. In agreement with the current study results, Basu *et al*. (2009) at seven locations and Kakani *et al*. (2014) at three environments reported that the responses of fenugreek genotypes were different for various traits at different locations and they found that environment, genotype and GEI had significant effect on pod per plant, seed per pod, thousand seed weight and seed yield per plant.

Yield performance

The analysis of variance for grain yield in 2018 cropping season showed significance differences at all locations except at Kulumsa (Table 3). The differences among the tested fenugreek genotypes indicated inconsistent grain yield performance across the test locations. Genotypes FG-3 (1334.21 kg ha^{-1}) and FG-10 (1303.03 kg ha^{-1}) attained higher pooled mean grain yield than the other genotypes. Nevertheless, low overall mean grain yield was obtained from Burka (920 kg ha^{-1}) and FG-6 (953.78 kg ha^{-1}). Genotypes FG-3 and FG-10 had

13.8% and 10.92% yield advantages over the grand mean (1174.68 kg ha^{-1}), respectively. Conversely, genotypes Burka and FG-6 showed 21.94% and 19.08% yield reductions over the grand mean. Mean yield differences from location to location indicated that the environments were diverse; where some of the test environments were favorable while others were not suitable for the tested genotypes. Differences for grain yield in fenugreek genotypes were reported by Million *et al*. (2013) and Wojo *et al.* (2015) who studied on fenugreek genotypic and phenotypic variability.

The analysis of variance for grain yield in 2019 cropping season showed significance differences at all locations (Table 4). Genotypes FG-1 (957.07 kg ha^{-1}) and FG-3 (874.03 kg ha^{-1}) provided higher pooled mean grain yield than other genotypes across the test locations. Conversely, low pooled mean grain yield was obtained from FG-6 (619.03 ha^{-1}) across the test locations. Genotypes FG-1 and FG-3 had 28.58% and 17.38% yield advantages over the grand mean (744.57 kg ha^{-1}) across the test locations, respectively. However, genotype FG-6 had the lowest pooled mean with 16.86% yield reduction over the grand mean. Mean yield differences from location to location indicated that the environments were diverse and differences among tested fenugreek genotypes indicated inconsistent performance of genotypes across the test locations.

Table 3. Mean grain yield of fenugreek genotypes at five locations in 2018 cropping season

Genotype	Debre Zeit	Chefe Donsa	Akaki	Kulumsa	Haramaya	Mean
FG-1	1513^{a}	1301^{bcd}	1561^{ab}	975	923^{bcde}	1254.84^{abc}
FG-2	1276^{ab}	1489^{abcd}	1053de	1274	1070^{ab}	1232.55^{abc}
FG-3	1524^{a}	1814^{a}	1719^{a}	969	643^{fg}	1334.21^{a}
FG-4	1526^{a}	1494^{abcd}	1288^{cd}	1076	850^{bcdef}	1247.2^{abc}
FG-5	852^{c}	1340^{bcd}	1266^{cd}	1179	1030^{abc}	1133.63^{cd}
FG-6	924^{bc}	1345^{bcd}	848^{e}	1140	506^{g}	953.78^{e}
FG-7	1073^{bc}	1674^{ab}	1098de	1222	780^{edf}	1162.31^{bcd}
FG-8	1024^{bc}	1364^{bcd}	1698^{a}	1226	833^{cdef}	1229.49^{abc}
Chala	1339^{ab}	1350^{bcd}	1568^{ab}	1044	700^{efg}	1200.71^{abc}
FG-10	1543^{a}	1598^{abc}	1103de	1139	1130^{a}	1303.03^{ab}
FG-11	1287^{ab}	1190^{cd}	1051de	1080	666^{fg}	1055.26^{de}
FG-12	1282^{ab}	1292^{bcd}	1387^{bc}	1267	976^{abcd}	1241.28^{abc}
Burka	1076^{abc}	1142^{d}	951^{e}	710	723^{efg}	920.14^{e}
Mean	1249	1415	1276	1100	833	1174.68
CV (%)	19.64	15.53	12.35	19.3	14.28	16.70

Means followed by different letter(s) in a column are significantly different at 5% probability.

Table 4. Mean grain yield of fenugreek genotypes at five locations in 2019 cropping season

Genotype	Debre Zeit	Chefe Donsa	Akaki	Kulumsa	Haramaya	Mean
FG-1	789.07^{ab}	1569.44^{a}	536.85^{ab}	1353.33^{ab}	1353.33^{ab}	957.07^{a}
FG-2	733.33^{abc}	1178.89^{bc}	304.26^{e}	1280^{abc}	1280^{abc}	760.14^{cd}
FG-3	881.66^{a}	1203.33^{b}	568.52^{ab}	1146.66^{bcde}	1146.66^{bcde}	874.03^{ab}
FG-4	730^{abc}	896.85^{def}	485.18^{bcd}	1223.33^{abcd}	1223.33^{abcd}	767.74^{cd}
FG-5	578.7^{cd}	857.59^{def}	347.04^{de}	1070^{cdef}	1070cd^{ef}	640.07^{e}
FG-6	610^{cd}	762.96^{ef}	346.11^{de}	1030^{cdef}	1030^{cdef}	619.03^{e}
FG-7	551.48^{d}	976.66^{cde}	653.33a	896.66^{ef}	896.66^{ef}	746.29^{cd}
FG-8	713.33^{abcd}	980^{cde}	377.4^{cde}	823.33^{f}	823.33^{f}	654.29^{e}
Chala	858.7^{a}	1053.33^{bcd}	430.92^{bcde}	960d^{ef}	960^{def}	746.77^{cd}
FG-10	790.18^{ab}	991.11^{bcd}	343.33^{de}	1053.33^{cdef}	1053.33^{cdef}	704.37^{de}
FG-11	805.74^{ab}	764.63^{ef}	526.66^{abc}	1223.33^{abcd}	1223.33^{abcd}	768.74^{cd}
FG-12	678.51^{bcd}	1012.96^{bcd}	452.40^{bcde}	1473.33^{a}	1473.33^{a}	814.11b^{c}
Burka	806.66^{ab}	710.92^{f}	298.33^{e}	1020^{cdef}	1020^{cdef}	626.85^{e}
Mean	732.88	996.82	436.18	1119.49	1119.49	744.57
CV (%)	13.94	13.19	21.42	14.81	14.81	16.26

Means followed by different letter(s) in a column are significantly different at 5% probability.

The overall performance of the genotypes across locations and over years were inconsistent for grain yield. Genotypes FG-1, FG-3 and FG-12 exhibited the highest pooled mean grain yields of 1105 kg ha^{-1}, 1104 kg ha^{-1} and 1027 kg ha^{-1} respectively; while genotypes Burka and FG-6 depicted the lowest pooled mean grain yields without statistically significant differences. Genotypes FG-1, FG-3 and FG-12 sequentially provided 15.15%, 15.05% and 7.1% yield advantages over the grand mean (959.54 kg ha^{-1}) across the test locations and over years. Conversely, genotypes Burka and FG-6 showed 19.38% and 18.04% yield reduction over the grand mean. (Table 5). This result is in agreement with the finding of Giridhar *et al.* (2016) who reported a highly significant mean grain yield differences among the tested fenugreek genotypes and their inconsistent performances across locations.

Table 5. Combined analysis for yield across five locations over two seasons

Genotype	Debre Zeit	Chafe Donsa	Akaki	Kulumsa	Haramaya	Mean
FG-1	1151.3^{abc}	1435.3^{ab}	1048.98^{ab}	1164.3^{abc}	730^{ab}	1105.96^{a}
FG-2	1004.8^{abcde}	1333.9^{abc}	678.89^{ef}	1277^{ab}	687.13^{abcd}	996.35^{bcd}
FG-3	1203.1^{a}	1509^{a}	1143.8^{a}	1058^{bcd}	606.67^{abcde}	1104.12^{a}
FG-4	1128.3^{abc}	1195.6^{cde}	886.94^{cd}	1149.8^{abc}	676.67^{abcd}	1007.47^{bc}
FG-5	715.5^{g}	1098.9^{defg}	806.57^{de}	1124.8^{bc}	688.52^{abcd}	886.85^{e}
FG-6	768.5^{fg}	1054.4^{efg}	597.41^{f}	1085.4^{bcd}	426.39^{f}	786.41^{f}
FG-7	794.1^{efg}	1325.4^{abc}	875.65^{cd}	1059.8^{bcd}	716.67^{abc}	954.3^{bcde}
FG-8	868.9^{defg}	1172.3^{cdef}	1037.87^{ab}	1025^{cd}	605.37^{bcde}	941.89^{cde}
Chala	1099^{abc}	1201.9^{cde}	999.91a^{bc}	1002.4^{cd}	565.46^{de}	973.74^{bcd}
FG-10	1167^{ab}	1294.6^{bcd}	723.33^{ef}	1096.6^{bc}	736.94^{a}	1003.7^{bc}
FG-11	1046.4^{abcd}	977.5^{fg}	789.17^{de}	1152^{abc}	595^{cde}	912d^{e}
FG-12	980.6^{bcdef}	1152.6^{cdef}	919.91^{bcd}	1370.4^{a}	715^{abc}	1027.7^{ab}
Burka	940.1^{cdef}	926.6^{g}	624.81^{f}	865.2^{d}	510.83^{ef}	773.5^{f}
Mean	989.81	1205.99	856.4	1110.05	635.43	959.54
CV (%)	18.95	15.02	15.13	17.16	17.07	17.36

Means followed by different letter(s) in a column are significantly different at 5% probability.

Vegetative performance

The genotypes showed significance differences for plant height, number of primary branch per plant, pod length and number of seeds per pod over years and across locations (Table 6). Genotype FG-4 showed higher mean value for plant height, while genotype Burkaa had short plant height among the studied genotypes. Genotype FG-8 showed higher mean value for number of primary branches per plant; whereas genotype FG-3 had small number of primary branches per plant. Genotype FG-3 depicted higher mean value for pod length, while genotype Chala had short pod length. Genotypes FG-1 and FG-2 showed higher mean values for number of seeds per pod; however, genotype FG-5 had small number of seeds per pod among the studied genotypes across locations and over years. Genotypes FG-1 and FG-12 showed low disease incidences; whereas FG-6 and Burka had high disease incidences among the studied genotypes across locations and over years. This result is in agreement with the findings of Prajapati *et al*. (2010) and Singh (2014) who reported the presence of significant differences for vegetative traits among the tested fenugreek genotypes.

Table 6. Combined analysis for vegetative parameters across five locations over two seasons

Genotype	PH	NPBPP	PL	NSPP	Disease incidence
FG-1	39.10^{ab}	3.93^{ab}	12.44^{ab}	11.19^{a}	31.47^{d}
FG-2	39.67^{ab}	4.21^{ab}	12.24^{ab}	11.29^{a}	54.67^{bc}
FG-3	40.60^{a}	3.65^{b}	12.79^{a}	10.75^{ab}	51.46^{c}
FG-4	41.48^{a}	3.89^{ab}	12.42^{ab}	11.09^{ab}	54.00^{bc}
FG-5	39.22^{ab}	3.93^{ab}	12.35^{ab}	10.15^{b}	56.80^{ab}
FG-6	37.05^{bc}	4.29^{ab}	12.13^{b}	10.48^{ab}	59.07^{a}
FG-7	39.17^{ab}	3.93^{ab}	12.47^{ab}	10.99^{ab}	57.33^{ab}
FG-8	38.50^{abc}	4.46^{a}	12.43^{ab}	10.87^{ab}	56.67^{ab}
Chala	41.03^{a}	4.11^{ab}	12.02^{b}	10.32^{ab}	57.87^{ab}
FG-10	40.17^{ab}	4.00^{ab}	12.56^{ab}	11.11^{ab}	53.87^{bc}
FG-11	40.45^{ab}	3.87^{ab}	12.65^{ab}	10.75^{ab}	58.13^{ab}
FG-12	39.28^{ab}	4.25^{ab}	12.48^{ab}	10.51^{ab}	32.67^{d}
Burka	35.48^{c}	3.93^{ab}	12.64^{ab}	10.41^{ab}	60.67^{a}
Mean	39.32	4.03	12.43	10.76	52.66
CV	17.68	32.87	10.2	18.37	11.50

PH=Plant height, NBPP=Number of primary branch per plant, PL=Pod length, NSPP=Number of seeds per pod.

Oleoresin content

The tested fenugreek genotypes did not show significant differences for oleoresin content across the test locations. However, based on the mean values genotype FG-7 scored higher oleoresin content (12.74%), while genotype FG-4 scored low oleoresin content (7.56%) among the studied genotypes across locations (Table 7).

Table 7. Oleoresin content (% oil) across five locations from 2018 cropping season samples

Genotype	Haramaya	Hirna	Chefe Donsa	Debre Zeit	Akaki	Mean	Rank
FG-1	5.79	8.03	12.87	13.42	10.46	10.11	5
FG-2	5.78	7.84	8.53	5.89	11.44	7.89	12
FG-3	7.09	11.43	8.48	8.46	12.68	9.63	8
FG-4	4.98	7.58	9.03	8.42	7.81	7.56	13
FG-5	5.93	8.18	12.26	7.87	7.48	8.34	10
FG-6	6.72	8.62	9.17	10.30	11.56	9.27	9
FG-7	6.70	9.01	16.37	16.70	14.91	12.74	1
FG-8	7.22	10.08	9.59	7.96	15.01	9.97	7
Chala	7.01	9.64	14.15	7.63	12.15	10.12	4
FG-10	7.20	7.24	9.31	8.68	7.82	8.05	11
FG-11	9.00	9.55	13.20	8.81	16.02	11.32	2
FG-12	6.83	8.91	10.21	12.45	14.33	10.55	3
Burka	6.84	7.81	16.50	8.79	9.98	9.984	6
Mean	6.70	8.76	11.51	9.64	11.67	9.65	

AMMI stability parameters and mean yield performance of genotypes across locations

The mean grain yields of the genotypes and AMMI stability values (ASV) were used to rank the genotypes and to identify genotypes with high mean yield and stable across the test environments (Table 8). The larger the IPCA scores (either negative or positive) were the more specific adapted genotypes for a certain environment; the smaller the IPCA scores (approaching to zero) were the more stable or widely adapted genotypes across the test environments.

FG-1 was the second stable or widely adapted genotype and had 12.26% yield advantage over the grand mean while FG-12 was moderately stable/adapted genotype with the grain yield advantage 7.1% over the grand mean (Table 8, Figure 1). These two genotypes were recommended for cultivation across the test locations among the tested genotypes. This result was in agreement with the findings of Solomon *et al*. (2008) in maize and Farshadfar (2008) in Bread wheat stability studies.

Table 8. Stability parameters from AMMI models at five locations and two seasons (2018-2019)

Genotype	Grand mean (GM)	Rank (GM)	IPCA[1]	IPCA[2]	ASV	Rank (ASV)
FG-1	1106.0	1	5.59	0.60	6.92	2
FG-2	996.4	6	-8.06	-2.06	10.15	9
FG-3	1104.1	2	13.97	0.20	17.23	13
FG-4	1007.5	4	0.18	-4.71	4.72	1
FG-5	886.9	11	-6.25	9.28	12.07	12
FG-6	786.4	12	-6.04	0.76	7.48	4
FG-7	954.3	8	0.18	9.82	9.83	8
FG-8	941.9	9	5.44	7.85	10.33	10
Chala	973.7	7	8.44	-2.25	10.65	11
FG-10	1003.7	5	-1.27	-8.54	8.69	6
FG-11	912.0	10	-4.21	-6.15	8.05	5
FG-12	1027.7	3	-8.10	2.55	9.78	7
Burka	773.5	13	0.13	-7.36	7.36	3
Grand mean	959.55					

AMMI= Additive Main Effect and Multiplicative Interaction, IPCA 1 and IPCA 2 = interaction principal component axis one and two, respectively, ASV = AMMI stability value

Among the studied genotypes FG-4 and FG-1 were selected as the most stable or wider adapted genotypes; FG-12 and FG-10 were moderately adapted genotypes; however, genotypes FG-3 and FG-5 were the most specific adapted genotypes among the studied genotypes across years and locations based on AMMI stability value and GGE biplot graph.

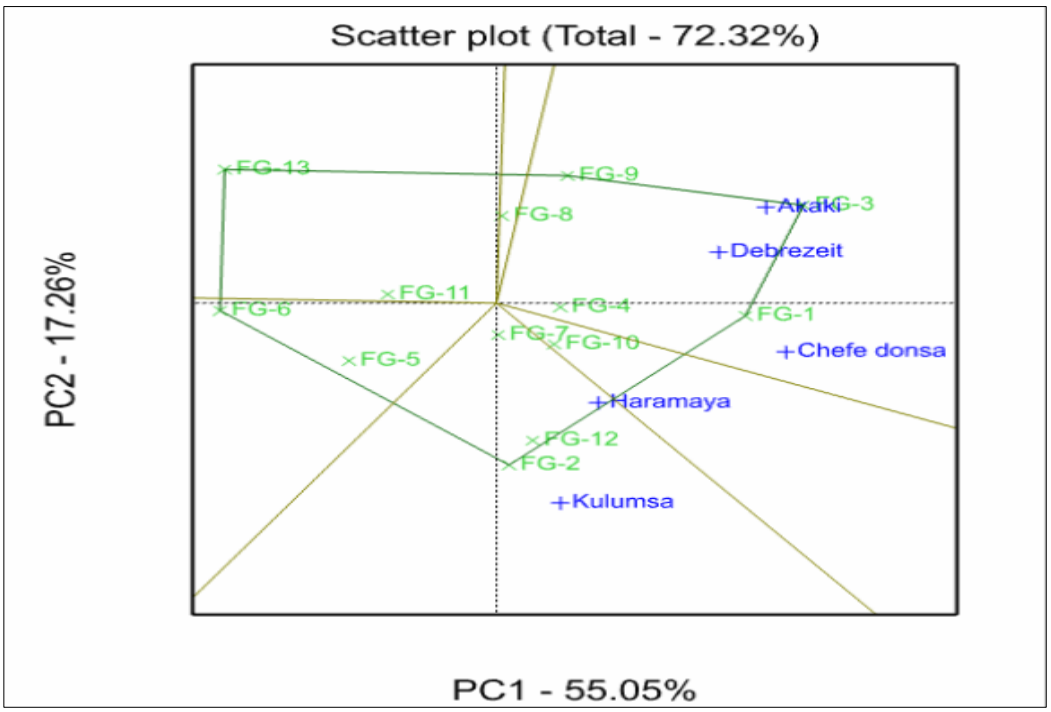

Figure 1. Which won where GGE biplot graph

Conclusion and Recommendation

Genotype FG-1 was the highest yielder among the tested genotypes and scored 1106 kg ha^{-1} with 12.26% yield advantage over the grand mean and 42.99% yield advantage over the standard check (Burka). In addition, genotype FG-1 scored 10.114% oleoresin which was 4.73% higher than the grand mean (9.65%) and 1.3% greater than the standard check (Burka). Furthermore, genotype FG-1 was the second most widely adapted/stable genotype across locations and over years. Conversely, FG-3 was the second high yielding genotype; however, it was less adapted/ unstable across locations and over years. Despite its better yield scores, FG-3 was not recommended for variety verification trial due to its low stability. Genotype FG-12 was the third high yielding genotype and scored 1027.7 kg ha^{-1} with 7.1% yield advantage over the grand mean and 32.86% yield advantage over the standard check (Burka). Besides, FG-12 scored 10.54% oleoresin which was 9.2% higher than the grand mean (9.65%) and 5.62% greater than the standard check (Burka). Moreover, FG-12 was moderately adapted/stable genotype across locations and over years. In conclusion, genotypes FG-1 and FG-12 were recommended for cultivation due to their high yielding potential, wider adaptability and high oleoresin contents among the tested genotypes. Accordingly, the variety verification and the national variety evaluation trials were evaluated by the national variety release technical committee; and two new varieties “Chafe” (FG-1) and “Turu” (FG-12) were released for wider production.

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Evaluation of Korerima (*Aframomum Corrorima*) Genotypes in Diverse Ecology and Variety Development

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Abstract

Ethiopia is the center of origin for Korerima however, there is no improved variety to maximize the production and productivity of the crop. Hence, there is a wide gap between the genetic potential and farmer's production. This research was conducted aiming to develop new korerima variety with high yield, wide adaptation and better in quality. The experiment evaluated 25 korerima genotypes collected from different agro-ecologies of the country in an experiment using a simple lattice design with two replications at four locations (Teppi, Jimma, Bonga and Gera). Combined analysis of variance (ANOVA) over locations revealed significant effect on plant height, number of leaves per plant, fresh and dry capsule yield per hectare. Genotype G-23, G-24 and G-25 were found to be high yielding and had better yield advantages over the local check (Jimma Local-J.L.) as well as the other genotypes tested. Moreover, the stability anlysis (AMMI model) identified G-23 and G-24 as widely adapted genotypes and hence, were selected as candidates for their high yielding and good quality traits. Therefore, they were promoted to variety verification trial and released as the first korerima varieties in the country with names Kefa -1 and Benchi Maji-1 respectively.

Keywords: Korerima, AMMI, Stability analysis, Variety

Introduction

Korerima (*Aframomum corrorima* **(**Braun) P.C.M. Jansen) is indigenous to Ethiopia and belongs to Zingiberaceae family. It is perennial herbaceous crop categorized under the monocotyledonous crops and its diploid with chromosome number of 2n=2x=48 (Surawit and Wondyifraw, 2013). Korerima is one of the well-known native spices crops in the country and also used as medicinal plants. The plant consists of an underground rhizome, a pseudo stem and several broad leaves. Korerima is shade lover plant and requires from 3-5 years to mature depending on the planting materials i.e., either by cutting its clumps or seeds and once it reach maturity the crop gives yield year to year for several years (Eyob, 2009).

The dried capsule or pod of Korerima is the main economical part of the crop and the seeds are used as a spice and it contains different types of essential oils having typical odour (Eyob *et al*., 2007). Korerima is used as condiment in different

traditional Ethiopian dishes and the crop fetches high prices both at local and export markets. The price of a kilo of dry Korerima capsule in the domestic market ranges from 80 to 100 Birr in the villages. Ethiopia exports about 200 MT of Ethiopian Korerima per year (Peethambaran *et al*, 2016).

In the country korerima cultivation, collection and maintenance were started before 1972 E.C in different agricultural research centers mainly at Teppi Agricultural Research Center and Jimma Agricultural Research Center.The production and productivity of korerima is continuously decreasing and it's very low as compared to its genetic potential. This is due to lack of improved production package, improved variety and decline of natural forest land (Jansen, 2002; Endashaw, 2007).

Although there was no improved variety developed, Korerima is highly domesticated and cultivated in Ethiopia long years ago and it is majorly grown in natural forest areas of Kaffa, Bench sheko, South Omo, Illubabor, Jimma, Sheka, and Gofa zones. In good agronomic practices with appropriate post-harvest handling, the yield of dried capsules could reach up to 5 – 8 qt/ha without fertilizers application (Jansen, 2002).

As part of korerima variety development efforts, collection, characterization and multi-location variety trials and verification trial were conducted at potential agro-ecologies of the country during 1984 to 2020 years. Korerima national variety and verification trials were undertaken in collaboration with different research centers (Teppi, Jimma and Bonga Agricultural Research Centers) coordinated by Teppi Agricultural Research Center. The research activities were conducted to develop improved Korerima variety through selection of superior genotypes across wider agro-ecological zone of the country. Hence, this study was held to select high yielding and good quality korerima genotypes for potential growing areas of the country.

Material and Methods

Description of the study areas

The current study was conducted at four locations representing potential korerima production agro-ecologies in the country. The agro-climatic conditions of the locations are described in Table 1.

Table 1. Description of test locations

Locations	Altitude (m.a.s.l)	Coordinates		Temperature		Rain fall	RH (%)	Soil	
		Latitude	Longitude	Min	Max			Type	PH
Jimma	1753	7 0 46'00"N	36^0 47'00"E	11.6	26.3	1572	67	Reddish brown/ Nitosols	5.20
Gera	1940	7^0 7'0"N	36^0 00'00"E	10.4	24.4	1878.9	75.03	Loam	-
Teppi	1200	7^0 3' 0"N	35^0 18' 0"	16	30	1678	75	Nitosols	5.6 – 6
Bonga	1714	7^0 16' M	36^0 14' E	15.1	26.7	1750	74	Nitosols	4.1-6.3

Experimental materials

Korerima accessions were collected from different part of the country and preliminary evaluation and selection of better advanced genotypes were done. A total of 25 genotypes were selected and promoted to national variety trial (NVT). The national variety trial was undertaken at Teppi, Jimma, and Bonga Agricultural Research Centers during 2011 to 2016. The description of the experimental materials was included in Table 2.

Table 2. Description of experimental materials

No.	Accession	Region	Zone	Woreda	Altitude (m a.s.l)
1	Jimma local	Oromia	Jimma	Jimma	1580
2	028/84	Oromia	Wollega	Arjo	1800
3	025/03	Oromia	Illubabor	Metu	1605
4	114/03	Oromia	Illubabor	Sombo	2229
5	059/03	Oromia	Wollega	Nekemte	2088
6	029/84	Oromia	Wollega	Gimbi	1930
7	016/84	Oromia	Illubabor	Sombo	2229
8	001/03	SNNPR	Sheka	Masha	1297
9	015/03	Oromia	Ilubabor	Sombo	2229
10	053/03	SNNPR	South Omo	Kemba	1850
11	045/03	SNNPR	Gamo gofa	Damot	2121
12	701/87	SNNPR	Kefa	Decha	2500
13	046/03	Oromia	Illubabor	Algea	1500
14	105/03	Oromia	Illubabor	Yayu	1387
15	038/01	SNNPR	Sidama	Arero	2829
16	093/00	Amhara	Gojam	Debremarkos	2446
17	018/00	SNNPR	Kefa	Yeki	1097
18	010/00	SNNPR	Kefa	Chena	1972
19	009/00	Amhara	Gojam	Metekel	1525
20	068/87	Amhara	Gojam	Agew midir	500-3700
21	021/00	SNNPR	Bench maji	Bebeka	950-1285
22	686/87	Amhara	Gojm	Metekel	1525
23	001/84	Oromia	Bale	Genale	1000
24	011/00	SNNPR	Sidama	Sidama	2759
25	014/00	Amhara	Gojam	Metekel	1525

Experimental procedure and design

The 25 genotypes were planted in an experiment designed in simple lattice with two replications on the four locations. Data on different parameters were collected per plot from the experimental field. The fresh and dried capsule yield (kg ha^{-1}) was estimated on the net plot basis while other parameters were estimated from sample plants. For this purpose, red ripe and dry capsules were collected from the net plot for each genotype. For plant height and number of leaves per plant, data were taken from ten sampled plants from each replication per genotype.

Data collection and analysis

Plant height (cm): Plant height was measured from ten randomly taken plants in centimeters from ground level to the plant tip and the average measurement was taken.

Number of leaves per tiller: Number of leaves produced from ten randomly taken plants in each net plot was counted and the average measurement was taken.

Fresh capsules weight (g): It was calculated from capsules collected from ten randomly taken plants in each net plot by weighing the total capsules collected and dividing by the number of capsules.

Dry capsule weight (g): It was calculated from capsules collected from ten randomly taken plants after drying, weighed and divided by the total number of capsules.

Oleoresins content (%): Oleoresin was determined through a hot continuous extraction (Soxhlet) method using acetone (95%) as organic solvent for 4 to 5 hours. About 10 g of powdered korerima embedded in filter paper were placed in glass columns blocked with non-absorbent cotton below which a volumetric flask (500 mL) was kept to collect the extract. A thin layer of cotton over korerima powder was placed. 250 mL of acetone were used for each sample extraction. Solvent removal from the miscella was done by pressure rotary vacuum evaporator at 40^{o}C and 90 RPM. Rotary evaporator was used for distilling off the solvent generally under vacuum. When the last traces of acetone were evaporated, the flask was placed in a hot air oven at 110±2^{o}C until two consecutive weightings taken at $1^{1}/2$-hours intervals did not differ by more than 1 mg (ASTA, 1997). Finally, the flask was cooled in a desiccator, and then weighed and quantified as percent weight-weight basis based on the formula described by ASTA (2002) and Daniel *et al*. (2008).

$$\text{Oleoresin content}(\%) = \frac{\text{weight of oil (g)}}{\text{weight of sample (g)}} * 100$$

General analysis of variance for grain yield and yield related traits for each environment and over environments was analyzed using SAS 9.3 statistical software. Duncan Multiple Range Test (DMRT) at 5% probability was used for mean comparison (Gomez and Gomez, 1984). Interaction principal component axes (IPCAs) scores of genotypes and environments were computed as stability parameters for AMMI model (Guach, 1988; Zobel *et al*., 1988) as per the established standard procedures for the model. GenStat statistical software (16th

edition) was used to compute stability parameters of AMMI model. Since AMMI model does not make provision for a quantitative stability measure, AMMI stability value (ASV) (Purchase, 1997) measure was computed in order to quantify and rank genotypes according to their yield stability.

$$ASV = \sqrt{\left[\frac{IPCAISS}{IPCA2SS}\ (IPCA1score)\right]^2 + [IPCA2score)^2}$$

The ASV is the distance from zero in a two-dimensional scatter graph of IPCA1 (Interaction Principal Component Analysis Axis 1) scores against IPCA2 (Interaction Principal Components Analysis Axis 2) scores. Since the IPCA1 score contributes more to GEI sum of squares; it has to be weighted by the proportional difference between IPCA1 and IPCA2 scores to compensate for the relative contribution of IPCA1 and IPCA2 to total GEI sum of squares and AMMI Stability Value (Purchase, 1997).

Results and Discussion

The analysis of variance (ANOVA) conducted for each location showed the presence of significant ($P<0.05$) and highly significant ($P<0.01$) differences among genotypes for yield and yield related traits. The combined analysis of variance over environments showed significant difference for environment, genotype and the interaction of genotype by environment (GEI) for plant height, number of leaves per tiller, fresh and dry capsule weight. Korerima genotypes exhibited significant differences for varied traits at different locations and the significant effect of genotype and genotype x environment on the studied traits was an indication of the differential response of genotypes across the test locations.

The significant effect of genotypes, environment and GEI suggested that genotypes exhibited different performance at different locations or environments *i.e.,* the mean performance of the genotypes differed from environment to environment and the genotypes responded differently relative to each other to a change in environment. The difference among the tested genotypes across the test locations occurs due to their differences in genetic makeup or the variation due to the environmental factors (non-genetic factors) such as locations, growing seasons, years, rainfall, the amount of precipitation received in each season, temperature, etc. which may have positive or negative impacts on genotypes or both the genetic makeup and environmental factors. The presence of significant GEI indicated the inconsistency in the performance of fenugreek genotypes across environments and these influences the yield and yield-related traits of fenugreek genotypes and also strong GEI causes difficulties in selection of widely adapted and stable genotypes under diverse environments. Misra *et al.* (2009) in finger

millet reported the presence of significance GEI effects on yield and yield components.

Table 3. Combined mean performance of vegetative and quality traits of Twenty five Korerima genotypes.

Treatment no.	Genotype code	PH (cm)	NLPT	FCY(t ha^{-1})	OC(%)
G-1	053/03	133.89^{abcdef}	18.15^{e}	1.427^{g}	3.7
G-2	046/03	141.38^{abcd}	20.60^{abcd}	1.930^{bcdefg}	5.4
G-3	114/03	135.84^{abcdef}	19.77^{abcde}	2.123^{bcdefg}	4.5
G-4	29/84	132.76^{abcdef}	18.09^{e}	2.408^{abcdef}	4.9
G-5	038/01	139.36^{abcde}	18.95^{bcde}	2.494^{abcde}	2.5
G-6	045/03	132.79^{abcdef}	18.66^{bcde}	1.954^{bcdefg}	3.95
G-7	105/03	135.19^{abcdef}	19.22^{bcde}	1.954^{bcdefg}	4.8
G-8	015/03	132.32^{abcde}	18.85^{bcde}	1.985^{bcdefg}	4.4
G-9	J.L	148.01^{a}	21.94^{a}	2.150^{abcdefg}	4.9
G-10	686/87	131.38^{bcdef}	21.05^{ab}	1.785^{cdefg}	3.6
G-11	001/00	148.12^{a}	18.52^{cde}	2.641^{abc}	6.4
G-12	093/00	131.56^{bcdef}	18.74^{bcde}	2.354^{abcdefg}	4.5
G-13	Bm31/03	128.70^{bcdef}	17.91^{e}	1.986^{bcdefg}	6.2
G-14	28/34	130.60^{bcdef}	18.69^{bcde}	1.627^{defg}	5.6
G-15	701/87	143.90^{ab}	18.00^{e}	1.905^{bcdefg}	4.55
G-16	68/67	142.43^{abc}	19.70^{abcde}	2.759^{ab}	2.65
G-17	25/03	135.25^{abcdef}	20.67^{abc}	2.211^{abcdefg}	3.75
G-18	BM34/03	124.81^{ef}	19.80^{abcde}	1.499^{gh}	5.25
G-19	059/03	125.97^{def}	18.20^{de}	2.199^{abcdefg}	3.8
G-20	018/00	121.51^{f}	18.07^{e}	1.832^{bcdefg}	4.9
G-21	16/84	127.50^{cdef}	19.11^{bcde}	1.571^{defg}	3.9
G-22	009/00	131.17^{bcdef}	18.54^{cde}	1.878^{bcdefg}	4.45
G-23	21/00	136.59^{abcdef}	17.56^{e}	3.067^{a}	5.25
G-24	010/00	129.43^{bcdef}	19.78^{abcde}	2.535^{abcd}	4.75
G-25	011/00	130.40^{bcdef}	18.10^{e}	2.409^{abcdef}	4.65
Grand Mean		134.03	19.07	2.107	4.64
CV (%)		12.04	12.93	44.45	12.03

PH=Plant height, NLPT=Number of leaves per tiller, FCY=Fresh capsule yield and OC=Oleoresin content.

The genotypes showed significance differences in plant height at all locations. Accordingly genotypes G-11 and G-9 showed the highest mean plant height performance of 148.12 and 148.01 cm, respectively, whereas genotype G-20 showed lowest plant height (121.51 cm) among the tested genotypes across locations. Significant differences in plant height among korerima genotypes were reported by Hassen *et al* (2019) and Simegn *et al*, (2016).

Across the four locations the mean performance of the genotypes for number of leaves per tiller showed significant difference. Genotype G-9 showed the highest number of leaves per tiller (21.94); whereas genotype G-23 however showed lowest number of leaves per plant (17.56) among the tested genotypes over locations. Besides, genotype G-23 showed the highest fresh capsule yield

performance i.e. 3.067 t/ha, whereas genotypes G-1 had lowest (1.43 t/ha) among the tested genotypes over locations. Prasatha and Venugopal (2004) and Heryanto and Syukur (2020) did variability study in cardamom genotypes and reported the presence of significant difference in number of leaves per tiller and fresh capsule weight among the tested genotypes. Nevertheless, the genotypes showed non-significant differences in oleoresin content across the test locations. However, based on numerical comparison, genotypes G-11 and G-13 scored high oleoresin content (6.4 and 6.2%), respectively; whereas genotype G-5 scored the lowest oleoresin content of 2.5% among the studied genotypes across locations.

Table 4. Mean dry capsule yield (t ha^{-1}) of twenty five Korerima genotypes at four locations.

Treatment No.	Genotype code	Jimma	Gera	Bonga	Teppi	Pooled Mean
G-1	053/03	0.985^{cdef}	0.384^{efg}	0.486^{h}	0.466^{cdefgh}	0.66^{j}
G-2	046/03	1.262^{abcde}	0.749 ^{bcdefg}	1.667^{bcdefg}	0.362^{efgh}	1.20^{cdefg}
G-3	114/03	1.253^{abcde}	0.59^{3efg}	1.667^{bcdefg}	0.555^{cdef}	1.13^{defgh}
G-4	29/84	1.469^{a}	1.323^{abcd}	1.667^{bcdefg}	0.406^{efgh}	1.23^{bcdefg}
G-5	038/01	1.091^{abcdef}	0.739^{bcdefg}	2.416^{abc}	0.552^{cdef}	1.46^{abc}
G-6	045/03	0.871^{def}	0.751^{bcdefg}	1.18^{efgh}	0.421^{defgh}	0.87^{hij}
G-7	105/03	1.372^{abc}	1.640^{a}	1.597^{bcdefg}	0.329^{efgh}	1.26^{bcdef}
G-8	015/03	1.482^{a}	0.689^{cdefg}	1.180^{efgh}	0.439^{cdefgh}	0.99^{fghi}
G-9	J.L	0.990^{cdef}	1.329^{abc}	1.319^{cdefgh}	0.382^{efgh}	0.97^{ghi}
G-10	686/87	1.284^{abcd}	0.744^{bcdefg}	0.902^{fgh}	0.50^{cdefg}	0.89^{hij}
G-11	001/00	1.321^{abc}	1.359^{ab}	1.25^{defgh}	0.495^{cdefgh}	1.14^{defgh}
G-12	093/00	1.23^{abcde}	0.546^{efg}	1.792^{bcdefg}	0.311^{fgh}	1.15^{defgh}
G-13	Bm31/03	0.843^{ef}	0.486^{efg}	1.944^{abcdef}	0.221^{gh}	1.04^{fghi}
G-14	28/34	0.852^{ef}	0.461^{efg}	2.014^{abcde}	0.387^{efgh}	1.13^{defgh}
G-15	701/87	1.458^{ab}	0.318^{efg}	1.25^{defgh}	0.533^{cdef}	1.08^{efgh}
G-16	68/67	0.795^{f}	1.027^{abcde}	2.986^{a}	0.366^{efgh}	1.65^{a}
G-17	25/03	1.232^{abcde}	0.896^{bcdef}	1.389^{cdefgh}	0.203^{h}	1.01^{fghi}
G-18	BM34/03	1.087^{abcdef}	0.171^{g}	0.763^{gh}	0.702^{abcd}	0.73^{ij}
G-19	059/03	1.161^{abcdef}	0.791^{bcdefg}	1.597^{bcdefg}	0.922^{a}	1.28^{bcdef}
G-20	018/00	0.776^{f}	0.823^{bcdefg}	0.902^{fgh}	0.466^{cdefgh}	0.75^{ij}
G-21	16/84	1.046^{bcdef}	0.441^{efg}	1.25^{cefgh}	0.727^{abc}	1.04^{fgh}
G-22	009/00	1.287^{abcd}	0.667^{defg}	1.18^{efgh}	0.723^{abc}	1.06^{efgh}
G-23	21/00	1.278^{abcd}	0.839^{bcdef}	2.50^{ab}	0.617^{bcde}	1.49^{ab}
G-24	010/00	1.286^{abcd}	0.741^{bcdefg}	1.944^{abcdef}	0.877^{ab}	1.34^{abcde}
G-25	011/00	1.499^{a}	0.811^{bcdefg}	2.292^{abcd}	0.615^{bcde}	1.38^{abcd}
Grand Mean		1.168	0.772	1.565	0.503	1.119
CV (%)		17.46	40.87	34.36	27.84	25.96

The analysis of variance for dry capsule yield per hectare showed significant difference at all locations. The genotypes had mean dry capsule yield of 1.119 t ha^{-1}. The highest dry capsule yield per hectare was obtained from G-16 (2.986 t

ha^{-1}) at Bonga, but lowest grain yield was obtained from G-18 (0.171 t ha^{-1}) at Gera (Table 4). The difference in grain yield in Korerima genotypes was reported by Simegn *et al* (2016) who studied genotype and phenotype variability of korerima genotypes. Based on the pooled mean, the performance of the genotypes was inconsistent for dry capsule yield per hectare across the test locations (Table 4) indicating that there is genotype by environment interactions but lacks stability. Genotype G-16 scored the highest pooled mean 1.650 t ha^{-1} and had 47.4% yield advantage over the grand mean across the test locations. However, genotype G-1 scored the lowest pooled mean 0.660 t ha^{-1} which is 41% below the grand mean.

Table 5. Stability parameters from AMMI models at four locations.

Treatment no.	Genotype code	Mean(q/ha)	IPCA[1]	IPCA[2]	ASV
G-1	053/03	0.660	1.24985	0.66968	2.00
G-2	046/03	1.200	-0.88186	0.63311	1.47
G-3	114/03	1.129	0.46617	-0.32639	0.77
G-4	29/84	1.234	0.89258	-1.64836	2.13
G-5	038/01	1.459	-1.73549	0.12473	2.62
G-6	045/03	0.870	0.70343	-0.69289	1.27
G-7	105/03	1.265	-0.6813	0.06639	1.03
G-8	015/03	0.996	1.51823	-0.63579	2.37
G-9	J.L	0.975	0.12245	-0.24411	0.31
G-10	686/87	0.898	1.09275	0.33953	1.68
G-11	001/00	1.143	0.06824	0.25196	0.27
G-12	093/00	1.152	-1.035	0.93967	1.82
G-13	Bm31/03	1.004	-0.54448	-0.57409	1.00
G-14	28/34	1.134	-1.50569	0.72556	2.38
G-15	701/87	1.084	0.17534	1.22215	1.25
G-16	68/67	1.653	-2.84466	-1.43899	4.52
G-17	25/03	1.013	-0.02489	-0.09507	0.10
G-18	BM34/03	0.735	1.50372	1.00611	2.48
G-19	059/03	1.279	-0.43421	1.1344	1.31
G-20	018/00	0.756	0.86983	-0.24961	1.33
G-21	16/84	1.045	0.0035	1.01596	1.02
G-22	009/00	1.067	0.60782	0.73978	1.18
G-23	21/00	1.494	-0.75832	-0.80946	1.40
G-24	010/00	1.340	0.29543	-0.2775	0.52
G-25	011/00	1.388	0.87655	-1.8768	2.30
Grand Mean		1.119			

The IPCA's scores for each genotype were calculated as stability parameters of AMMI model. The larger the IPCA's scores either negative or positive were the more specific adapted genotypes for certain environments; the smaller the IPCA's scores (approaching to zero) were the more stable or wider adapted genotypes across the test environments. However, AMMI stability value (ASV) for each genotype was calculated to identify more stable genotypes easily since it considered both IPCA1 and IPCA2 scores according to Purchase (2000). The mean dry capsule yields per hectare of the genotypes and ASV used to rank the genotypes and to identify genotypes with high mean yield and stable across the test environments as presented in Table 5.

The 25 korerima genotypes were categorized based on IPCA scores, ASV and mean performance of the dry capsule yields. Based on AMMI stability model parameters and mean yield performance of the genotypes across the test locations, G-24 and G-11 were found to be more stable or wider adapted genotype and had 19.75% and 2.14% yield advantage over the grand mean, respectively. Genotype G-23 was moderately stable genotype in yield and had 33.51% advantage over the grand mean. Therefore, G-24 and G-23 were selected as suitable genotypes and verified and recommended as varieties for cultivation across the test locations among the tested genotypes.

Conclusion and Recommendation

Twenty five korerima genotypes were collected and evaluated for yield, wider adaptability and quality traits to select best genotype (s) as a variety for production in the country. Accordingly, genotypes G-23, G-25 and G-24 had better yield advantages among the tested genotypes over the locations respectively. However, genotype G-3, G-9, G-17, G-11 and G-24 were selected as the most stable or widely adapted genotypes which scored < 1 ASV based on AMMI stability model. From quality analysis, genotypes G-11, G-13, G-14 and G-23 had high oleoresin content. In summary, among the tested genotypes, G-23 (21/00) and G-24 (010/00) were identified as superior genotypes based dry capsule mean performance, quality (oleoresin content) and adaptability for wider cultivation in Korerima growing areas in Ethiopia.

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Evaluation of Cocoa (*Theobroma Cocoa*) Variety in Ethiopia

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Abstract

Cocoa is a food-industrial crop majorly grown in West and Central African countries, It plays an important role in the value chain of the chocolate industry. However, cocoa has not been cultivated in Ethiopia. Therefore, the aim of this experiment was to evaluate the performance of a cocoa variety for registration to create an opportunity for famers to produce additional cash crop to increase their income and to generate foreign currency. The evaluation trial was conducted at Bebeka, Tepi and Gemadero locations with one introduced cocoa variety during 2016 to 2021 cropping seasons in single plots. The performance of the variety for vegetative, yield and quality traits was compared with world average. Accordingly, the candidate variety across the three locations had 37.5% dry bean mean yield advantage over the world average. In addition, the fat content of the variety ranged from 58.22 to 59.35% which was greater than the world average fat content of cocoa (56%). Therefore, the national variety release technical committee evaluated the field performance of the variety in 2021 and the variety was registered by the name of "Forastero-1" for cultivation across diverse agro-ecologies of the country.

Keywords: Cocoa, chocolate, dry bean, fat content, yield

Introduction

Cocoa (*Theobroma cocoa*) is a diploid crop with 2n = 2x = 20 chromosomes which originated in the wet tropical regions of northern Latin America (Miranda, 1962). Criollo and Forastero are the two major types of cocoa produced in the world, each with its own morpho-geographical classification: Criollo and Forastero (Cheesman, 1944). In addition, there is a hybrid cocoa of the two types known as Trinitario Cocoa, which is predominantly grown in Central America. Because of the necessity for ideal climate characteristics, such as moderate temperatures, high moisture, and adequate rainfall, the natural habitat for producing cocoa plants is concentrated among the countries that make up the Equator (ICCO, 2013). Cocoa is a food-industrial crop that is mostly used in the chocolate industry and has played an important role in poverty reduction in the humid tropics. More than 90% of the cocoa produced in the world is grown by small-scale farmers (Poelmans and Swinnen, 2016). Cocoa is grown by about 5 to 6 million farmers in Africa, Asia, Latin America, and Oceania. Côte d'Ivoire,

Ghana, Indonesia, Nigeria, Cameroon, and Brazil are the top six cocoa-producing countries (UNCTAD, 2010).

Properly fermented and dried seeds or beans are the most valuable part of the crop. The cocoa chocolate value chain transfers billions of dollars around the world, creating financial gains for producing countries as well as national and multinational businesses. In 2013, 4.6 million tons of cocoa beans were grown on about 10 million hectares in more than 50 countries, with a total export value of $15 billion (FAOSTAT, 2018). The protein level of dried cocoa beans ranges from 15 to 20%, with a fat content of about 50% (Spencer and Hodge, 1992). Within species, morphological and structural traits of seeds sometimes show considerable and strong discriminating variability (Adewale *et al.*, 2010a).

Ethiopia has suitable and diverse agro-ecology for production and cultivation of different tropical and subtropical fruits. Currently, avocado, mango, orange, banana and papaya are the major types of fruits that are grown in the country (Teklay *et al*., 2016). Cocoa is majorly produced in the humid tropics, and Ethiopia has a similar agro-ecology to this region, mainly in the southwest part of the country, which is suitable for the production of the crop. Among the two types of cocoa (Forasterio and Criolo), the Forasterio type is the most commonly produced in the world for the chocolate industry. So far, there is no production of cocoa in the country, and one variety (the Forasterio type) was introduced. Therefore, the aim of this activity was to evaluate the performance of the variety across locations and to register for cultivation.

Materials and Methods

One variety of cocoa was introduced from abroad and its adaptation was evaluated at Tepi Agricultural Research Center and. Then, cocoa plants were established at three locations (Table 1): Bebeka (Guraferda woreda), Tepi (Yeki woreda) and Gemadero (Godere woreda) in 2016 to further evaluate its performance across different locations. The seedlings were planted in open field (without shade) across the three locations at spacing of 2.5m x 2.5m between plants and rows and a total of 40 plants were used at each location.

All necessary vegetative (plant height, leaf length, leaf width, number of branch per plant); yield components (number of pod per plant, pod weight, pod length, pod width, hundred bean weight, fresh bean weight per plant and dry bean weight per plant) and quality (fat content) data for two seasons (2017/18 and 2018/19) from Tepi and Bebeka and one season (2018/19) data from Gemadero location were collected.

The fat content of cocoa was determined by AOAC (1990: 963.15) method. Round bottom flasks of 500mL were dried in an oven at 105°C, cooled in a desiccator, weighted and 250mL of petroleum ether was measured into the round bottom flasks. Each test sample of 10g powdered cocoa was measured into a thimble and was set up for extraction for 4 hours using the Soxhlet apparatus. The set up was allowed to cool and the solvent drained into the round bottom flask. The petroleum ether solvent was removed using rotary evaporator and concentrated fat obtained. The concentrated fat content was dried in an oven at 100°C until constant weight was attained. After successive 1 hour drying period, it showed additional loss of less than 0.05% fat and then cooled in a desiccator (AOAC, 1990). In the end, the extract was weighed and the flasks were taken and recorded usinf the following formula:

$$\text{Fat content} = \frac{\text{weight of the extracted fat (g)}}{\text{weight of the sample (g)}} x100$$

The mean value of collected data for each respective trait was computed across the test locations and years. The fat content extraction was undertaken at Tepi Agricultural Research Center food science and nutrition laboratory by using hexane. Hexane has been broadly used to extract cocoa butter in solvent extraction (Li and Hartland, 1996).

Table 1. Description of study sites

Locations	Altitude (m.a.s.l)	Annual rain fall (mm)	Global position	
			Latitude	Longitude
Tepi	1220	1678	7°03'	35°13'
Bebeka	1200	1760	7°52.7'	35°52'
Gemadero	1200	1900	7°28'	35°24'

Results and Discussion

Mean performance for vegetative, yield and yield components

The mean performance for plant height ranged from 135 to 208 cm across the test locations. The maximum plant height value (213.65cm) was recorded at Bebeka in 2018/19 cropping season. The leaf length ranged from 24.5 to 30.4cm and leaf width varied from 7.9 to 9.59cm across the test locations and seasons. The number of branches per plant varied from 4.9 to 19 across the test locations (Table 2). This result was in agreement with the finding of Martínez *et al*. (2017) who studied on morphological characterization of traditional cocoa using 33 morphological descriptors.

The number of pod per plant ranged from 12.18 to 26.75 while pod weight per plant varied from 10.4 to 16.2kg across the test locations. Pod length and pod girth ranged from 7.0 to 11.55cm and from 7.0 to 6.61cm, respectively (Table 2).

Hundred bean weights varied from 141 to 143g across the test locations. Significance difference for hundred bean weight was reported by Oyedokun *et al*. (2011). Fresh bean weight per plant ranged from 570 to 1030g while dry bean weight per plant varied from 260 to 490g across the test locations. The mean dry bean weight ranged from 0.4 to 0.78 t ha^{-1}, and the maximum dry bean weight (1.72 t ha^{-1}) was recorded at Bebeka in 2018/19 cropping season (Table 2). This result is in agreement with the finding of (Santos *et al*., 2011) who studied on morphological characterization of leaf, flower, fruit and seed traits among Brazilian Cocoa and Aikpokpodion (2010) who studied on variation in agro-morphological characteristics of cocoa.

Table 2. Mean vegetative and yield data of cocoa across locations and seasons

Parameters	Gemadero	Bebeka			Tepi		
	2018/19	2017/18	2018/19	Pooled Mean	2017/18	2018/19	Pooled Mean
PH (cm)	208.25	150.50	213.65	182.07	111.80	159.05	135
LL (cm)	30.40	24.00	25.00	24.50	29.30	28.48	28.9
LW (cm)	9.59	7.70	8.10	7.90	8.20	8.08	8.14
NBPP	5.00	4.90	19.00	14.40	5.60	14.28	9.94
NPPP	12.18	13.20	40.30	26.75	12.5	20.9	16.7
PWPP (kg)	16.20	17.00	9.05	13.025	15.6	5.21	10.4
PL (cm)	15.00	17.00	20.10	18.55	14.8	16.52	11.2
PG (cm)	6.15	7.00	9.30	8.15	7.40	8.61	8.00
HBW (gm)	141.00	140.2	145.80	143.00	141.3	142.2	142
FBWPP (gm)	570	660	1400	1030	550	920	740
DBWPP (gm)	260	320	670	490	230	380	310
DBWPH (t/ha)	0.4	0.5	1.07	0.77	0.38	0.6	0.49
FC (%)		58.22 – 59.35					

PH=Plant height, LL=Leaf length, LW=Leaf width, NBPP=Number of pods per plant, PWPP=Pod weight per plant, PL=Pod length, PG=Pod girth, HBW=Hundred bean weight, FBWPP=Fresh bean weight per plant, DBWPP=Dry bean weight per plant, DBWPH=Dry bean weight per hectare and FC=Fat content.

Figure 1. Cocoa pods, dried beans and flour

Productivity of the candidate variety

Currently, the top five producers of cocoa in the world are Côte d'Ivoire, Ghana, Cameroon and Nigeria in West Africa. The first two countries have a considerably higher level of production than the rest of the countries. Côte d'Ivoire and Ghana accounted for 33% and 19.2% of the global production, respectively (FAOSTAT, 2018). However, the productivity of cocoa in major producing country is very low due to low soil fertility and poor management practices (Marta *et al*., 2018). The pooled mean productivity of the candidate cocoa variety in Ethiopia ranged from 0.4 to 0.78 t ha^{-1} and the average productivity across the three locations is 0.59 t ha^{-1}. The yield advantage ranged from 14-109% over the five major producing countries (Figure 2).

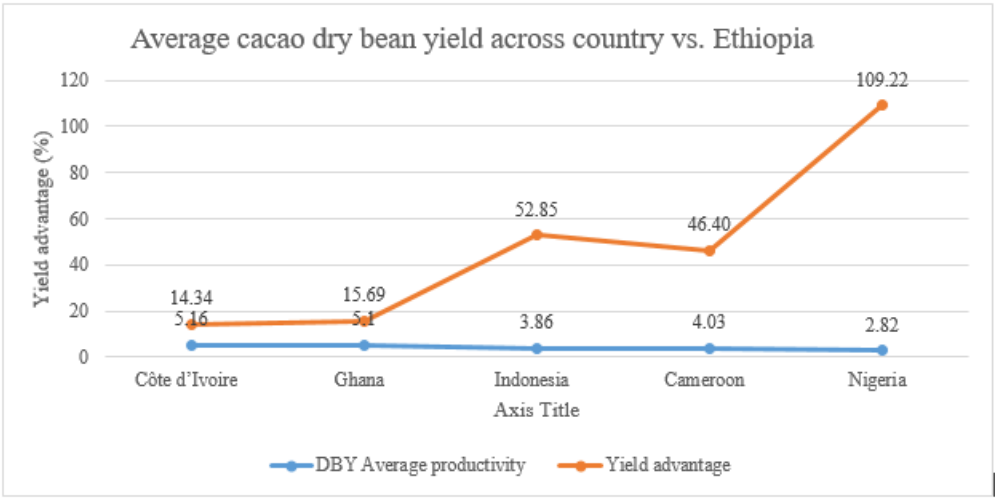

Figure 2. Productivity of cocoa in the major producer countries

Fat content

The fat content of the variety ranged from 58.22 to 59.35% across locations, which is competitive with the current world production and highly preferable in the cocoa market.

Disease and pest

The candidate variety was tolerant to major diseases of cocoa except few symptoms of black pod rot disease caused by *Phytophthora* species observed on some pods. High rainfall increases the spread of *Phytophthora* species within the canopy. Therefore, a site with relatively low rainfall and good drainage is recommended. A well-drained soil will reduce the amount of inoculum in and on the soil. Infected pods should be removed from the area and destroyed. In addition, trees should be spaced and pruned to allow for increased airflow in and around the orchard. This will reduce the relative humidity and further reduce spread of the disease. Furthermore, leaf mulch on the ground will reduce the amount of splashing water when it rains.

Conclusion and Recommendation

The evaluation of the introduced cocoa variety across locations revealed that the performance of the variety was comparable with the world's recent production of the crop. The world average dry bean yield of cocoa was 0.4 t ha^{-1}. However, the yield of the candidate variety from the two seasons of data across the three locations was 0.56 t ha^{-1}. The fat content of the variety ranged from 58.22 to 59.35%. In conclusion, the candidate variety was better in dry bean yield and quality than that of the world average. Therefore, the variety release technical committee evaluated the field performance of the candidate variety named "Forastero-1," and registered for cultivation.

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