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**Abstract:** Durum wheat (*Triticum turgidum* L. var *durum*) is an indigenous pre-dominant tetraploid wheat species in Ethiopia. Ten released durum wheat varieties were evaluated during 2016 and 2017 main cropping seasons at five districts representing various agro-ecologies of northwestern Ethiopia. The experiment was laid-out using Randomized Complete Block Design, replicated three times. Grain yield and protein contents (%) of entries were scored and the ANOVAs were performed for the traits under study. Additive Main effect and Multiplicative Interaction (AMMI) model was used to determine the stability of the genotypes across environments. Analysis of variance revealed a significant difference among the tested varieties for the grain yield in all tested locations. The AMMI analysis of variance of the grain yield showed that the presence of a highly significant difference among genotypes, environments and genotype–environment interaction with the contribution of 10%, 75.6% and 14.4% of the total sum of square variance, respectively. Genotypes Denbi, OBSA and Tate were identified as the most stable genotypes.

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**PUBLIC INTEREST STATEMENT**
Durum wheat is one of the industrial crops; the grain of durum wheat is mainly required for the manufacturing of pasta products (macaroni, spaghetti and semolina). This study explores the adaptable and high-yielding Durum wheat varieties in northwest Amhara region, Ethiopia. Farmers participated for selection adaptive and high-yielding durum wheat varieties; this will help to easily popularize the selected varieties in the area. Due to this grain yield, productivity of durum wheat will be increased. Ethiopia import wheat from abroad with hard currency. Therefore, this technology can benefit the local smallholder farmers engaged in wheat production and the country by serving as import substitution.
Mukiye and Utuba recommend for Shebel Berenta; Filakit and TOLTU recommend for Debre; Elias and Mangudo recommended for Wonberema woreda.

Subjects: Agriculture & Environmental Sciences; Plant & Animal Ecology; Agronomy

Keywords: AMMI; Durum wheat; GGE; PVS and stability

1. Introduction

Ethiopia is the largest wheat producer in sub-Saharan Africa (Paul Mansingh et al., 2017). Durum wheat (*Triticum durum* subs. Abyssinicum or *T. aethiopicum*) is an indigenous predominant tetraploid wheat species in Ethiopia (Alemu et al., 2020; Kabbaj et al., 2017). Durum wheat is among the diversified crop species, about 12% (about 7000 accessions) of the Ethiopian national gene bank holding constituted durum wheat (Mengistu & Pè, 2016). Ethiopia is among very few countries endowed with highly suitable environmental conditions to produce durum wheat (Legesse, 2017). The Ethiopian farmers have cultivated durum wheat for long years. Durum wheat is traditionally grown by small-scale farmers on heavy black soils (vertisols) at altitudes ranging from 1800 to 2800 meters above sea level, exclusively under rain-fed conditions.

In 2016, more than 1.7 million small-holder farmers produce wheat (both durum and bread wheat) on more than 554,000 hectares of arable land in Amhara region (CSA, 2017). The grain of durum wheat is mainly required for the manufacturing of pasta products (macaroni, spaghetti and semolina). In Ethiopia, it is also consumed in a variety of dishes. The most common Ethiopian recipes are *dabo* (Ethiopian bread), *injera*, *nifra* (boiled whole grain sometimes mixed with pulses), *kolo* (roasted grain), *dabokolo* (ground and seasoned dough, shaped and deep fried), *kinche* (crushed kernels cooked with milk or water and mixed with spiced butter) (Alemu et al., 2020).

Before the introduction of improved bread wheat varieties, durum wheat was the dominant wheat crop produced in Ethiopia (Gebre-Mariam, 1991). Currently, bread wheat is becoming the major cereal crop replacing durum wheat landraces which had been grown before (Zegeye et al., 2001). There has been a declining trend of durum wheat production in the country due to the introduction of high-yielding bread wheat varieties, in spite of the growing demand of durum wheat grains both from the national and in the international markets.

Variety development is a continuous process in different research institutes and universities in Ethiopia year after year. Whereas the introduction of new durum wheat variety for the farmer is very minimal, the varieties are used for a long period of time continuously without considering their adaptation domain, grain yield stability and testing whether they are losing their yield potential or not. High yielding durum wheat varieties have recently been released in Ethiopia. However, farmers in Western Amhara Region commonly use local durum wheat varieties.

Recently, with the current privatization policy and booming of agro-industries in the country (Eshetie, 2018), there is a rising demand for durum wheat grains for the manufacturing of pasta and macaroni products. Due to the shortage of durum wheat grains in the country, pasta and macaroni-processing factories imported durum wheat grains from abroad to satisfy their annual durum wheat grains demand, costing the country a lot of foreign currency.

Participatory variety selection (PVS) is a breeding approach that brings breeders, social scientists, farmers and extension personnel together in a field setting in order to prioritize and target traits of importance. PVS can effectively be used to identify farmer-acceptable varieties and thereby overcome the constraints that cause farmers to grow low-yielding varieties which are susceptible to disease and old or obsolete varieties (Witcombe et al., 1996). Moreover, participatory research increases the job efficiency of the scientists (Bellon, 2001) and farmers’ knowledge that enables them to be retained effectively from year to year (Grisley & Shamambo, 1993). PVS is a very
important practical and cost-effective way to revealed ideal plant characteristics and varieties for
targeted environments by obtaining farmer input (Legesse, 2017). Variety selection by farmers at
the same low-input farming conditions also addresses the needs of more marginalized farmers
(Dawson et al., 2007). It is a rapid and cost-effective way to assess and select potential varieties
(Abidin, 2004). Joshi and Witcombe (1996) reported that adoption rates of varieties would be
improved through increased farmers’ participation.

Thus, PVS was conducted to examine the adaptability and grain stability of durum wheat
varieties possessing acceptable grain protein content.

Therefore, there is a need to evaluate the recently released durum wheat varieties across the
environment and years. Hence, it is crucial to evaluate grain yield stability of durum wheat genotypes
used in the region with the objectives of evaluating the extent of grain yield stability of durum wheat
varieties and estimate the magnitude of genotype x environment (GE) interaction on grain yield.

2. Material and Methods
Ten durum wheat varieties were evaluated at eight environments across two years (2016 and 2017
growing seasons). Durum wheat varieties information is shown in Table 1 and environments in Table 2.

The experiment was laid out using Randomized Complete Block Design (RCBD), replicated three
times. The area of each experimental plot was 3 m² (1.2 m x 2.5 m) with six rows which were 0.2 m
apart each other and spacing between the two adjacent blocks was 1 m. Planting was carried out by
hand drilling using a seed rate of 150 kg/ha. Fertilizer was applied at the rate of 138/46 kg of N/P2O5 in
the form of urea and NPS, respectively. From the recommended amount of fertilizer, the whole NPS
was used at planting, while urea was applied half at planting and the remaining half at tillering stages.
For the vertisol areas, broad beds and furrows were made manually before sowing to drain excess
water. Weeding and other management practices were done uniformly for all treatments as required.

3. Data collection and analysis
Data were collected from the central four harvestable rows for traits to be taken on plot and plot
yield was adjusted to 12.5% moisture content and converted to ton per hectare.

3.1. Statistical Analysis
The data of 10 durum wheat varieties in multi-location and multi-year trials were analyzed to
determine whether the effect of the GE interaction was significant; means were separated using
the least significant differences (LSD) test with significance set at $p < 0.05$ and $p < 0.01$.

| Name   | Pedigree              | Year of release | Released center |
|--------|-----------------------|-----------------|-----------------|
| Denbi  | AJAIA/BUASHEN         | 2009            | DZARC/EIAR      |
| FLAKIT | EN-25                 | 2007            | SRARC/ABARI     |
| Mangudo| ICAJ/HAN 22           | 2012            | DZARC/EIAR      |
| Mosobo | DZ—2178               | 2004            | ADARC/ABARI     |
| Mukye  | STJ3//BCR/LK54/3/TER-3| 2012            | DZARC/EIAR      |
| OBSA   | ALTAR 84 ALTO 1//AJAYA| 2006            | SARC/OARI       |
| Tate   | CD94523               | 2009            | SARC/OARI       |
| TOLTU  | 4/B/R9096#21001(980SN Patho)) | 2010 | SARC/OARI |
| Ude    | CD 95294-2Y           | 2002            | DZARC/EIAR      |
| Utuba  | IDON-MD-2009-off/53/2009 | 2015  | DZARC          |

DZARC: Debre-Zeit Agricultural Research Center; SRARC: Sirinka Agricultural Research Center; SARC: Sinana Agricultural Research Center; ADARC: Adet Agricultural Research Center.
| Year | Location       | Geographical location | Weather data |
|------|----------------|-----------------------|--------------|
|      |                | Latitude | Longitude | Altitude | Average Max T (°C) | Average Min T (°C) | Total RF (mm) |
| 2016 | Enemay         | 10°25'N   | 38°13'E   | 2514     | 22.5               | 10               | 1002          |
| 2016 | Shebel-Berenta | 10°27'N   | 38°20'E   | 2100     | 26                 | 10.6             | 1273          |
| 2016 | Wonberema      | 10°39'N   | 36°05'E   | 2062     | 27.4               | 11.8             | 1595          |
| 2017 | Debre-Elias    | 10°18'N   | 37°29'E   | 2230     | 24.7               | 15               | 2179          |
| 2017 | Enemay         | 10°25'N   | 38°13'E   | 2514     | 24.7               | 11.13            | 1316          |
| 2017 | Lay-Gaint      | 11°50'N   | 38°21'E   | 2937     | 18.7               | 8.8              | 1013          |
| 2017 | Shebel-Berenta | 10°27'N   | 38°20'E   | 2100     | 26.4               | 11.4             | 1745          |
| 2017 | Wonberema      | 10°39'N   | 36°58'E   | 2062     | 26.1               | 8.5              | 1632          |
The additive main effect and multiplicative interaction (AMMI) and GGE biplot analysis were performed using GenStat 18th edition statistical package (VSN International, 2015).

The AMMI model first fits the additive effects for the genotypes and the growing environments (five growing environments and two seasons) and multiplicative term for GE interactions. The AMMI model is expressed by:

$$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^{N} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij};$$

where $Y_{ij}$ is the yield of the $i$th genotype in the $j$th environment, $\mu$ is the grand mean; $g_i$ and $e_j$ are the deviations of genotype and environment from the grand mean, respectively, $\lambda_k$ is the square root of the eigenvalue of the PCA axis $k$, $\alpha_{ik}$ and $\gamma_{jk}$ are the principal component scores for PCA axis $k$ of the $i$th genotype and the $j$th environment, respectively, and $\varepsilon_{ij}$ is the residual term (Zobel et al., 1988).

AMMI stability value (ASV) was calculated for each genotype according to the relative contributions of the principal component axis scores (IPCA1 and IPCA2) to the interaction sum of squares. The ASV as described by Adjebeng-Danquah et al. (2017) and Purchase et al. (2000) was calculated as follows:

$$ASV = \sqrt{\left(\frac{IPCA1 \text{ sum of squares}}{IPCA2 \text{ sum of squares}} \cdot (IPCA1 \text{ score})^2 + (IPCA2 \text{ Score})^2\right)}$$

where IPCA1 Sum of squares/IPCA2 Sum of squares is the weight given to the IPCA1-value by dividing the IPCA1 sum of squares (from the AMMI analysis of variance Table) by the IPCA2 sum of squares. The larger the IPCA score is, either negative or positive, the more adapted a genotype is to a certain environment. Smaller ASV scores indicate a more stable genotype across environments (Farshadfar et al., 2011).

The GGE biplot model is

$$Y_{ij} - \mu - Bj = p_1 \sigma_{1j} \delta_{1j} + p_2 \sigma_{2j} \delta_{2j} + \varepsilon_{ij}$$

Where:

$Y_{ij}$ is the expected yield of genotype $i$ in environment $j$; $\mu$ is the grand mean of all observations; $Bj$ is the main effect of environment $j$; $p_1$ and $p_2$ are the singular values of first and second-largest principal components, PC1 and PC2, respectively; the square of the singular value of a PC is the sum of squares explained by the PC; $\sigma_{1j}$ and $\sigma_{2j}$ are the eigenvectors for the $i$-th genotype for PC1 and PC2, respectively; and $\delta_{1j}$ and $\delta_{2j}$ are the eigenvectors for the $j$-th environment for PC1 and PC2, respectively; and $\varepsilon_{ij}$ is the residue not explained by the primary and secondary effects.

3.1.1. Farmers selection and preference ranking

Farmers who evaluated the trial were representative of the area and have long experience in farming. From each district, about 10 to 15 farmers (both male and female) participated. Before the beginning of the selection process, selected farmers from the villages were asked to set their selection criteria. Plant height, disease tolerance, yield performance, and overall appearance (vigorous of the varieties) were identified as the most important farmers’ selection criteria. Farmers observe the entire experimental plots by moving around one by one before they start selection. To avoid biasness, they were not allowed to discuss each other about the performance of the varieties. A set of three colored cards (Green, Yellow and Red) were given to each farmer for selection. Green card indicates the best adapted and highly preferred variety. Yellow and Red cards, on the other hand, indicate medium and poorly adapted varieties, respectively. Thus, farmers were oriented to evaluate the performance of the varieties using the colored cards. After the
evaluation, the cards were counted and the preference ranking was computed as described by Christinck et al. (2005) as follows:

\[ \text{Pref} = \frac{(0 \times NR + 1 \times NY + 2 \times NG)}{(NR + NY + NG)} \times 100 \]

Where \( NR \) is the number of red cards, \( NY \) is the number of yellow cards, and \( NG \) is the number of green cards.

3.1.2. Grain Protein Content Analysis
Grain protein content of the varieties were analysed using Near-Infrared Reflectance Spectroscopy (NIRS) in Amhara agricultural research institute grain quality laboratory.

4. Result and discussion

4.1. Grain yield performance
Analysis of variance revealed a significant difference among the tested varieties for the grain yield in all tested locations. The highest grain yield of 5.2 t ha\(^{-1}\) was recorded by Variety Danbi followed by Tate with grain yield of 5.1 t ha\(^{-1}\) at Shebel Berenta. Variety Danbi was also top yielder at Enemay and Debere Elias. The lowest grain yield was observed at Wonberma with variety Ude (2 t/ha) (Table 3).

The AMMI analysis of variance of the grain yield (Table 4) showed that the presence of a highly significant difference among genotypes, environments and GE interaction, contributing 9.27%, 77.33% and 13.4% of the treatment sum of squares, respectively (Table 4). The results of AMMI analysis showed similar results of (Kendal, 2015) 86.69% for environmental effects, only 9.67% for genotypic effects, and 1.53% for GEI effects performance of durum wheat was highly influenced by environmental effects. The contribution of the environment is very high, indicating the test environments were highly variable and have a great influence on the grain yield performance of durum wheat varieties. In addition, the contribution of the interaction (GEI) is relatively higher than the contribution of genotypes, which indicated a particular genotype may not show the same phenotypic performance under different environmental situations or different genotypes may respond differently to a specific environment.

| Genotypes  | Shebel Berenta | Enemay | Wonberma | Debere Elias | Lay-Gaint |
|------------|----------------|--------|----------|--------------|-----------|
| Denbi      | 5.2\(^{ac}\)    | 4.6\(^{a}\) | 2.8\(^{a}\) | 3.6\(^{ab}\) | 3.7\(^{ab}\) |
| FLAKIT     | 3.6\(^{a}\)     | 4.0\(^{ab}\) | 2.3\(^{ab}\) | 2.2\(^{a}\) | 3.0\(^{a}\) |
| Mosobo     | 4.5\(^{abc}\)   | 4.3\(^{ab}\) | 2.5\(^{ab}\) | 3.9\(^{a}\) | 3.4\(^{ab}\) |
| Mukiye     | 4.5\(^{abc}\)   | 3.9\(^{ab}\) | 2.4\(^{ab}\) | 2.2\(^{a}\) | 3.0\(^{a}\) |
| Mangudo    | 4.2\(^{abc}\)   | 3.4\(^{b}\)  | 2.2\(^{ab}\) | 2.8\(^{cd}\) | 3.1\(^{b}\) |
| OBSA       | 5.0\(^{a}\)     | 4.1\(^{ab}\) | 2.8\(^{a}\)  | 2.6\(^{cd}\) | 4.2\(^{a}\) |
| Utuba      | 4.5\(^{abc}\)   | 3.8\(^{ab}\) | 2.4\(^{ab}\) | 2.6\(^{cd}\) | 3.0\(^{a}\) |
| Tate       | 5.1\(^{a}\)     | 3.8\(^{ab}\) | 2.3\(^{ab}\) | 3.1\(^{bc}\) | 3.1\(^{b}\) |
| TOLTU      | 4.7\(^{bc}\)    | 4.3\(^{ab}\) | 2.4\(^{ab}\) | 2.4\(^{cd}\) | 3.6\(^{ab}\) |
| Ude        | 3.9\(^{ab}\)    | 3.5\(^{a}\)  | 2.0\(^{a}\)  | 3.1\(^{bc}\) | 3.2\(^{a}\) |
| CV         | 11.4            | 12.9     | 14.5      | 14.7         | 13.7      |

*Varieties with similar letters did not show statistically significant difference with Duncan multiple range test mean separation.
Therefore, the identification of stable and high yielding genotypes should get more attention in order to recommend stable genotypes for commercial production.

The GEI sum of squares were further partitioned to Interaction Principal Component Analysis scores (IPCA), AMMI ANOVA showed that the first three principal component axes (IPCA1, IPCA2 and IPCA3) were significant at ($p < 0.001$) and captured 37.83%, 30.61% and 17.82% of the total GE interaction sum of squares, respectively, while the fourth principal component axis captured 6.22% (mostly noise) of the total GE interaction sum of squares which did not help to predict validation observations. In this study, the interaction of 10 durum wheat genotypes with eight environments was best predicted by the first two principal components of AMMI model. Similar results were reported by different scholars (Bahrami et al., 2009; Mohammad et al., 2011; Tarakanovas & Ruzgas, 2006).

Using mean grain yield and IPCA1 scores, genotypes and environments are plotted on a biplot graph. On the biplot, genotypes and environments located on the right side of the grand mean on the ordinate are high yielding, while those on the left are low yielding (Figure 1). Therefore, Denbi, Mosobo, Tate, OBSA and TOLTU were high-yielding genotypes, while Denbi was the highest yielding followed by Mosobo. Similarly, Shebel-Berenta was potential environment. Purchase (1997) reported that the IPCA scores of genotypes in the AMMI analysis are indications of stability of genotype across environments. The closer the IPCA scores to zero implied that more genotypes are stable across their testing environments.

As indicated in Figure 2, genotypes, Mangudo which is near to the interaction biplot is the most stable genotypes in all environments. However, the mean yield of Mangudo is below average and there are other genotypes that exceed Mangudo. In contrast, genotypes, FLAKIT, Tate and Mukiye are far from the origin indicating their strong interaction with the environments. Among the environments, Wonberema, and Enemay are close to the interaction biplot, while Debre-Elias, Lay-Gaint and Shebel Berenta were distant from the origin (Figure 2). According to the ASV, the most stable genotype is Utuba followed by Mangudo and Tate. However, the highest in grain yield performance is Denbi followed by Mosobo which is relatively less stable (Table 5).

ASV ranked the genotypes based on the least score (Table 5). In this stability measure, genotypes with least ASV or have the smallest distance from the origin are considered as the most stable genotypes, whereas those which have the highest ASV are considered as unstable. Utuba was the most stable genotype for grain yield, since it had the least ASV value and ranked first. FLAKIT, on the other hand, was considered the least stable because it had the highest ASV value.

### Table 4: Combined ANOVA for AMMI model of the grain yield ton ha$^{-1}$

| Source       | DF  | SS       | MS       | % SS contribution |
|--------------|-----|----------|----------|-------------------|
| Total        | 239 | 197.72   | 0.827    |                   |
| Treatments   | 79  | 157.02   | 1.988    |                   |
| Genotypes    | 9   | 14.56    | 1.618    | 9.27***           |
| Environments | 7   | 121.42   | 17.345   | 77.33***          |
| Interactions | 63  | 21.04    | 0.334    | 13.40***          |
| IPCA 1       | 15  | 7.96     | 0.53     | 37.83***          |
| IPCA 2       | 13  | 6.44     | 0.495    | 30.61***          |
| IPCA 3       | 11  | 3.75     | 0.341    | 17.82*            |
| IPCA 4       | 9   | 1.31     | 0.146    | 6.22NS            |
| Residuals    | 15  | 1.58     | 0.105    |                   |
| Error        | 144 | 21.75    | 0.151    |                   |

*** Very highly significant difference observed, NS No significant difference.

Mekonnen et al., Cogent Food & Agriculture (2020), 6: 1746229
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ASV was used by different scholars (Ferney, 2007; Mohammed, 2009; Mut et al., 2010). The sum of the yield and stability rankings (YSI) ranked Denbi, OBSA and Tate as the genotypes that have equal YSI value combined high yield with stability. Though Utuba was stable, it is low-yielding variety and thus undesirable. Three genotypes Denbi, OBSA and Tate can be considered as high yielding and stable varieties.

The GGE biplot method provides considerable flexibility, allowing plant breeders to simultaneously select for yield and stability (Kendal & Sener, 2015). GGE biplot based on the principal component analysis (PCA) model, particularly its genotype-focused scaling form, provides a superior means for visualizing both mean performance and stability of the tested genotypes (Yan & Kang, 2003). Figure 3 shows the “Average Environment Coordination” (AEC) of the GGE biplot for 10 varieties evaluations regarding the mean vs. stability. This AEC is based on genotype-focused Singular Value Partitioning (SVP) (Yan & Kang, 2003). Genotypes with the smallest perpendicular line and close to AEC are called stable genotype. Genotypes Tate, OBSA and Denbi had the smallest perpendicular line and close to AEC, implying their stability across diverse environments (Figure 3); similar results were also reported by Kendal (2019) in durum wheat cultivar comparison study.

4.2. Grain protein content
Grain protein content in durum wheat has been known as an important component having an influence on the pasta quality. The grain protein percent ranged from 7.8% for variety TOLTU at Enemay to 12.6% for variety Mukiye at Wonberma (Table 6). All the tested durum wheat varieties yielded less than 10%
grain protein content at Enemay and Lay-Lay-Gaint, which is below the acceptable range. Variety Denbi and Mossoba exhibited <10% protein content at Dere-Elias and Wonberma, and variety TOLTU had <10% protein content at Shebel Berenta and Wonberma Woredas. A grain protein content of >13% for durum is a standard in quality throughout the grain industry, whereas wheat with protein contents below 11% give products of inferior quality (Riley et al., 1998; Temtme, 2017). Durum wheat protein content is an important criterion for marketing and purchasing wheat, and thus it is included in almost every flour specification. Grain quality is largely dependent on varieties but is also highly influenced by the environmental conditions, particularly on nitrogen availability, soil N and rate and time of N application. Thus, nitrogen fertilization management offers the opportunity for increasing wheat protein content and quality (Garrido-Lestache et al., 2005; Temtme, 2017).

4.3. Participatory durum wheat variety selection (PVS)
Accordingly, farmers’ preferred durum wheat variety is presented across locations as follows:

4.3.1. Shebel-Berenta
The top three varieties selected by farmers were Denbi, Mukiye and Utuba (Table 7). These varieties ranked 1st, 5th and 6th in grain yield at Shebel-Berenta (Table 3). Based on grain yield performance and farmers’ selection, variety Denbi was found superior over the rest of the tested durum wheat varieties at Shebel-Berenta.
Table 5. IPCA1, IPCA2, ASV, GYR and YSR scores for 10 genotypes sorted on mean yield

| Genotype | Mean  | IPCAg1 | IPCAg2 | ASV    | ASV R | GY R | YSI |
|----------|-------|--------|--------|--------|-------|------|-----|
| Denbi    | 3.711 | -0.51447 | 0.04928 | 0.623755 | 6    | 1   | 7   |
| OBSA     | 3.588 | 0.34382  | 0.35574 | 0.547023 | 4    | 3   | 7   |
| Tate     | 3.456 | -0.03927 | -0.49579 | 0.498057 | 3    | 4   | 7   |
| Utuba    | 3.154 | 0.20217  | -0.26468 | 0.360225 | 1    | 8   | 9   |
| Mosobo   | 3.698 | -0.53229 | -0.27831 | 0.700962 | 8    | 2   | 10  |
| TOLTU    | 3.423 | 0.51128  | 0.06585 | 0.621449 | 5    | 5   | 10  |
| Mangudo  | 3.087 | 0.14943  | -0.34538 | 0.389751 | 2    | 9   | 11  |
| Mukiye   | 3.206 | 0.50423  | -0.17953 | 0.635323 | 7    | 6   | 13  |
| FLAKIT   | 3.185 | 0.02757  | 0.89765 | 0.898268 | 10   | 7   | 17  |
| Ude      | 3.012 | -0.65246 | 0.19516 | 0.812375 | 9    | 10  | 19  |

ASV – AMMI stability value, ASVR – rank of the genotypes based on the AMMI stability value, GYR – the rank of the genotypes based on yield across environments, RYSI – rank of genotypes based on Yield stability index.

Figure 3. Biplot showing Grain yield rank and stability of 10 Durum wheat genotypes in eight environments.
Plot = ranking, Method = environment, Scaling = symmetric, Ranking lines = projection. PC1 and PC2 are the first and second principal components, respectively. Sum of PC 1 and PC 2 = 66.75%.
4.3.2. Enemay
Ude, TOLTU and FLAKIT were the top three farmers' preferred durum wheat varieties. However, these varieties ranked 9th, 3rd and 5th in grain yield, according to their order at Enemay testing site. In agreement with farmers' selection criteria, metric analysis also depicted variety TOLTU was best adapted at Enemay and similar environments.

4.3.3. Debre Elias
Mosobo, Mangudo and OBSA varieties were the top three farmers' preferred varieties. The varieties were ranked 1st, 5th 7th in mean grain yield. Based on farmers' selection and mean grain yield performance, variety Mosobo was found the best-adapted variety at Debre-Elias and similar environments.

4.3.4. Wonberema
Based on farmers' selection criteria, Denbi, Mangdo and Mosobo were found to be the top three varieties, ranking 1st, 9th and 3rd in grain yield.
4.3.5. Lay-Gaint

Mangudo, Mukiye and Denbi were the top three farmers’ preferred varieties, ranking 7th, 9th and 3rd in mean grain yield.

Overall, the farmers’ preference and the grain yield rank of Durum wheat were similar except at Lay Lay-Gaint; the top yielder variety OBSA were not selected by the farmer. The result of this study showed that farmers were as efficient as breeders in identifying high-yielding varieties with desirable traits for their specific environment. Similar result was also found by Fentie & Jemberu (2012).

5. Conclusion and recommendation

Genotypes Denbi, OBSA and Tate were identified as the most stable genotypes by using both AMMI yield stability index and GGE biplot comparison, while the remaining tested genotypes showed inconsistent performances across the tested environments. Denbi variety was listed as top three varieties by farmers’ preference at Shebel Berenta, Wonberema and Lay Lay-Gaint woreda, whereas the protein content of Denbi was <11% across the tested locations. FLAKIT, Mukiye and Utuba exhibited >11% grain protein content at Shebel Berenta, Debre Elias and Wonberma woredas, but FLAKIT had low yield performance across location.

Considering the grain yield potential, farmers’ preference and grain protein content, Mukiye and Utuba are recommended for Shebel Berenta and similar environments. Filakit and TOLTU are recommended for Debre Elias woreda since Filakit and TOLTU had comparable grain yield with Mukuie and Utuba. For Womberma variety, Mangudo is recommended because it is 3rd in grain yield and possesses acceptable GPC and 2nd in farmers’ preference. Due to the low protein content, Lay-Gaint and Enemay Woreda, no durum wheat varieties were recommended. Further study needs to be planned including the fertilizer management. The grain yield performance of the genotypes at Debere Elias and Wonberma were very low, so further study on the agronomic management, fertilizer rate and application should be done to improve this low productivity.

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Competing Interests

The authors declare no competing interests.

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