Adaptability study and yield stability analysis of lentil (Lens culinaris Medik) varieties at East Hararghe Oromia Ethiopia

Habte Berhanu[1], Fikadu Tadesse[2], Hussein Abro[3]
[1,2,3]Oromia Agricultural Research Institute, Fedis Agricultural Research Center, Ethiopia

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ABSTRACT

Evaluation and selection of lentil varieties with wide adaptability across diverse environments is very important, before recommending them to achieve a high rate of varietal adoption. Because lentil yield is a complex quantitative attribute that is highly impacted by the environment, many tools were used to investigate multi-environmental trials and recommend optimal varieties and conditions. The Genotype by Environment Interaction (GEI) and AMMI (Additive Main Effects and Multiplicative Interaction) tools were used to estimate seed yield by analyzing variation in variety yields across mult-environments. The ideal-genotype biplot revealed that Alemaya-98 and Assano outperformed all other varieties, with both exhibiting high mean yield and good performance stability across environments. According to genotype-environment interaction sources of variation, Girawa 2022 was the most appropriate environment for lentil cultivation. As a result, the Alemeya-98 and Assano variety were suggested for further demonstration and production.

Corresponding Author:

Habte Berhanu
Oromia Agricultural Research Institute, Fedis Agricultural Research Center
in Harar City and situated at 525 km from Finfinne to East of the country
Email: habteberhanu13@gmail.com

1. INTRODUCTION

Lentil yield is a complex quantitative feature that is heavily impacted by the environment (Subedi, M., et al., 2021). It is the oldest ancient annual food crop, having been grown as a vital food source for over 8,000 years (Dhuppar, P. et al., 2012; Balkrishna et al., 2021). Ethiopia is regarded as the second most diverse lentil producing region (Takele, E. et al., 2022). Total harvested area: 5,585,879 hectares; total production: 5,610,103.65 tons. Worldwide, Africa harvested approximately 148,282 ha and 179,392.93 tons of area and lentil output, with East Africa covering an average of 93,488 ha and total production of 126,804.89 tons. Ethiopia harvested 87,369 ha of land and 122,766.45 tons, with a yield of 1.4 tons per hectare (FAOSTAT, 2023).

Ethiopia is experiencing an increase in lentil productivity due to improved net planting and productivity per unit area. Its productivity per unit area remains low when compared to other pulse crops (Amsalu, B., et al., 2016; Feleke et al., 2021). According to the Fikre, A., et al., (2019) study, the total land area and total volume of lentil production have expanded at a compound growth rate of 4% and 9%, respectively, while crop productivity has grown at a compound rate of 5%. According to the writers, Ethiopia exports an average of 2,339,693 kg of lentils and incurs birr 18,684,845. Ethiopian lentils are most commonly exported to Pakistan and the United Arab

Emirates, accounting for 20% and 16%, respectively. Lentil is called poor man's meat due to its low price compared to meat (Damte, T., & Tafes, B. 2023).

Historically, in plant breeding, a large number of statistical models have been developed and used for studying genotype-environment interaction (Crossa, J., 2012). The author added that these models have helped plant breeders assess the stability of economically important traits and predict the performance of newly developed genotypes evaluated under varying environmental conditions. Therefore, the experimental work was developed and performed with the objective of identifying an adapted, high-yielding, and stable variety for the study areas and to investigate the environmental and genotypic effects on seed yield and yield-related traits.

2. METHOD

2.1 Testing Sites and Locations

Five lentil varieties were collected from Debrezit Agricultural research Center and evaluated against local check under adaptation trial. The experiment was carried out at two locations of Fedis Agricultural Research Center testing sites and Girawa on farm for three consecutive years during 2020 to 2022 the main season (Table 1).

Table 1. The study Environments and their main agro ecological features

Locations	Distance from Addis Ababa (km)	GPS co-ordination			RF (mm)	Temp. (°C)
		Latitude	Longitude	Altitude (m) a.s.l.		
Fadis	559	9.014 N	42.062 E	1702	600-700	28-32
Girawa	526	9° 8' 17"N	41° 50' 8"E	2,471	650-900	30 -25

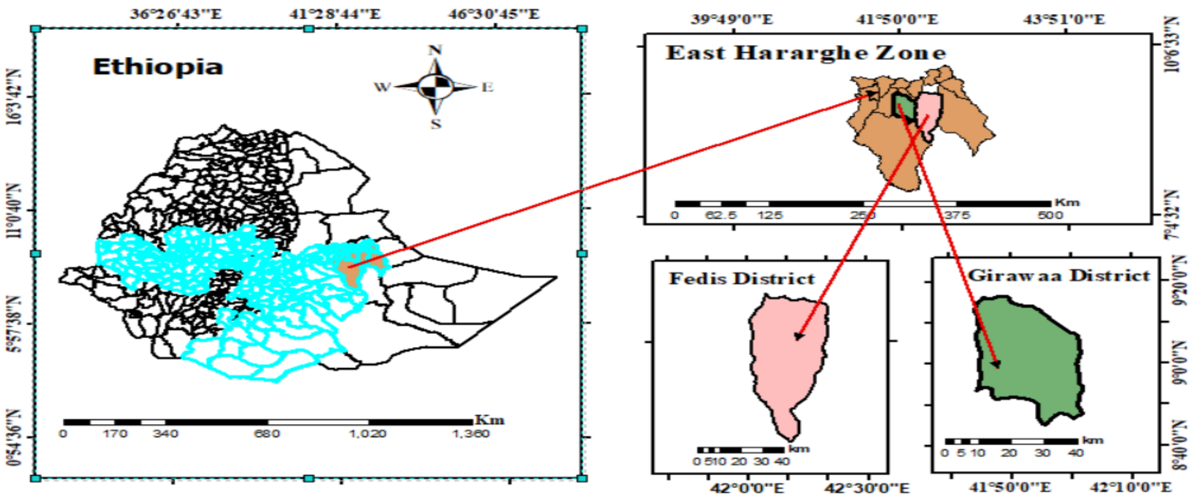

Figure 1. Map of the study areas

2.2 Experimental materials

Five released lentil varieties including local check were used in an experiment during trial evaluation (Table 2).

Table 2. Pedigree, origin, area of adaptation and year of release of soybean varieties used the study

No	Variety name	Pedigree	Year of release	Source center
1	Alemaya-98	Flip 89-63L	1998	DezARC
2	Assano	Flip 88-46	2003	SARC
3	Dembi	E1-142x r-186-3	2013	DezARC
4	ADAA	Flip-86-14L	1995	DezARC
5	Local check		-	Farmers

2.3 Experimental design and procedures

The treatments were laid down in a randomized complete block design (RCBD) with four replications. The experiment was planted in 0.4m inter row spacing and 0.5m plot spacing having 3 m plot length. The fertilizer and seed with recommended rate was applied in the row at planting as per the recommendation and all other recommended agronomic management practices were applied properly. Hand weeding was made to keep plots weed-free during the experimentation. Harvesting of the crop was done manually when the pod turned yellowish and the crop reached its physiological maturity.

2.4 Data Collected and Analysis

Data were collected both on plot and plant basis. The two central rows were used for data collection based on plots, for seed yield (kg/ha). Five plants from the central two rows were randomly selected for data collection on plant basis and the averages of the five plants in each experimental plot were used for statistical analysis for traits such as days to flowering, days to maturity, plant height (cm), primary branches per plant, number of seeds per pod and number of pods per plant. The analysis of variance was made using R-software and Duncan's multiple range test (DMRT) was used to compare the difference between treatment means at 5% probability levels.

2.5 AMMI stability value (ASV)

The AMMI stability value (ASV) as described by Purchase (2000) was calculated as follows:

$$ASV = \sqrt{[[(IPCA1sum\ of\ square \div IPCA2sum\ of\ square) * IPCA1score]\ 2\ +\ (IPCA\ 2\ SCORE)\ 2\ ]}$$

Where; SS_{IPCA1}/SS_{IPCA2} was the weight given to the IPCA1-value by dividing the IPCA1 sum of squares by the IPCA2 sum of squares.

2.6 Genotype and Genotype by Environment Interaction biplot analysis

Genotype and Genotype by Environment Interaction biplot analysis was conducted using R-software.

3. RESULTS AND DISCUSSION

Variety (G), environment (E) and their interactions (G × E) were found to be a significant ($p \leq 0.01$, $p \leq 0.05$) source of variation for all examined traits seed yield (Table 3). Varieties for seed yield traits showed a considerable extent of variation due to Environment. The interaction effect of Genotypes and Environments shows significant variation indicating further evaluation for stability is needed to identify best genotypes and best environment.

Table 3. Mean squares (MS) analysis of variance (ANOVA) and partitioning of treatment sum of squares (EV %) for seed yield (SY)

Source of variation	Degree of freedom	Sum square	Mean square
Replication(R)	3	1747.4	582.5
Variety(V)	4	8870.2	2217.5*
Environment(E)	5	105898.5	21179.7**
Interaction(I)	20	23564.8	1178.2*
Error(e)	87	47540.3	546.4
Total	119	187621.2	

3.1 Yield and yield components

From the analysis of variance seed yield and yield related components show significant variation. Except number of seed per plant all studied traits show significant variation among the varieties tested (Table 4).

Table 4. Comparison of means for seed yield (kg per ha) and yield related components of Lentil varieties tested across environments

Variety	Days to maturity	Primary branch/plant	Plant height (cm)	Pod/plant	Seed/pod	Seed Yield (Kg)
Dembi	108.80bc	6.09b	35.57a	52.81b	1.68	1649ab
Alemaya-98	100.20a	7.68ab	36.64a	60.75ab	1.71	1712a
Assano	100.20a	7.65ab	35.00a	65.92a	1.45	1690ab
ADA	105.70ab	8.89a	36.89a	60.68ab	1.59	1471b
Local	115.10c	6.53ab	40.90b	59.26ab	1.59	1496b
CV	12.10	22.80	16.60	13.70	9.20	20.70
L.S.D	7.35	2.22	3.51	10.87	NS	197.40

Note: CV=coefficient of variation, L.S.D= least significant difference

According to the means comparison, significant differences ($p < 0.05$) were detected for Seed yield, days to maturity, primary branch/plant, plant height and pod/plant among the five lentils varieties averaged across eight growing environments. Seed yield ranged from 1471 kg ha^{-1} (ADA) to 1721 kg ha^{-1} (Alemaya-98). Days to maturity varied significantly among the tested varieties, ranging from 100 days (Assano and Alemaya) to 115 days (Local variety). Among the varieties, local check showed considerably taller plant height, while Dembi measured shorter. Assano recorded a remarkable number of pod/plant reaching values of 65.92, whereas variety Dembi recorded lowest values 52.81. Numbers of seeds per pod don't show significant variation among the varieties (Table 4). The number of pods per plant ranged from 52.81 to 65.92 and coefficient of variation 13.7%. The highest and lowest numbers of pods per plant were recorded from Variety Dembi and Assano, respectively. The number of seeds per pod ranges from 1.45 to 1.71 and the coefficient of variation 29.2%. Higher numbers of seeds per pod were recorded in variety Alemaya-98, whereas lower seeds per pod were recorded from variety Dembi among other tested varieties. This high variation in the number of seeds per pod was reported by Hussan et al. (2018) and (Takele, E. et al., 2022) reported high significant variation in lentil genotypes for above-ground biomass and seed yield.

Table 5. Mean grain yield (kg ha-1) of five lentil varieties evaluated at two environments for three years

Variety	Locations						Combined Mean grain yield (kg ha^{-1})
	Fedis			Girawa			
	2020	2021	2022	2020	2021	2022	
Dembi	1926	1677	970	1872	1836	1615	1649
Alemaya-98	1788	2003	1185	1935	2061	1400	1712
Assano	1785	2068	1113	1600	1943	1634	1690
ADA	1094	2007	918	1369	1959	1479	1471
Local	1632	1779	1050	1684	1933	1498	1496
Mean	1645	1907	1047	1672	1946	1520	1624

In this study, seed yield ranges from 1471 kg ha-1 to 1712 kg ha-1 with a mean value of 1624 kg ha-1 and a coefficient of variation of 20.7% (Table 5). Variety Alemaya-98 possessed a high seed yield followed by Dembi. On the other hand, Variety ADA had the lowest yield compared with the other tested varieties. The varieties perform differently in different environments and years. The mean of varieties Fedis 2021 is the highest yield while Fedis 2022 is the lowest mean. Alamaya-98 gave the highest yield at Fedis 2022 and Girawa 2021.

3.2 AMMI Analysis

The Additive Main effects and Multiplicative Interaction (AMMI) model has been used extensively for analysis of multi-environment yield trials for the purpose of understanding complex genotype x environment interactions and increasing accuracy (Gauch J., 2013). According to the AMMI analysis of variance, the effect of genotype (G) accounted for 4.72% of the total sum of squares (SS) for seed yield, whereas the environmental (E) effects and GEI accounted for 56.44% and 1.26% of the total SS, respectively. Indicating the environmental factors that contribute the lion share created variation among the varieties. The first two principal components PC 1 and PC 2 account for 91.2 variations of the interaction effects and they are significant variations. Similarly, KAYA, Y.,*et al*., (2002) reported the mean squares for the PCA 1 and PCA 2 were significant at P = 0.01 and cumulatively contributed to 78.64% of the total genotype by environmental interaction.

Table 6. Additive main effects and multiplicative interactions analysis of variance for seed yield (kg ha^{-1}) of the varieties across environments

Source of Variation	Degree of freedom	Sum Square	Mean Square	explained %	percent	Accumulation
Total	119	1876.20	15.77			
Environment	5	1058.98	211.79**	56.44		
Variety	4	88.70	22.17**	4.72		
Interaction	20	235.65	11.78*	1.26		
PC1	8	185.67	23.21**	78.82	78.8	78.8
PC2	6	29.17	4.86*	78.79	12.4	91.2
PC3	4	18.82	4.71	12.37	8.0	99.2
PC4	2	1.97	0.98	7.98	0.8	100
Residuals	87	475.40	5.464401	0.83		

A large sum of squares for environments indicated that the environments were diverse, with large differences among environmental means causing most of the variation in seed yield. The magnitude of the varieties was four times larger than that of the interaction sum of squares, indicating that there were significant differences in varietal response across environments. Results from AMMI analysis (Table 5) also showed that the first principal component axis (PCA 1) of the interaction captured 78.82% of the interaction sum of squares while, the second principal component axis (PCA 2) explained a further 12.40% of the genotypes by environmental interaction sum of squares.

Table 7. AMMI stability value and Genotype selection index

Variety	Yield(kg/ha)	Rank	ASV	Rank	GSI	IPCAg1	IPCAg2
Dembi	1649	3	1.7454	4	7	-1.61324	-0.66633
Alemaya-98	1712	1	1.4139	3	4	-0.25843	1.39014
Assano	1690	2	0.4856	2	4	0.12773	-0.46854
ADA	1471	5	2.0385	5	10	2.01366	-0.31738
Local check	1496	4	0.2767	1	5	-0.26972	0.0621

Note: ASV= AMMI stability value, and GSI=Genotype selection index

Genotype selection index should consider the mean grain yield and ASV should be considered to determine the stability of the genotype (Tadele T. *et al*., 2021). The larger the ASV value, either negative or positive, the more specifically adapted a genotype was to certain environments. A smaller ASV value indicated a more stable genotype across environments (Purchase, 1997). Accordingly, Local check (0.2767), Assano (0.4856) and Alemaya-98 (1.4139) estimates a smaller ASV (Table 6). Even though local check was stable its yield was too low as compared to the improved variety. Another very important tool is Genotype selection index (GSI) which estimates high yield and stable varieties. The smaller in GSI indicated that the high yielding and stable varieties. Accordingly, Alemaya-98 and Assano varieties score small GSI which are 4 and they are high yielder and stable Varieties.

3.3 Genotype and Genotype by Environment interaction (GGE) biplot analysis

Lentil is grown in a wide-range of environmental conditions and so the yield of several genotypes tested across locations and over years differed due to high GE interactions (Sabaghnia, et al., 2008). The relationship between the different test environments and this was visualized by the line connecting each environment to the biplot origin or environment vectors (Fig 3). The cosine of the angle between two environments was used to calculate the correlation between them (Dehghani et al., 2009). Environments and genotypes that fall in the central (concentric) circle are considered ideal environments and stable genotypes, respectively (Yan, 2002). An environment is more desirable and discriminating when located closer to the center circle or to an ideal environment (Naroui et al., 2013). Accordingly, Variety (G2) and Girawa 2022 were stable varieties and ideal environments. Environments, Girawa 2022 and Girawa 2020 and correlated positively which is acute angle while Girawa 2022 and Fedis 2021 correlated negatively which is found on obtuse angle(Fig 2).

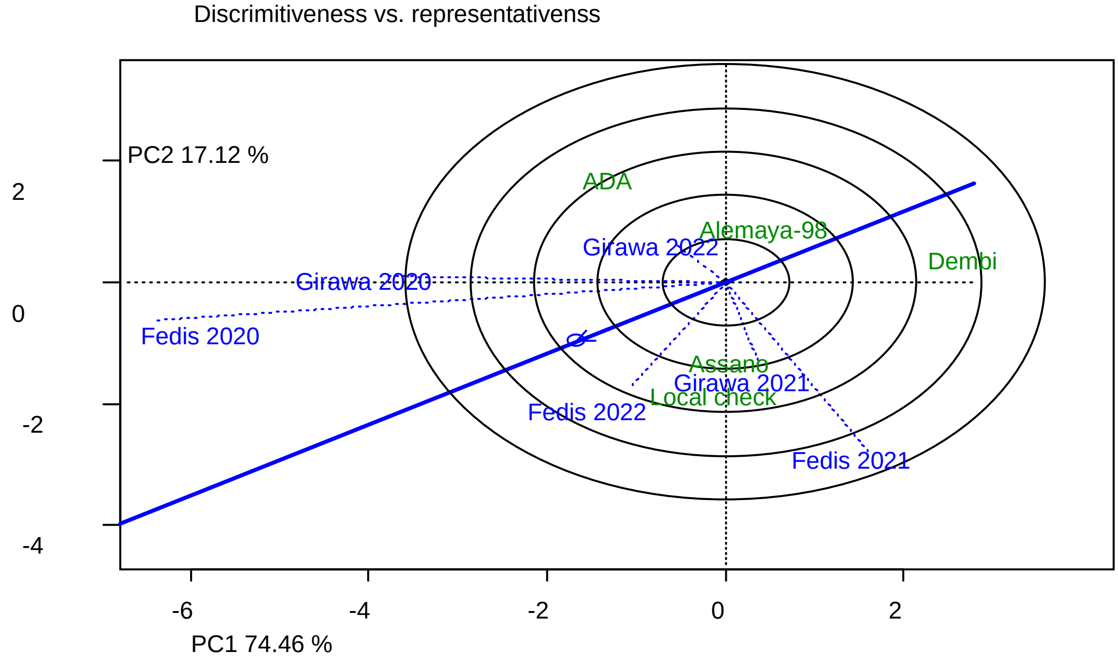

Figure 2. GGE biplot Discrimitiveness vs. representativenss

GGE biplot discriminating ability and representativeness is an important measure of the testing environments and genotypes. The concentric circles on the biplot as shown in (Figure 3) 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 discriminatory ability of the environments. Therefore, among the six environments, Girawa 2022 and Girawa 2021 were most discriminating (informative) and Fedis 2020 and Fedis 2021 least discriminating. Test environments that are consistently non-discriminating (non-informative) provide little information on the varieties and, therefore, should not be used as test environments. The average environment (represented by the small circle at the end of the arrow) has the average coordinates of all test environments, and Average Environment Axis (AEA) or Average-Tester-Axis (ATA) (Yan, 2002) is the line that passes through the average environment and the biplot origin. A test environment that has a smaller angle with the AEA is more representative of other test environments. Thus, Girawa 2022 and Girawa 2021 are most representative whereas Fedis 2020 and Fedis 2021 least representative. Test environments (locations and years) that are both discriminating and representative are good test environments for selecting generally adaptable varieties.

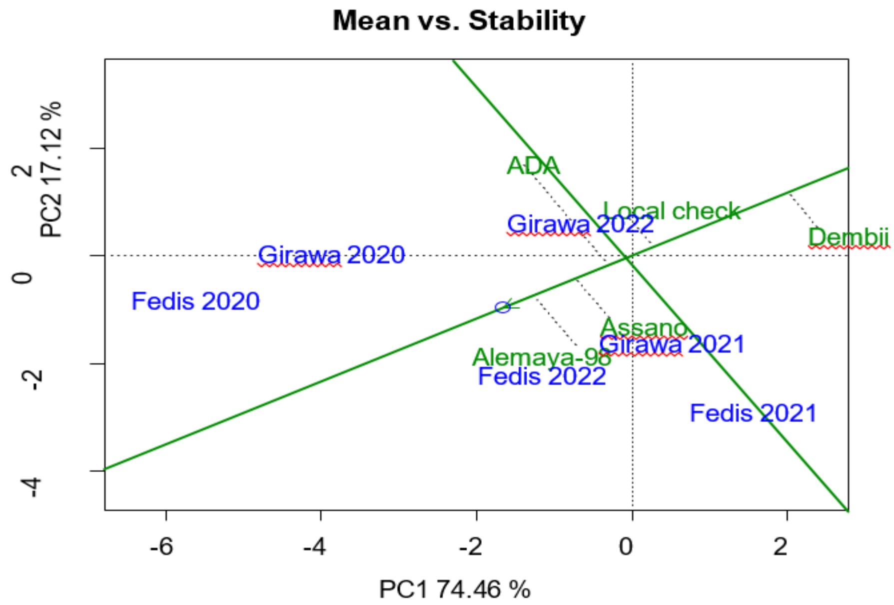

Figure 3. GGE Biplot Mean vs Stability

Mean vs stability Biplot gives the average environment coordination (AEC) view of the GGE biplot (Fig.3). The single-arrowed line is the AEC abscissa, it points to higher mean yield across environments. Thus, Alemaya-98 and Assano had the highest mean yield. The non-arrowed line is the AEC ordinate; it points to greater variability (poorer stability) in either direction. Thus, ADA was highly unstable and below average yield, whereas Alemaya-98 and Assano were highly stable. The biplot also shows the yield of varieties at individual sites. For instance, variety Local check had the highest average yield because it yielded the highest at sites Girawa 2022 and Girawa 2021, and above average at all other sites. On the other hand, the average yield of varieties ADA and Dembi were below average, because they yielded below average at sites in pairs, Girawa 2020, Fedis 2020 and Fedis 2022, respectively. With respect to the test sites, Fedis 2020 was most discriminating as indicated by the longest distance between its marker and the origin.

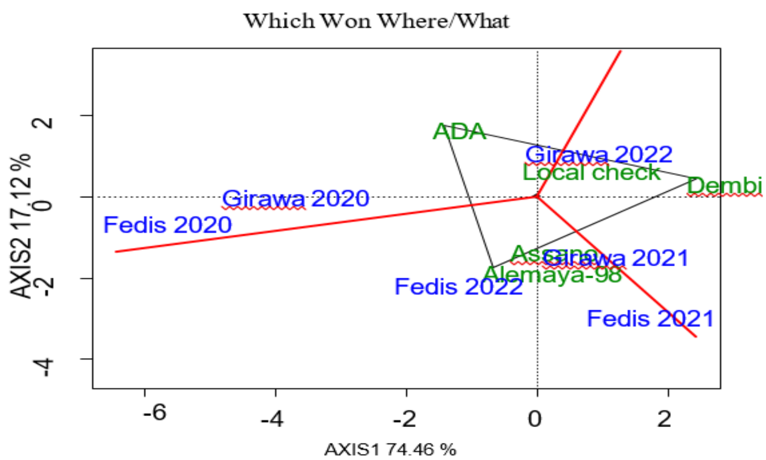

Figure 4. Which won where GGBiplot graph representation

A line that starts from the biplot origin and perpendicularly intersects a polygon side represents the set of hypothetical environments in which the two varieties defining that side perform equally; the relative ranking of the two varieties would be reversed in environments on opposite sides of the line (the so-called "crossover GE"). Therefore, the perpendicular lines to the polygon sides divide the biplot into sectors, each having its own winning genotypes. The winning varieties for a sector are the vertex variety at the intersection of the two polygon sides whose perpendicular lines form the boundary of that sector (Yan, 2002). If all environment markers fall into a single sector, this indicates that, to a rank-two approximation, a single variety had the highest yield in all environments. If environment markers fall into different sectors, this indicates that different varieties won in different sectors. Revealing the which-won-where pattern of a GED set is an intrinsic property of the GGE biplot rendered by the inner-product property of the biplot (Yan and Kang, 2003). In the which-won-where view of the GGE biplot (Fig. 4), the six environments fell into three sectors with different winning varieties. Specifically, Assano and Alemaya-98 were the highest yielding varieties in Girawa 2021 and Fedis 2022. Variety evaluation is meaningful only for a specific mega-environment, and an ideal genotype should have both high mean performance and high stability within a mega- environment.

4. CONCLUSION

Lentil yield is influenced by a number of traits along with the environments as if it is a complex trait. ANOVA revealed that significant variation was obtained among varieties for yield and yield related traits. From the results Alemaya-98 and Assano were high yielder and show better performance in Phenological appearance as well. AMMI and GGE biplot analysis tools are very interesting tools to detect whether the varieties are stable or not. Accordingly, the two models AMMI and GGE biplot Alemeya-98 and Assano were high yielder and stable varieties. Therefore, these two varieties (Alemeya-98 and Assano) were recommended for demonstration and further multiplication in the study areas and areas with similar agroecology.

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REFERENCES

Balkrishna, A., Sharma, G., Sharma, N., Kumar, P., Mittal, R., & Parveen, R. (2021). Global perspective of agriculture systems: from ancient times to the modern era. In *Sustainable Agriculture for Food Security* (pp. 3–45). Apple Academic Press.

Crossa, J. (2012). From genotype x environment interaction to gene x environment interaction. *Current Genomics*, *13*(3), 225-244.

Damte, T., & Tafes, B. (2023). Lentil Research in Ethiopia: Achievements, Gaps and Prospects.

Dehghani, H., Sabaghnia, N., & Moghaddam, M. (2009). Interpretation of genotype-by-environment interaction for late maize hybrids' grain yield using a biplot method. *Turkish Journal of Agriculture and Forestry*, *33*(2), 139-148.

Dhuppar, P., Biyan, S., Chintapalli, B., & Rao, S. (2012). Lentil crop production in the context of climate change: an appraisal. *Indian Research Journal of Extension Education*, *2*(Special Issue), 33-35.

Feleke, G., Meseret, A., Eshetu, S., & Tafes, B. (2021). Optimizing Phosphorus and Row Spacing Management for the Production of Lentil (Lens culinaris Medikus) in Vertisols of Ethiopia. *International Journal of Plant & Soil Science*, *33*(17), 82–93

Fikre, A., Shiferaw, T., & Tekalign, A. A 2019. Review of Five Decades of Legumes Improvement Program in Ethiopia: the Transition in Breeding Practices and Product Delivery.

Gauch Jr, H. G. (2013). A simple protocol for AMMI analysis of yield trials. *Crop Science*, *53*(5), 1860-1869.

KAYA, Y., Palta, C., & Taner, S. (2002). Additive main effects and multiplicative interactions analysis of yield performances in bread wheat genotypes across environments. *Turkish Journal of Agriculture and Forestry*, *26*(5), 275-279.

Sabaghnia, N., Sabaghpour, S. H., & Dehghani, H. (2008). The use of an AMMI model and its parameters to analyse yield stability in multi-environment trials. *The Journal of Agricultural Science*, *146*(5), 571-581.

Subedi, M., Khazaei, H., Arganosa, G., Etukudo, E., & Vandenberg, A. (2021). Genetic stability and genotype× environment interaction analysis for seed protein content and protein yield of lentil. *Crop Science*, *61*(1), 342-356.

Tadesse, T., Sefera, G., Asmare, B., & Tekalign, A. (2021). AMMI analysis for grain yield stability in lentil genotypes tested in the highlands of Bale, southeastern Ethiopia. *Journal of Plant Sciences*, *9*(1), 9-12.

Takele, E., Mekbib, F., & Mekonnen, F. (2022). Genetic variability and characters association for yield, yield attributing traits and protein content of lentil (Lens Culinaris Medikus) genotype in Ethiopia. *CABI Agriculture and Bioscience*, *3*(1), 9.

Yan, W. (2002). Singular-value partitioning in biplot analysis of multienvironment trial data. *Agronomy journal*, *94*(5), 990-996.