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Adaptation and Performance Evaluation of Lentil (*Lens Culinaris* Medik) Varieties in East Shewa and West Arsi Zones, Oromia Regional State, Ethiopia

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Abstract: Lentil is a self-pollinating annual crop originated in the Near East. Ethiopia is considered as a center of diversity for lentil, making Ethiopia one of the major lentil-producing countries in Africa. So far little has been done to address the impact of climate change, which enables farmers to solve their problem via adaptations at farm-level. Therefore, the current study was conducted with the objectives of evaluating and selecting relatively high yielding varieties. Five lentil varieties (viz; Ada'a, Alemaya 98, Derso, Gudo and Teshale) were evaluated using randomized complete block design with three replications at Dugda, AdamiTulluJiddoKombolcha and ArsiNegelle districts for two consecutive cropping seasons under rain fed conditions. The analysis of variance of an individual environment revealed that seed yield showed a highly significant difference ($P \leq 0.01$) at all test environments. This indicated that, varieties might not express the same seed yield performance at a specified test location's environmental conditions; or different varieties may respond differently to a specified environment. The combined analysis of variance for seed yield also revealed the presence of highly significant difference ($P \leq 0.01$) amongst varieties, environments and their interaction. The mean seed yield values of varieties averaged across the locations showed that the variety Derso had the highest mean yield (1.103 $tonha^{-1}$) as followed by the varietyAlemaya 98 (0.953 $tonha^{-1}$) while, the variety Ada'a had the lowest (0.863 $tonha^{-1}$) mean seed yield. The varieties, years, locations, and variety by environment interaction contributed more in varying the seed yield performance. However, the presence of blocking and/or replicating within the testing environment could not influence the seed yield performance of the tested varieties. It could be concluded that the variety Derso and Alemaya 98 were the most adapted and stable varieties for the present ecology of study areas and other similar agro-ecologies.

Keywords: Lentil, High Yielding Varieties, Locations, Seed Yield Performances

1. Introduction

Lentil (*Lens culinaris*Medik) is a self-pollinating diploid (2n= 14 chromosomes) annual crop and belongs to the genus *Lens* of the Vicieae tribe in the Leguminosae (Fabaceae) family, commonly known as the legume family. It originated in the Near East and rapidly spread to Egypt, central and southern Europe, the Mediterranean basin, Ethiopia, Afghanistan, India and Pakistan, China and later to the New World, including Latin America and North America [1].

Ethiopia is considered as a center of diversity for lentil and currently lentil is an important pulse crop [2-4]. This makes Ethiopia one of the major lentil-producing countries in Africa [5] and is listed in the top ten countries in the world [6]. Lentil is grown as a source of protein; 23-24% [7] for human consumption and also a rich source of minerals and vitamins for human nutrition and the straw is valuable for animal feed. It is a potential export and cash crop that has the highest price in domestic and international markets compared to all other food leguminous crops and cereals [8].

The crop is generally grown in rotation with cereals to break cereal disease cycles and to fixatmospheric nitrogen, thus reducing the demand and cost for nitrogen fertilizers for other cerealcrops production. The average yield of lentil in Ethiopia is not greater than 800kg ha^{-1} [5]. This is mainly due to the changing climate and its consequences and otherarray of stresses that lead to crop damage and result in reduction in the yields of lentil [9-12].

Lentil requires a minimum of 350mm rainfall and a maximum of 550mm during its growthperiod. In the high rainfall areas, good drainage is essential because water logging will have agreat negative effect on yields and aggravate disease spread, like wilts and root rots. Drought andsevere or prolonged hot weather, especially during pod setting and grain filling period, can alsocause loss in yields through pod cracking [13].

So far little has been done to address the impact of climate change, which enables farmers tosolve their problem via adaptations at farm-level. Furthermore, low productivity per unit areaand low grain quality (small seeded, undesired color, low plumpness) was typical features of the Ethiopianlentil [9, 11]. Therefore, the current study wasconducted with the objectives of evaluating the performance of lentil varieties and selectingrelatively high yielder lentil varieties in East Shewa and West Arsi Zones.

2. Materials and Methods

2.1. Study Area

The study was conducted at three locations viz; Dugda, AdamiTulluJiddoKombolcha andNegelleArsi districts for two consecutive years (2020/2021 &2021/22 cropping seasons) under rain fed conditions. All districts are found on the main road from Addis Ababa toShashemene town.

2.2. Breeding Materials, Experimental Design and Managements

Five lentil varieties (viz; Ada'a, Alemaya 98, Derso, Gudo and Teshale) were used during thisstudy. The materials were evaluated using Randomized Complete Block Design (RCBD) withthree replications at three locations in the main cropping season for two years (2020/2021 and 2021/22).

The plot size for each experimental unit was 1.5m * 2m (4 rows, each 2m long). The total area ofa plot was $3m^2$. The spacing between rows, plots and blocks were 30cm, 50cm and 100cm, respectively. Seed sowing was carried out in the first week of June. It was done by hand drillingand covered slightly with the soil. The detailed descriptions of the experimental materials useddduring the study are presented as follows in the table below:

Table 1. *List of breeding materials/varieties used during the study.*

Entry	Varieties	Source/Origin	Year of release
1	Derso (Alemaya FLIP-88-411-02-AK-14)	DzARC/EIAR	2012
2	Teshale (FLIP 96-46L)	DzARC/EIAR	2004
3	Alemaya 98 (Flip 89-63L)	DzARC/EIAR	1997/98
4	Gudo (Flip 84-78L)	DzARC/EIAR	1995
5	Ada'a (Flip-86-14L)	DzARC/EIAR	1995

Note: ARC = Agricultural Research Center, EIAR = Ethiopian Institute of Agricultural Research, DzARC = Debra Zeit Agricultural Research Center

2.3. Data Collection

Data on days to 50% flowering, plant height (cm), number of branches per plant, number of pods per plant, number of seeds per pod, number of seeds per plant, days to maturity and seed yield per hectare were recorded during this study.

2.4. Data Analysis

All the recorded data were subjected to analysis of variance following the standard procedure for each location. Combined analysis of variance over locations was computed using the Gen-Stat 18th Edition Statistical Computer Software Programs.

Bartlett's chi-square test was considered to determine the validity of the combined analysis of variance and homogeneity of error variances among environments. After the significant difference of interaction effects and homogeneous residual variations were confirmed, combined analysis was considered.

2.4.1. Cultivar Superiority Measure (P)

Cultivar Superiority was considered to test the seed yield performance its stability over the environments. It measures mean seed performance and stability simultaneously [14]. Mathematically the value of cultivar superiority is obtained as follows:

$$P_i = \frac{n(X_i - M)^2 + \Sigma_j (X_{ij} - X_i - M_j + M)^2}{2n} \quad (1)$$

Where;

P_i = Cultivar Superiority Values.

X_{ij} = the response of the i^{th} genotype in the j^{th} environment,

X_i = the mean of genotype 'i' inoverall environments,

M_j= the genotype with maximum response among allgenotypes in the j^{th} environment.

M = the mean of the genotypes with maximumresponse over all environments and,

'n' = the number of environments.

2.4.2. AMMI Stability Analysis

The additive main effects and multiplicative interaction (AMMI) is used to integrate the analysis of variance and principal component analysis into a unified approach. An initial analysis of variance was performed for each location to validate the existence of differences among the varieties. Subsequently, the homogeneity between residual variances was determined, and a combined analysis of variance was employed to test the varietal and environmental and their interaction effects.

3. Results and Discussion

The analysis of variance of an individual environment revealed that the number of pods per plant, number of seeds per plant, days to maturity and seed yield were showed a highly significant difference ($P \leq 0.05$) at all test environments.

The variation due to the genotypes was found to be significant at all environments. This indicated that, varieties could not express the same seed yield performance at a specified environmental condition; or different varieties had responded differently to a specified environment. For instance, at Adami Tullu Jiddo Kombolcha, the variety Teshale ranked 3rd in its seed yield (0.92 tonha^{-1}), while the same variety ranked 4th for its seed yield of 0.87 tonha^{-1} and 0.86 tonha^{-1} at Dugda and Negelle Arsi respectively. The variety Derso was found to have the highest mean seed yield at all locations (Table 2).

Table 2. *Mean Number of pods per plant (NPoP^{-1}), Number of seeds per plant (NSP^{-1}), Days to maturity (DM) and Seed yield (SYPHa^{-1}) of five lentil varieties tested at each location.*

Genotypes	Test Environments											
	AdamiTulluJiddoKombolcha				Dugda				NegelleArsi			
	NPoP^{-1}	NSP^{-1}	DM	SYPHa^{-1}	NPoP^{-1}	NSP^{-1}	DM	SYPHa^{-1}	NPoP^{-1}	NSP^{-1}	DM	SYPHa^{-1}
Ada'a	74.00^{c}	135.80^{b}	97.00^{c}	0.87^{ab}	77.50^{b}	142.30^{b}	99.00^{c}	0.87^{a}	72.00^{c}	131.70^{bc}	114.00^{c}	0.83^{a}
Alemaya 98	64.50^{b}	118.00^{ab}	100.50^{d}	0.98^{c}	65.00^{a}	119.80^{ab}	100.50^{d}	0.97^{b}	64.67^{bc}	108.80^{ab}	115.50^{d}	0.91^{b}
Derso	83.33^{d}	153.80^{b}	90.00^{a}	1.16^{d}	79.67^{b}	146.00^{b}	91.00^{a}	1.10^{c}	80.67^{d}	161.30^{c}	110.00^{a}	1.05^{c}
Gudo	55.83^{a}	92.70^{a}	100.50^{d}	0.84^{a}	60.33^{a}	91.20^{a}	101.50^{d}	0.88^{a}	56.50^{a}	93.20^{a}	116.50^{c}	0.88^{ab}
Teshale	70.67^{bc}	129.30^{ab}	92.50^{b}	0.92^{bc}	63.83^{a}	116.30^{ab}	94.00^{b}	0.87^{a}	62.50^{ab}	116.20^{ab}	112.00^{b}	0.86^{a}
GM	69.70	125.90	96.10	0.95	69.27	123.10	97.20	0.94	67.30	122.20	113.60	0.91
MSE	36.92	983.00	1.17	0.003	26.90	1015.00	1.28	0.0018	40.20	730.00	0.08	0.001
SE (d)	3.51	18.10	0.63	0.047	2.99	18.39	0.65	0.034	3.66	15.60	0.17	0.026
LSD	7.27	37.54	1.30	0.098	6.21	38.14	1.36	0.072	7.59	32.35	0.34	0.055
CV	8.7	24.9	1.1	6.0	7.5	25.9	1.2	4.5	9.4	22.1	0.3	3.5

Key: GM = Genotypic means; MSE = Mean Square of Error; SE (d) = Standard Error of Difference; LSD = Least Significant Difference and CV = Coefficient of Variation. Values with the same letters in a column mean to 'not statistically significantly different'.

The results of Bartlett's homogeneity test have shown that, error variances for Days to 50% flowering (D50%F) and Seed yield per hectare (SYHa^{-1}) were homogenous. This in turn allowed for further pooled analysis (combined analysis) across the test environments. Accordingly, the combined ANOVA showed a significant difference amongst the genotypes, environments and GEI for both D50%F and SYHa^{-1} (Table 3).

Table 3. *Combined analysis of variance for Days to 50% flowering (D50%F) and Seed yield per hectare (SYHa^{-1}) of five lentil varieties across locations.*

Traits	Source of Variations					
	Replications (2)	Genotypes (4)	Environments (2)	GEI (8)	Residual (28)	Total
Sum Squares						
D50%F	0.1778	115.7778	914.1778	5.1556	1.8222	1037.11
SYHa^{-1}	0.0024	0.5105	0.0376	0.0740	0.0284	0.65
Mean Squares						
D50%F	0.0889^{ns}	28.9444**	457.0889**	0.6444**	0.0651^{ns}	
SYHa^{-1}	0.0012^{ns}	0.1276**	0.0087**	0.0092**	0.0017^{ns}	

Key: '**' stands for highly significant differences at ($P \leq 0.05$); 'ns' for non-significant difference; DF = Degree of freedom; D50%F = Days to 50% flowering; SYHa^{-1}= Seed yield per hectare.

The combined analysis of variance for seed yield revealed the presence of highly significant difference ($P \leq 0.05$) among the genotypes, environments and their interaction (Table 3). This indicates that the genotypes, environments and their interaction had contributed more in varying the seed yield performance. However, the presence of blocking and/or replicating within the testing environments could not influence the seed yield performance of the tested varieties.

The mean seed yield values of the tested genotypes averaged across the environments showed that the variety Derso had the highest mean seed yield (1.12 tonha^{-1}) as followed by the variety Alemaya 98 (1.03 tonha^{-1}) while, the variety Ada'a had the lowest (0.86 tonha^{-1}) mean seed yield (Table 4).

Table 4. *Combined mean values of Days to 50% flowering (D50%F) and Seed yield per hectare (SYHa^{-1}) for tested five lentil varieties over locations.*

Genotypes	D50%F	SYHa^{-1} (ton)
Ada'a	56.33^{b}	0.86^{a}
Alemaya 98	56.33^{b}	1.03^{c}
Derso	59.56^{d}	1.12^{d}
Gudo	59.22^{c}	0.84^{a}
Teshale	55.78^{a}	0.91^{b}
GM	57.44	0.95
MSE	0.065	0.002
SE (d)	0.120	0.020
LSD	0.246	0.040
CV	0.4	4.4

Key: GM = Grand means; MSE = Mean Square of Error; SE (d) = Standard Error of Difference; LSD = Least Significant Difference and CV = Coefficient of Variation. Values with the same letters in a column mean to 'not statistically significantly different'

The combined analysis of variance across the environments for seed yield revealed that genotypes, environments, replications (blocks within environments), genotypes by environments interaction (GEI) and residual contributed 78.19%, 5.76%, 0.37%, 11.33% and 4.35% respectively (Table 5). The largest percent contribution under the genotype indicates that the genotypes had influenced more to the total seed yield variations over the locations.

Table 5. *Percent contribution of genotypes, environments, replications, GEI and residual effects on seed yield over the locations.*

Genotypes (4)		Environments (2)		Replications (2)		GEI (8)		Residual (28)	
SS	SS (%)	SS	SS (%)	SS	SS (%)	SS	SS (%)	SS	SS (%)
0.5105	78.19	0.0376	5.76	0.0024	0.37	0.0740	11.33	0.0284	4.35

Key: GEI = Genotype by Environment Interaction; The numbers in the brackets stand for the degree of freedom

The additive main effects and multiplicative interaction analysis of variance (AMMI ANOVA) revealed that the variances due to genotypes showed a highly significant difference ($P \leq 0.05$) while, the genotype by environment interaction effect showed a significant difference ($P \leq 0.05$). On the other hand, the presence of blocking and/or replicating within the testing environments could not contribute more to the seed yield performance of the tested lentil varieties.

AMMI analysis of variance for seed yield showed that most of the total sum square of the model was attributed to genotypic effects (77.80%). The genotype by environment interaction (GEI) effects had contributed 11% while, the environmental effects had contributed 2.34% to the total sum square of the model as indicated in the Table 6.

Table 6. *AMMI analysis of variance for seed yield of five lentil varieties across locations.*

Sources of Variation	DF	Mean Squares	Sum Squares	%Explained From TSS	%Explained From GEI
Total	44	0.0148	0.6491		
Treatments	14	0.0423**	0.5916		
Genotypes	4	0.1262**	0.5050	77.80	
Environments	2	0.0076*	0.0152	2.34	
Replications (blocks within locations)	6	0.0012^{ns}	0.0072	1.11	
Interaction (GEI)	8	0.0089*	0.0714	11	
$IPCA_1$	5	0.0135**	0.0676	10.41	94.66
$IPCA_2$	3	0.0013^{ns}	0.0038	0.59	5.34
Error	24	0.0011^{ns}	0.0503	7.75	

Key: '*' and '**' represent highly significant difference and significant difference respectively; 'ns' for non-significance; DF = Degree of Freedom; TSS = Total Sum Squares; GEI = Genotype by Environment Interaction.

The observed largest sum of square along with highly significant mean of square for the genotypes showed that the genotypes were highly diverse, with large differences among genotypic means, causing most of the variation to the total seed yield performance.

The presence of genotype by environment interaction, GEI was clearly demonstrated by the AMMI model, and the interaction was partitioned among the first two interaction principal component axes, IPCAs ($IPCA_1$ and $IPCA_2$). AMMI analysis of variance have also revealed that IPCA1 and IPCA2 of the interaction (GEI) contributed about 94.66% and 5.34% respectively to the total GEI sum of squares (Table 6).

The mean squares for $IPCA_1$ and $IPCA_2$ had cumulatively contributed the entire percentage to the total GEI sum square. Therefore, the AMMI model with only two IPCAs ($IPCA_1$ and $IPCA_2$) was considered as the best predicting model for this interaction.

The cultivar superiority values for each of the tested five lentil genotypes at the three testing environments were also displayed as in the table below.

Table 7. *Lin & Binn's Cultivar Superiority values for five lentil genotypes over the Environments.*

Varieties	Means	Cultivar Superiority	Ranks
Ada'a	0.861	0.03380	4
Alemaya 98	1.031	0.00387	2
Derso	1.117	0.00000	1
Gudo	0.838	0.04356	5
Teshale	0.914	0.02051	3

The smaller the value of cultivar superiority value, the lesser its distance to the genotype with maximum yield and the better the genotype is [15]. Those genotypes with the lowest cultivar superiority values would be considered as the most superior genotype in terms of stability in a given set of environments [14].

Accordingly, the variety Derso was found to have the smallest cultivar superiority value with higher mean seed yield as followed by the variety Alemaya 98 (Table 7). This indicates that these varieties were relatively more stable and have a wider adaptation as compared to the other tested varieties. Different authors such as Akcura *et al.*, [16] and Bahrami *et al.*, [17] used this stability parameter to identify high yielding and stable bread wheat and barley genotypes respectively.

4. Summary and Conclusion

The analysis of variance of an individual environment revealed that seed yield performance showed highly significant difference ($P \leq 0.05$) at all individual test environments. This indicates that varieties might perform differently at different test environment.

The combined mean seed yield values of genotypes averaged across the environments showed that the variety Derso had the highest mean yield (1.12 $tonha^{-1}$) as followed by the variety Alemaya 98 (1.03 $tonha^{-1}$).

The observed highest variation to the total variations was attributed to the genotypic effects. This in turn shows that the genotypes had contributed more (78.19%) in varying the seed yield performance. Most of the total sum of squares of the AMMI model (77.80%) was also attributed to the genotypic effects and the rest were attributed to the environmental effects (2.34%) and to their interaction, GEI (11%).

Lin and Binnscultivar superiority measures for stability analysis identified the variety Derso as the most stable with its cultivar superiority value of 0.0000 and the largest mean seed yield as followed by the variety Alemaya 98 with its cultivar superiority value of 0.00387. Generally, in the present study, the variety Derso and Alemaya 98 were the most adapted and stable varieties for the present ecology of study areas. This experimental study will play its own significant role in encouraging the test varieties to be grown and used to the study areas and ecologies. Not only this, but also it will be the bench mark for the further similar and related studies.

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