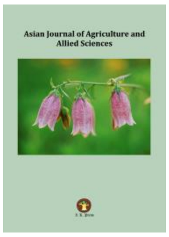

Asian Journal of Agriculture and Allied Sciences

Volume 8, Issue 1, Page 130-141, 2025; Article no.AJAAS.12642

Evaluation of Improved Durum Wheat (*Triticum turgidum var. durum*) Varieties in North Shewa Oromia

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/ajaas/2025/v8i158

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.ikprress.org/review-history/12642

Original Research Article

Received: 25/10/2024
Accepted: 28/12/2024
Published: 15/01/2025

ABSTRACT

Evaluating durum wheat varieties in various conditions is crucial in determining their stability performance and adaptability. In this study, 10 durum wheat varieties were evaluated in four sites to examine genotype-environment (G E) interactions and their effect on yield stability across varied environments. A field experiment was conducted at the four stations of Fitche Agricultural research center for two consecutive years. The experiment was layout in Randomized Completed Block Design (RCBD) with three replications. Nine agronomic and yield-related trait data were evaluated and analyzed. The pooled over- locations analysis result indicated that significant differences among tested varieties for most traits including grain yield were observed. The maximum grain yield was recorded from Gerardo variety with mean of 2156.2kgha^{-1} where as the minimum was recorded from Tesfaye variety. The results of the GGE biplot revealed that the variety "Gerardo" is stable across the testing locations since it is situated inside the concentric circle. In order to enhance the production of durum wheat in Northern Oromia other similar ecologies, the Gerardo variety was found to be the most stable and productive variety.

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Cite as: *Negash, Geleta, and Zewdu Tegenu. 2025. "Evaluation of Improved Durum Wheat (Triticum Turgidum Var. Durum) Varieties in North Shewa Oromia". Asian Journal of Agriculture and Allied Sciences 8 (1):130-41. https://doi.org/10.56557/ajaas/2025/v8i158.*

Keywords: Durum wheat; yield; adaptability.

1. INTRODUCTION

"Durum wheat (*Triticum turgidum ssp.durum*) is a monocotyledonous plant of the *gramineae* family and of the *triticeae tribe* and blongs to the genus *triticum"* (Clarke et al., 2002). "It is a tetraploid (x=7 and = 2n=28) with AABB genomes. Durum wheat is an economically important cereal crop grown throughout the world, although but not as widely as bread wheat. It is widely grown in part of the wheat growing areas of the world. It can grow at an altitude ranging from 1500 to 3200 masl. However, the most suitable areas fall within 1900 to 2700 masl where the annual rainfall range is between 600 and 2000 mm. The major durum producing countries are the European Union (Italy, Spain, France, and Portugal), Canada, and Syria United State of America, and North Africa" (Canadian Food Inspection Agency [CFIA], 2013).

Durum wheat serves as the raw material of numerous foods such as pasta and semolina in the alimentation of world population. Different scholars (Messele, 2001) reported "the uniqueness of the Ethiopian tetraploid wheat germplasm for different important traits. Durum wheat usually attracts a significant quality over the bread wheat grades". "The total area under cultivation for wheat in the country is estimated to be 1.897 million hectares in which durum wheat and bread wheat species are reported together as a lamp sum" (Central Statistical Agency [CSA], 2021). "Ethiopia is considered a durum wheat diversity hotspot and the largest producer in Sub-Saharan Africa (SSA) with an annual production of 0.6 million tons" (Mefleh et al., 2019). "It is grown over a wide range of environments that are different in soil fertility, weed incidence, disease, pests and water-logged conditions" (Teklu & Karl, 2008). "In Ethiopia, durum wheat breeding/improvement program has focused mainly on improving grain yield and disease resistance" (Abebe et al., 2008; Tesfaye & Mohammed, 2008) but gives less attention of quality. "However, currently, due to the expansion of agro-industries, a grain quality has become an increasingly important trait for variety release" (Ministry of Agriculture and Rural Development [MoARD], 2004). Currently, "there is a large market for durum wheat for domestic consumption and for export to other countries where there is a greater demand for food due to increasing populations and improving standard of living. However, the production of durum wheat is still lower in terms of quality and quantity than the global average and research yield" (Ministry of Agriculture and Rural Development [MoARD], 2004).

"Biotic factors such as weeds and several pathogens, and applying old technologies are the main constraints for durum wheat production. Another major issue is durum wheat production; farmers grow local varieties that are low-yielding, disease-prone, and poorly adapted to specific locales. In Ethiopia, numerous Research Institutes have developed durum wheat varieties, and some of them are promised and under production at various sites. Therefore, evaluating and selecting varieties that are highly productive, disease-resistant, and adaptable is the easiest breeding technique. Evaluating genotypes across time and location is critical for assessing their stability, performance, and adaptation. Multi-environment yield traits are indispensable in assessing of genotype by environment interaction (GEI) and identification of superior genotypes in the final selection cycles" (Kaya et al., 2006; Mitrovic et al., 2012). "The GGE (genotype main effect (G) plus GxE interaction) biplot modle, provides breeders a more complete and visual evaluation of all aspects of the data by creating a biplot that simultaneously represents mean performance and stability,as well as identifying mega-environments" (Royo et al., 2007; Yan & Kang, 2003; Kang, 1993; Yan, 2001).

This study was done with the objective to identify high yielding, adaptable and disease-tolerant durum wheat varieties for the study area and similar agro ecologies.

2. METERIALS AND METHODS

2.1 Study Area

This study was carried out over the course of two years in the major cropping seasons of 2021 and 2022 at the Fitche Agricultural Research Center's four research stations: Wachale, Debre Libanos, Hidabu Abote, and Jida research sub sites.

2.2 Experimental Material

Ten durum wheat varieties released from Regional and National Agricultural Research Center were evaluated (Table 1). The varieties were selected based on their potential and agro-ecological adaptation.

Table 1. Description of research materials

Varieties	Year of Released	Maintainer (Seed source)
Alemtena	2015	DZARC/EIAR
D.2018		
Fetan	2018	Debere Ziet ARC/EIAR/
Gerardo		
Mangudo	2012	SARC/OARI
Mukiye	2012	DZARC/EIAR
Tesfaye	2017	DZARC/EIAR
Utuba	2015	DZARC/EIAR
Werer	2009	DZARC/EIAR
Yerer	2002	DZARC/EIAR

2.3 Experimental Design and Management

"Ten durum wheat varieties were planted in randomized completed block design (RCBD) with three replications were used across locations. The plot size was 3.6m^2 and the space between row, plot and rep are 0.2 m, 0.5 m and 1mrespectively having 6 rows. Data recorded from the four central rows of each plot. Seeding rate of 150kgha^{-1} was used. Seed drilled by hand in the rows drawn using manual row maker. Sowing date was done at early-mid July, broad bed and furrows was used to facilitate surface drainage of the Vertisols" (Erokossa et al., 2006). Fertilizer was applied at a rate of 100kg and 150kgha^{-1} of NPS and UREA, respectively. Split application of UREA fertilizer at sowing (50%) and the remaining was applied at the tillering stage. Post-emergence weed control was by hand weeding. Weeding was carried out 30 days after emergence and the second one at 35 days after the first weeding based on weed status.

2.4 Data Collection Method

Twelve plants were selected randomly before heading from each plot and tagged with thread and all the necessary plant based data were collected from these sampled plants.

Plot Based: Days to heading (DH), Days to maturity (DM), Grain Filling Period (GFP) Grain yield (Kgha^{-1}).

Plant Basis: Plant height (PH), Productive tillers (PT), spike length (SL), Spiklete per spike (Spkltspike) seeds per spike (SdSpike).

2.5 Statistical Analysis

Analysis of variance is calculated using the model;

$$Yij = \mu + Gi + Ej + GEij$$

Where:Yij is the corresponding variable of the i^{-th} genotype in j^{-th} environment, μ is the total mean, Gi is the main effect of i^{-th} genotype, Ej is the main effect of j^{-th} environment, GEij is the effect of genotype x environment interaction.

$$Y_{ij} = \mu + g_i + e_j + \sum_1^N \lambda k\ Yik\ \delta jk + \varepsilon ij$$

2.6 AMMI Model

Where:Yij is the grain yield of the i^{-th} genotype in the j^{-th}environment, μ is the grand mean, gi and ej are the genotype and environment deviation from the grand mean, respectively, ʎk is the eigenvalue of the principal component analysis (PCA) axis k, Yik and δjk are the genotype and environment principal component scores for axis k, N is the number of principal components retained in the model, and Ɛij is the residual term.

2.7 AMMI Stability Value (ASV)

ASV is the distance from the coordinate point to the origin in a two-dimensional plot of IPCA1 scores against IPCA2 scores in the AMMI model (Purchase, 1997). Because the IPCA1 score contributes more to the GxE interaction sum of squares, a weighted value is needed. This weighted value was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction sum of squares as follows:

$$ASV=\sqrt{[(SSIPCA1 + SSIPCA2)\ (IPCA1score)]2\ + (IPCA2score)2}$$

Where, SS_{IPCA1}/SS_{IPCA2} is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares. "The larger the ASV value, either negative or positive, the more specifically adapted a genotype is to certain environments. Smaller ASV values indicate more stable genotypes across environments" (Purchase, 1997).

2.8 Genotype Selection Index (GSI)

Stability is not the only parameter for selection as most stable genotypes would not necessarily given the best yield performance. Therefore, based on the rank of mean grain yield of genotypes (RYi) across environments and rank of AMMI stability value RASVi), genotype selection index (GSI) was calculated for each genotype as:

GSIi= RASVi + RYi

Analysis of variance was carried out using R software (version 4.2.2).

3. RESULT AND DISCUSSION

3.1 Combined Analysis of Variance

The mean square of analysis of variance (ANOVA) is presented in Table 2. Highly significant differences were observed among the main and interaction effects ($p\leq 0.0$) for most of the parameters. The combined analysis of variance revealed that significant differences were recorded across location for all parameters. Variety*location were significant for some traits such as days to heading, days to maturity, grain filling period and grain yield.

3.2 Combined Mean Performance

The mean value of days to heading was ranged from 68.6 for Gerardo to 82.6 for Tesfaye variety with the overall mean value of 74.9. Tesfaye variety had the longest days to heading, where Gerardo recorded short days to heading. The mean value of days to maturity ranged from 121.5 for Mukiye variety to 127.9 was recorded for both D.2018 and Tesfa varieties with over all mean value of 124.9. Both D.2018 and Tesfaye had the longer mean value of days to maturity where as Mukiye has shortest days to maturity (Table 3). This result supported with Girma (2012), Wosene *et al*., (2015) and Tashome (2017) who reported significant variation of varieties for days to heading and days to maturity. The study also indicated significantly in plant height among the varieties. The mean value of plant height ranged from 62.6cm for D.2018 to 87.8cm for Gerardo variety with the overall mean value of 68.3cm Bedasa (2014) also reported that there is a significant difference in plant height among the varieties Gerardo variety was recorded highest plant heights that have a possibility of susceptible to lodging problem. The mean value of grain yield varied from 1558.7kgha^{-1} for Tesfaye to 2156.2kgha^{-1} for Gerardo variety with the overall mean value of 1759.2kgha^{-1}, Therefore, Gerardo (2156.2kgha^{-1}) and Fetan (1957.6kgha^{-1}) showed significantly high mean of grain yield over the rest varieties.

3.3 Yield Mean Performance Over Location

Yield mean performance of the tested durum wheat varieties over tested environments (Fig. 1) Due to environmental and growing season's variation, some varieties were different throughout locations while some of them were consistently performed in a set of tested environments. For instance, highest yield was recorded at Hidabu-Abote site in 2021 and the lowest grain yield was recorded at Wachale site in the same growing season. Yield and yield performance fluctuation across environment indicating that, high influence over year fluctuating weather condition even on the same trait of single variety Gima (2012). "Gerardo variety was almost constantly recorded grain yield performance over locations and growing seasons and obtained over all mean grain yield of 2156.2kgha-1 that might be due to the genetic potential of the variety" (Mengistu et al., 2013). "The difference in yield rank of varieties across the growing environments displays the prevalence of GxE interactions. Therefore, these varieties" (Gerardo and Fetan) were identified for better mean performance of yield and some yield contributing traits.

3.4 Yield Over Variety Mean Performance

Yield potential and the actual yield performance by varieties were presented in Fig. 2 the grain yield across varieties ranged from the lowest 1558.7kgha^{-1} for Tesfaye variety to the highest of 2156.2kgha^{-1} for Gerardo which was the top ranking across varieties. However, Alemtena, Mangudo and Mukiye varieties were recorded the same mean grain yield and spastically they exhibited none significantly different. These indicating that, there are high yield potential among varieties. Fig. 2 indicating that, the yield potential of each variety is quiet different that means Gerardo variety can recorded up to 3.5-6 tons yield potential per hectare. This wide variation might be due to their genetic potential of the varieties

Table 2. Analysis of variance (ANOVA) for grain yield and yield related traits of durum wheat varieties evaluated in 2021- 2022 main cropping season

SV	DF	DH	DM	GFP	PH	SL	Spklt/spike	sd/spike	PPT	Yield kgha
Vrt	9	183**	75**	105.5**	612.4**	4.033**	7.34**	172.25**	2.69**	445784**
Year	1	946**	816**	4.8ns	135.9**	11.638**	11.63**	47.2ns	6.021**	4994ns
Loc	3	2992.3**	6792.7**	774.1**	1234.3**	15.58**	33.15**	67.9*	6.94**	18415310**
Rep	2	43**	82**	16.7ns	211.6**	0.607.	6.7**	224.44**	3.008**	162035ns
vrt:*lo	27	18**	18**	36.3**	0.7ns	0.8ns	0.01ns	0.37ns	0.7ns	318314**
Residu	72	4	6	10.8	17.5	0.222	1.07	30.83	0.588	112094

*Key: * **, significant at 5% and 1% respectively, Vrt = varieties, Loc = Location, rep = replication, vrt*loc= variety by location, loc*rep = location by replication, DF = degree of freedom, DH= Days to Heading; DM = Days to Maturity; GFP = grain filling period, PPT= productive tillers per plant, PH= Plant Height; SL=spike Length; Spklt/spike = spikelet per spike, sd/spike = seed per spike, Yield kgha= Yield kilogram per hectare*

Table 3. Combined mean performance of grain yield and yield attributing traits

vrt	DH	DM	GFP	PH	SL	Spklt/spike	sd/spike	PPT	Yield kgha
Alemtena	73.	123.7bc	50cd	65.5bcde	5.2cd	16.4cd	21def	3.4a	1575.9cd
D.2018	79b	127.9a	48.9d	62.6e	6.2ab	18.1a	24bcdef	2.9ab	1837.3bc
Fetan	73.9d	123.2bcd	49.3cd	68.6b	5.5c	17.1bc	24bcde	2.9ab	1957.6ab
Gerardo	68.6f	124.4b	55.8a	87.8a	6.1b	17.8ab	25.4bcd	3.3ab	2156.2a
Mangudo	73.1de	124.9b	51.8bc	67.3bc	5.1d	16.9bc	26bc	3.2ab	1571.6cd
Mukiye 7de	72e	121.5d	49.5cd	66.3bcd	5.2cd	15.9d	19.6f	2.9abc	1629.6cd
Tesfaye	82.6a	127.7a	45.1e	67.6bc	5.2cd	16.4cd	28ab	2.7bc	1558.7d
Utuba	73.2de	122.25cd	49d	65cde	4.9d	16.4cd	20.7ef	2.3cd	1793.8bcd
Werer	75.75c	128.9a	53.2ab	63.8de	5d	15.9d	22.7cdef	1.9d	1709.7bcd
Yerer	76.9c	124.75b	47.8d	68.8b	6.6a	17.8ab	32.2a	2.7bc	1801.4bcd
Mean	74.9	124.9	50.1	68.3	5.5	16.9	24.5	2.8	1759.2
LSD (5%)	1.7	1.9	2.7	3.4	0.4	0.8	4.5	0.6	272.5
CV%	2.8	1.9	6.6	6.1	8.6	6.1	22.7	27.2	19

Key: vrt = varieties, DH = Days to Heading; DM = Days to Maturity; GFP= grain filling period, PPT= productive tillers per plant, PH = Plant Height; SL= spike Length; Spklt/spike = spikelet per spike, sd/spike = seed per spike, Yield kgha^{-1} = Yield kilogram per hectare, LSD = least significant differences, CV = Coefficient of variation

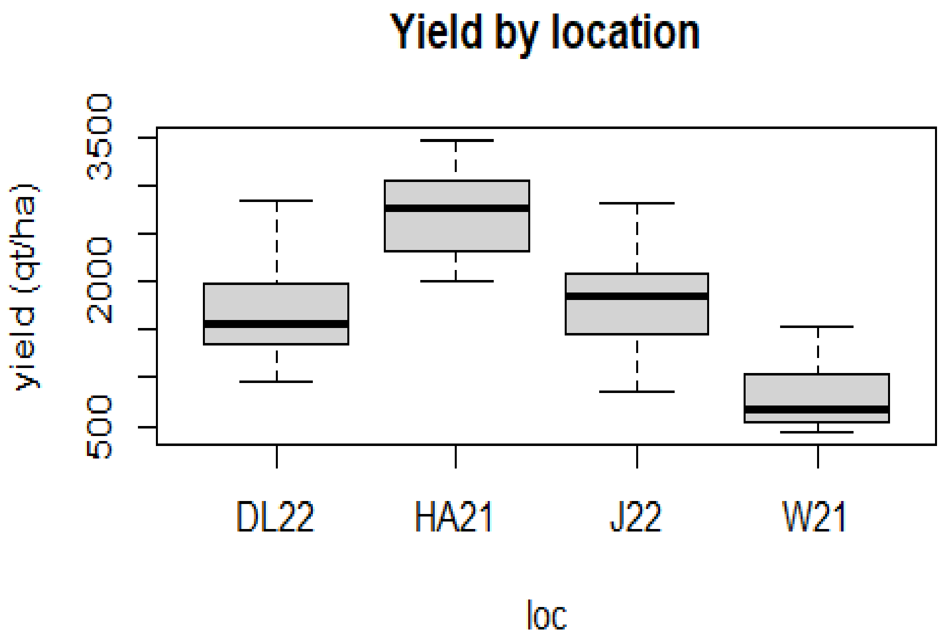

Fig. 1. Yield by location

Key: loc = location, qt/ha = Kilogram per hectare, DL22 = Derbe-Libanos site in 2022, HA21 = Hidabu Abote site in 2021, J22 = Jidda site in 2022, W21= Wachale site in 2021

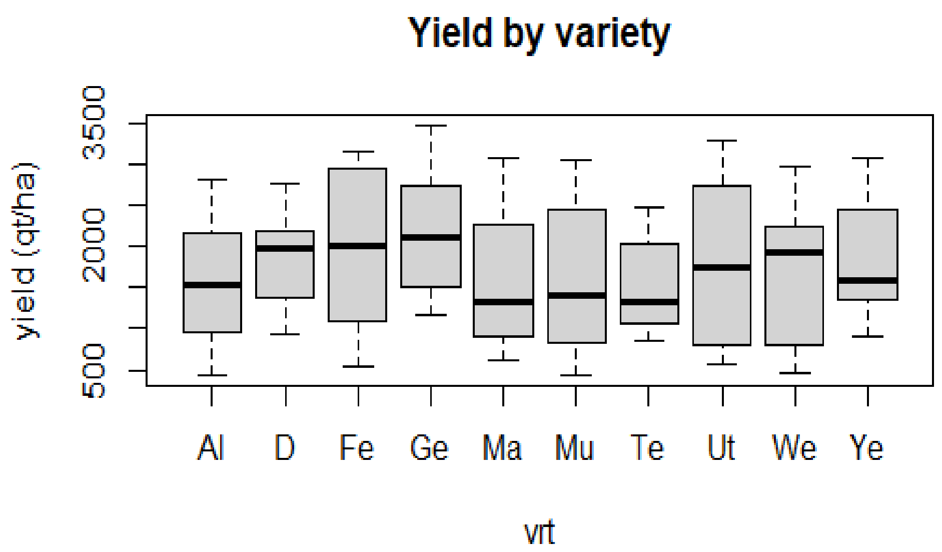

Fig. 2. Yield by varieties

Key: vrt = Varieties, qt/ha = Kilogram per hectare, Al= Alemtena variety, D = D.2018, Fe = Fetan, Ge = Gerardo, Ma = Mangudo, Mu = Mukiye, Te = Tesfaye, Ut = Utuba, We = Werer, Ye = Yerer

3.5 Stability Parameters

3.5.1 Stability analysis

Environment and genotypes by environment interaction were highly significant (P≤0.01). (Table 4). Similar result was reported by Ntawuruhunga et al. (2001). "This indicate that one of the basic factors that affect GEI could either be genotypic or environment in nature" (Debelo et al., 2001; Anandan et al., 2009) also reported that 74.3% of the interaction sum of squares was explained by IPCA1. These vertex cultivars are the highest-yielding cultivar in all environments that share the sector with it. Vertex cultivars in which any environments fell in their sectors were the poor performing varieties. Variety such as Gerardo located at the origin would rank the same in all environments and is not responsive to the change in environments.

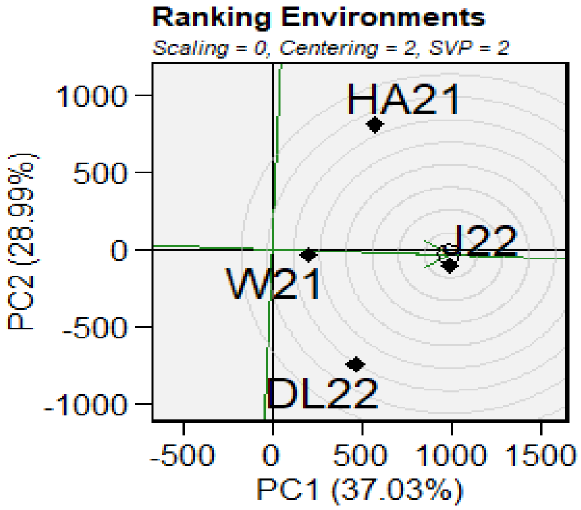

Fig. 3. GGE biplot based on environment focused scaling for comparison of the environment with ideal environment

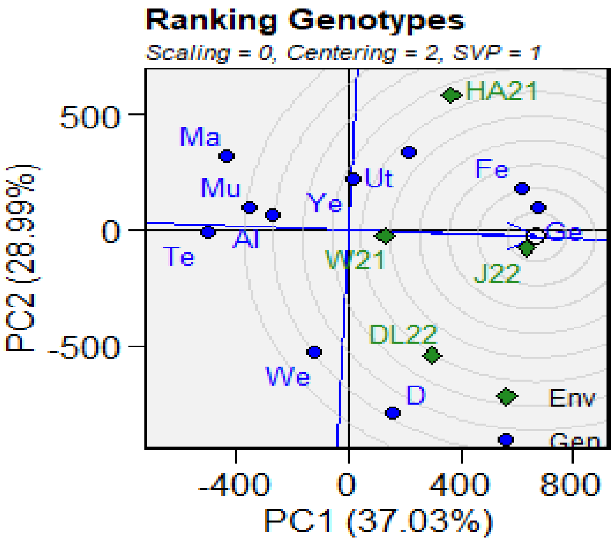

Fig. 4. GGE biplot view of the average –environment coordination (AEC) view to rank genotypes relative to an ideal genotype (the center of concentric circle) ranking genotype based on both mean and stability

Table 4. ANOVA table for AMMI model

S.V	DF	SS	EX.SS%	MS
Total	119	76517422	100.0	643004
Treatments	39	67857450	88.7	1739935**
Genotypes	9	4012054	5.2	445784**
Environments	3	55250926	72.2	18416975**
Block	8	589183	0.8	73648ns
Interactions	27	8594470	11.2	318314**
IPCA 1	11	3657107	4.8	332464**
IPCA 2	9	3085674	4.0	342853**
Residuals	7	1851688		264527*
Error	72	8070789		112094

*DF = degree of freedom, SS = sum of squares, MS = mean squares, IPCA = Interaction Principal Component Axis, EX. SS% = Explained Sum of square ns *, ** non-Significant, Significant at the 0.5% and 0.1% level of probability, respectively*

So, Gerardo variety was the best yielder among tested varieties and relatively stable across various environments (Fig. 3). Varieties such as Mangudo, Alemtena, Tesfaye and Mukiye were inferior in yield performance but stable genotype-focused scaling considers stability and mean grain yield parallel and environments as well as variety that fall in the central (concentric) circle of variety-focused scaling are considered as an ideal environments and stable variety respectively (Fig. 3).

"The average environment is defined by the average values of PC1 and PC2 for the all environments, and it is presented with a circle" (Purchase, 1997). The average ordinate environment (AOE) is defined by the line which is perpendicular to the AEA (average environment axis) line and pass through the origin. This line divides the genotypes in to those with higher yield than average and in to those lower yield than average. By projecting the genotypes on AEA axis, the genotypes are ranked by yield; where the yield increases in the direction of arrow. In this case, the highest grain yield was Gerardo variety but the lowest one Tesfaye variety (Fig. 3). Stability of the genotypes depends on their distance from the AE abscissa. Genotypes closer to or around the center of concentric circle indicated these genotypes are more stable than others. The genotype ranking is shown on the graph of genotype so-called "ideal" genotype (Fig. 3).

"An ideal variety is defined as one that is the highest yielding across test environments and it is completely stable in performance (that ranks the highest in all test environments; like Gerardo variety" (Farshadfar et al., 2012; Yan & Kang, 2003). Even though such an "ideal" genotype may not exist in reality, it could be used as a reference for genotype evaluation (Mitrovic et al., 2012). The ideal test environment should have large PC1 scores (more power to discriminate genotypes in terms of the genotypic main effect) and small (absolute) PC2 scores (more representative of the overall environments). Such an ideal environment was represented by an arrow pointing to it (Fig. 4). "Actually, such an ideal environment may not exist, but it can be used as an indication for genotype selection in the METs. An environment is more desirable if it is located closer to the ideal environment. Therefore, using the ideal environment as the center, concentric circles were drawn to help visualize the distance between each environment and the ideal environment" (Yan & Rajcan, 2002). Accordingly, (J22= Jidda site in 2022), which fell into the center of concentric circle, was an ideal test environment in terms of being the representative of the overall environments and the most powerful to discriminate the genotypes (Fig. 4) (Mokonin, 2014; Campbell et al., 1995; Chaney, 1990; DeLacy et al., 1996; Farshadfar, 2008; Eticha et al., 2010; Gauch, 2006).

4. CONCLUSION AND RECOMMENDATION

In the current study, ten durum wheat varieties were chosen and tested in four different northern Oromia environments to identify genotypes that were highly productive, disease-resistant, and region-adapted. The combined analysis of variance revealed significant effect of the main effects and interactions for grain yield and main traits. Gerardo and Fetan varieties had shown significantly higher mean values of grain yield across locations and years. On the other hand, Mangudo, Alemtena, and Mukiye cultivars considerably early heading and maturity, but low yield According to GGE biplot analysis, Gerardo variety was revealed better performance in term of yield and stability, Therefore, Gerardo and Fetan are promising varieties in northern Oromia, and demonstration and popularization are necessary to boost durum wheat output and productivity in the study areas and other similar agro-ecology.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

ACKNOWLEDGEMENT

The authors sincerely grateful to Oromia Agricultural Research Institute (IQQO) for financial support, Fitche Agricultural Research Center staff members are warmly acknowledged for technical assistance. Thanks are due, especially for cereal research team members significantly for their technical support and field work. And as well Debre-Zeiyt agricultural research center is acknowledged for the provision of test materials.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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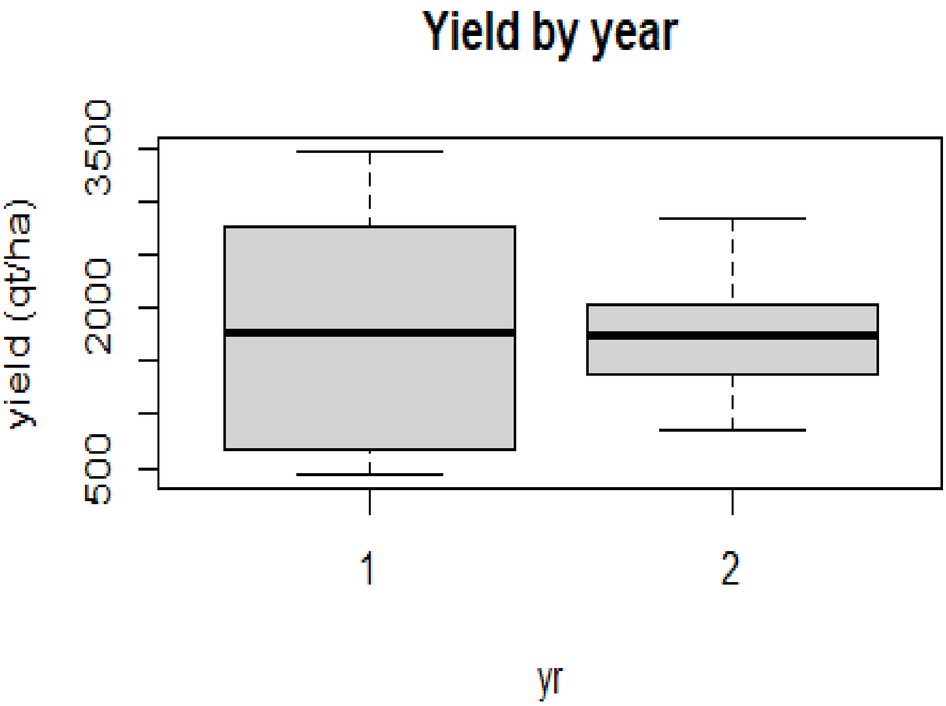
APPENDIX 1

Yield vs Year

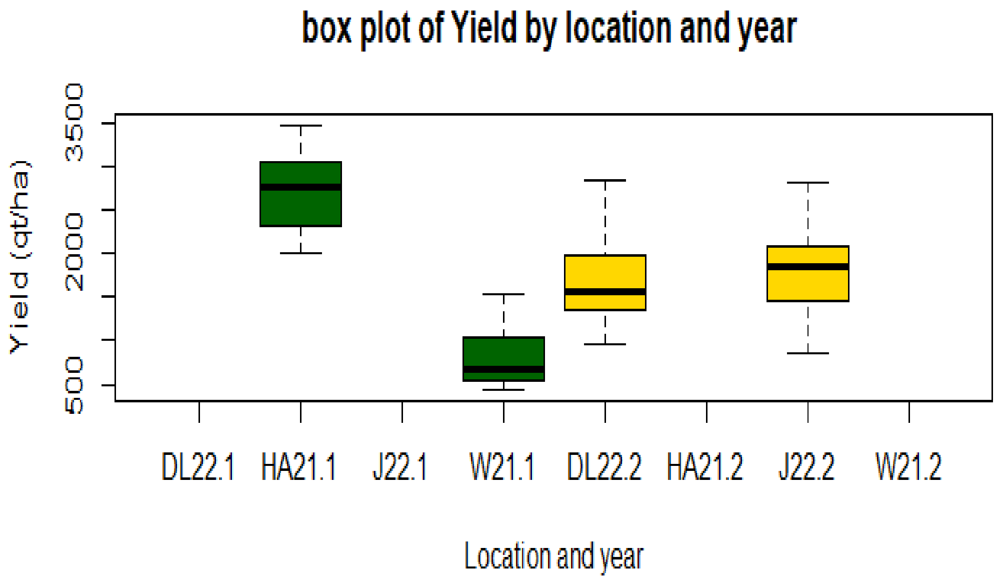


Key: qt/ha = Kilogram per hectare

Appendix picture 1. Yield across the year

APPENDIX 2

Yield vs Location vs Year



Key: qt/ha = Kilogram per hectare, DL = Derbelibanos site, J= Jidda site,HA = Hidabu Abote site, W= Wachale site

Appendix picture 2. Yield vs. Location and Year

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