GENOTYPE X ENVIRONMENT INTERACTION AND YIELD STABILITY FOR COMMON BEAN (PHASEOLUS VULGARIS L) IN RAYA VALLEY, TIGRAY, ETHIOPIA

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ABSTRACT
Nine common bean genotypes were evaluated at two different environments in Raya valley of southern Tigray, Ethiopia for three consecutive years during 2016-2018 main cropping seasons. The aim of the study was to determine the effect of G × E interaction and to identify the best adaptable varieties for selection environments and yield stability. The study was conducted using a randomized complete block design with 3 replications. Combined analysis of variance for grain yield and most of yield component traits showed highly significant ($p \leq 0.01$) differences among the genotypes, environments and for GEI effects. This indicated that the tested environments have an influence on the selected varieties differentially responded to the changes in the test environments. As a result, environment two was identified as more favourable to common bean production, despite some varieties were showed good performance in some traits at both locations. But, no single variety is found that generally superior in all evaluated traits across all locations and years. However, the varieties "Nasir, SAR-119, Awash-2 and SAR-125" were the better performed with yield from combined analysis of 20004.47 kg/ha, 1979.83 kg/ha, 1843.1kg/ha and 1791.49 kg/ha, respectively, followed by genotypes of Awash-1 [1548.93 kg/ha] and Awash Melka [1525.11 kg/ha]. Generally, the application of combined analysis facilitated the visual comparison and identification of superior genotypes, thereby supporting decisions on common bean variety selection and recommendation in tested environments.

Keywords: Common bean, Yield stability, combined analysis.

1. INTRODUCTION
Common bean (*Phaseolus vulgaris* L.) belongs to the Fabaceae family and originated from South America and introduced into Africa during the past four centuries. Now a day, Africa is the second most important common bean producing region in the tropics, following Latin America (Brazil and Mexico) (Allen, 1995). But, it is grown primarily by small-scale farmers in eastern Africa, like Ethiopia. In Africa, common bean is an admired crop among small-scale farmers, given its short growth cycle (about 70 days) which permits production when rainfall is irregular. The wide range of growth habits among bean varieties has enabled the crop to be cultivated well under different agro-ecological surroundings. In addition, common bean is very favored by low income countries farmers because of its fast maturing that enables households to get cash returns essential to pay for food and other household needs when other crops have not yet matured (Legesse *et al*., 2006).

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In Ethiopia, common bean is a well-established component of agriculture crops, and is regarded as the main cash crop and protein source of the farmers in many lowland and mid-altitude regions. Additionally, common bean is a suitable rotation crop with maize, sorghum, and vegetables to maintain soil fertility and keep sustainable agriculture in the country (Tolessa *et al*., 2014). The major producing regions are Oromiya (mainly East Shewa, East and West Hararghe, West Arsi zones) and SNNPR (Wolaita, Sidama, Gedeo, Alaba, Dauro and Guraghe zones). The northern part of Ethiopia however, produce in small amount of area coverage, since they produce Mung bean in large, especially Amhara region. Some parts of Tigray region also producing on small scale farms only for the purpose of cash crop and animal feed, but not for human consumption. This is because of it is not well known to local farmers of this region as it used as good human food and farmers' miss understand for health care after consuming of the grain of this crop.

Meanwhile, in the recent years of common bean breeding program is targeted to develop improved varieties and to address all agro-ecologies across the country to ensure that the crop is used valuable as income source, human consumption and environmental resilience. But, a major challenge for plant breeders is determining the appropriate common bean genotypes due to genotype x environment (GE) interactions, which determine the differential response of genotypes among environments. Therefore, in addition to high yielding, newly developed common bean varieties should have a stable performance and broad adaptation over a wide range of environments. However, frequent variation practiced both over years and across locations even within a shorter distance in Ethiopian environmental conditions (Ethiopian Mapping Authority, 1988). In such cases, genotype × environment (G × E) interaction effect is expected to be greater (Falconer *et al*., 1996), so that the genotype-environment interactions are of major importance to the plant breeder in developing improved varieties (Kang, 1993). The genotypes grown in different environments frequently show significant fluctuations in yield performance and these changes are influenced by the different environmental conditions and are referred to as G × E interaction (Allard *et al*., 1964).

Thus, to reduce the effects of GE interactions, evaluation of different genotypes/ varieties in different environments over years is convenient to determine best performed common bean varieties, to know their magnitude, to identify more stable genotypes adapted to specific environments (Tadessa *et al*., 2018) and also to identify locations that best represent the target environment (Yan *et al*., 2001). Therefore, this study aimed to identify the effect of GEI and to evaluate the adaptability and yield stability of released common bean varieties in the study areas.

2. MATERIALS AND METHODS

2.1. Description of the study area

The experiment was conducted at two locations (1) at research station of Mehoni Agricultural Research center "Fachagema" and (2) at farmer's field "Kara Adishow" in Raya Valley, Northern Ethiopia for three consecutive main cropping seasons (2016-2018). The two locations are belongs to the same agro-ecology as it described in (Table 1), but slightly different in productivity. The dominant soil type of the two locations is vertisol with pH of 7.8-8.2., but the soil of the research station (location 1) is slightly affected by salinity.

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Table 1 Description of the test locations

Locations	Geographical Position		Altitude (m.a.s.l.)	Avg. Rain fall (mm)	Temperature (°C)		Soil type
	Latitude	Longitude			Max	Min	
Fachagema	12° 41'50" N	39° 42'08" E	1578	540	32	14	Slightly vertisol
Kara Adishow	12°40’48” N	39°41’06”E	1590	565	31	13	Vertisol

2.2. Treatments and experimental design

Nine total Common bean varieties (Table 2) were used for the study. The experimental design was a Randomized Complete Block Design with three replications. The experimental plots consisted six rows of 4 m long with 0.1 m and 0.4 m intra- and inter-row spacing respectively. The plot size was 4m × 2.4m (9.6m^2) with harvestable plot size of 1.6m × 4m (6.4 m^2). A 1.5m between replications, and leave 0.5m between plots were maintained. 100kg of DAP was homogeneously applied for all treatments during sowing time. All management practices were done manually and uniformly to all plots as per recommendations for both locations.

Table 2 Description of the 9 common bean genotypes tested across 2 different environments during 2016-2018 cropping season

Genotype Code	Genotype Name	Source
G1	Deme	Melkassa
G2	Awash-1	Melkassa
G3	Awash-2	Melkassa
G4	Nasir	Melkassa
G5	Awash Melka	Melkassa
G6	SAR-119	Melkassa
G7	SAR-125	Melkassa
G8	SAB-736	Melkassa
G9	SAB-632	Melkassa

3. RESULTS AND DISCUSSION

3.1. Analysis of variance The combined analysis of variance showed significant differences of all tested effects, indicating a differentiated response of the common bean varieties to environmental changes (Table 2). Tadesse *et al*. (2018) also reported similar results, by studied common bean varieties and found significant effects of genotypes, environments and GE interaction.

3.2. Phonological characters

The results from analysis of variance revealed that there is significant variation among varieties in most of tested phonological traits (Table 3). After the significance of the GxE interaction was identified, the results of comparisons of phenotypic means were presented separately per location for a given years (Table 4). Based on their combined mean for evaluated phonological traits,

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some varieties were selected as they are well performed at Raya valley agro-ecology. But, there were no single genotypes/varieties that showed generally superior performance in phonological traits across the test locations and years. In addition to genetic variability, the weather fluctuation was also exerts variation on the phonological traits of the varieties. However, some varieties were performed with good morphological performance even though the weather condition of the same location is not constant in given years. Accordingly, significantly lowest days to 50% flowering and 90% maturity, and highest in plant height, pod per plant and seed per pod was recorded from G4 (Nasir), G3 (Awash 2), G6 (SAR 119), G7 (SAR 125) consequently (Table 3). Identification of these traits also used to select the genotypes that are early matured and have good performance in yield and yield components.

Table 3. Combined analysis of variance (ANOVA) for yield and yield attributed traits of common bean varieties tested at two locations for three years (2016-2018).

Source of variation	Df	DF	DM	PH	PP	SP	HSW	GY
Blocks	2	1.05NS	0.56NS	3.3NS	0.86NS	0.2NS	0.74NS	423NS
Genotypes (G)	8	9.1**	24.1**	636.6**	206.08**	4.53**	357.97**	2066381**
Locations (L)	1	70.67**	526.3**	532.2**	1.45**	2.32**	1.8NS	4337505**
Years (Yr)	2	277.8**	593.3**	2383 **	201.24**	2.33**	404.4**	9207891.4**
G*Loc	8	0.7NS	7.6**	39.9**	25.16**	0.44**	70.82**	195369.9**
G*Yr	16	2.93**	10.05**	88.4**	19.45**	0.58**	129.4**	289154.5**
G*Loc*Yr	18	2.84**	19.97**	72.7**	26.05**	0.42**	164.4**	1644940.8**
CV (%)		**1.61**	**0.94**	**3.94**	**11.2**	**6.35**	**11.8**	**11.15**
R-square		**0.92**	**0.97**	**0.98**	**0.92**	**0.85**	**0.9**	**0.96**

Whereas **= highly significant at $P \leq 0.01$, *= significant at $P \leq 0.05$, NS = non-significant at P = 0.05, CV= coefficient of variance, Df= Degree of freedom, DF= Days to flowering, DM= Days to maturity, PH= Plant height, PP= Pod per plant, SP= Seed per pod, HSW= Hundred seed weight and GY= Grain yield.

Table 4. Combined mean of phonological traits of 9 common bean varieties evaluated at two locations over three years.

Genotypes	DF			DM			PH			PP			SP			HSW (gm)		
	Loc-1	Loc-2	Mean	Loc-1	Loc-2	Mean	Loc-1	Loc-2	Mean	Loc-1	Loc-2	Mean	Loc-1	Loc-2	Mean	Loc-1	Loc-2	Mean
G1	51.4	49.9	50.7^{a}	89.0	86.8	87.9^{a}	52.96	53.3	53.1^{a}	10.16	8.7	9.5^{d}	4.7	4.6	4.7^{b}	33.8	34.9	34.3^{a}
G2	50.2	48.7	49.4^{bc}	87.6	84.7	86^{bc}	41.28	46.2	43.7^{c}	14.8	17.8	16.3^{b}	5.5	5.5	5.5^{a}	22.0	19.95	21de
G3	51.0	49.4	50.2^{ab}	88.2	85.2	86.7^{b}	44.6	49.7	47.1^{b}	15.9	20.6	18.3^{a}	5.3	5.6	5.5^{a}	22.7	20.3	21.5^{de}
G4	51.0	49.6	50.3^{ab}	87.3	84.0	85.7^{cd}	46.8	47.3	47.1^{b}	18.4	17.7	18.1^{a}	5.6	5.6	5.6^{a}	25.2	23.0	24.1^{cd}
G5	51.8	50.0	50.9^{a}	88.9	83.78	86.3^{bc}	41.7	48.1	44.9^{c}	14.36	13.0	13.7c	4.9	5.7	5.3^{a}	23.0	18.3	20.7^{e}
G6	49.8	49.0	49.4^{bc}	85.1	82.67	83.9^{d}	38.18	44.6	41.4^{d}	16.5	15.2	15.8^{b}	5.4	5.6	5.5^{a}	26.4	26.0	26.2^{c}
G7	50.0	49.3	49.7^{b}	86.7	83.9	85.3^{cd}	44.32	43.56	43.9^{c}	13.6	12.0	12.8^{c}	4.8	5.0	4.9^{b}	27.3	23.9	25.6^{c}
G8	49.6	48.6	49.1^{bc}	88.7	83.8	86.2^{bc}	31.7	34.5	33.1^{f}	11.5	10.4	10.9^{d}	4.2	4.2	4.2^{c}	23.7	28.1	25.9^{c}
G9	49.7	48.1	48.9^{c}	87.7	81.9	84.8^{d}	33.0	39.9	36.4^{e}	10.9	8.9	9.9^{d}	4.3	4.9	4.6^{b}	26.0	33.6	29.8^{b}
Mean			49.8			85.9			43.4			13.9			5.1			25.4

Means with the same letter are not significantly different. Whereas DF= Days to flowering, DM= Days to maturity, PH= Plant height, PP= Pod per plant, SP= Seed per pod, HSW= Hundred seed weight and GY= Grain yield

Table 5. Mean grain yield (kg ha−1) of 9 common bean varieties (G1 to G9) tested at two locations (Fachagema/Loc.1 and Kara Adisho/Loc.2) over three years (2016 to 2018).

Genotypes	Environments								
	Environment -I (Loc.$_1$)				Environment - II (Loc.$_2$)				Combined mean
	Year 1	**Year 2**	**Year 3**	**Mean**	**Year 1**	**Year 2**	**Year 3**	**Mean**	
G 1	1802.6	794.5	746.7	1114.6^{d}	1064.8	2747.7	930	1580.85^{d}	1347.72^{de}
G 2	1627.1	1093.6	1134.7	1285.1^{cd}	1489.3	2657.5	1291.4	1812.7^{bc}	1548.93^{c}
G 3	2298.1	1340.8	1435.4	1691.4b	1408.6	3081.4	1506.5	1998.8^{b}	1845.1^{ab}
G 4	2472.5	2021.5	1227	1907^{a}	1711.3	3224.2	1370.3	2101.9^{a}	2004.47^{a}
G 5	2288	761.5	669	1239.5^{cd}	1405.7	2954.1	1072.3	1810.72^{bc}	1525.11^{cd}
G 6	2162.9	2031.5	1477.1	1890.5^{ab}	1943.8	2906.6	1357.1	2069.2^{ab}	1979.83^{a}
G 7	2692.8	1717.3	1096.9	1835.7^{ab}	1468.2	2478.1	1295.6	1747.30^{c}	1791.49^{b}
G 8	1022.9	926.8	546.1	831.9e	835.5	1930.1	1086.1	1283.9^{f}	1057.9^{f}
G 9	1134.9	969.5	1034.7	1046.3de	920.6	1801.9	1423.5	1382^{ef}	1214.18^{ef}
Mean				1426.89				1754.15	1590.52

Means with the same letter are not significantly different.

3.3. Evaluation of Test Environments

Evaluating the test environment is important to identify suitable locations that can be used effectively to select superior genotypes for target-environment. Once the significance of the GxE interaction was confirmed, the results of comparisons of grain yield means were presented separately per environment for a given years (Table 3). Depend on the tested traits of a given varieties with the factor under consideration, there were a significant variation between selected environments. As a results, the evaluated varieties well performed at environment-I in their tested traits, whereas they poor performed at environment-I (Table 4). Therefore, environment two could be considered as more suitable than environment one for common bean production (Fig. 1).

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3.4. Evaluation of Adaptability and Yield Stability of Common Bean Varieties

The result of this research revealed that some genotypes are well adapted to tested environments while others are more limited in their potential distribution. This indicated that there is genetic variation among tested common bean genotypes. In addition to genetic variation, there is also a fluctuation of natural condition, like rain fall, that influence crop growth and yield performance. For instance, at environment-I all evaluated genotypes were good performed in their agronomic performance and grain yield at first year, but extremely decreased in second and third year in the same location this is due to irregular rain fall distribution, whereas inversely performed at second environment (decreased in 1st year and increased in 2nd & 3rd years). This indicated that there is weather fluctuation between short distance locations under the same season. Meanwhile, the result from combined mean analysis is revealed that year-two and three is the favorable seasons for crop production than year-one (Table 4).

However, the season fluctuation is less/not important to determine the crop's potential for their adaptability or yield stability. The varieties that perform uniformly in tested environments regardless of the productivity of environment are stable varieties, others those their performance is influenced by environment are categorized under unstable varieties. The highest-yielding genotypes at different location for consecutive year are the fact that the best-adapted and stable varieties to tested agro-ecologies. Thus, analysis for grain yield and other yield components of varieties per test locations is used to identify best performed common bean varieties for the agro-ecologies in this investigation. Although, the environment two is more favorable than environment one for common bean growth, some genotypes/varieties are shows good performance uniformly at both locations.

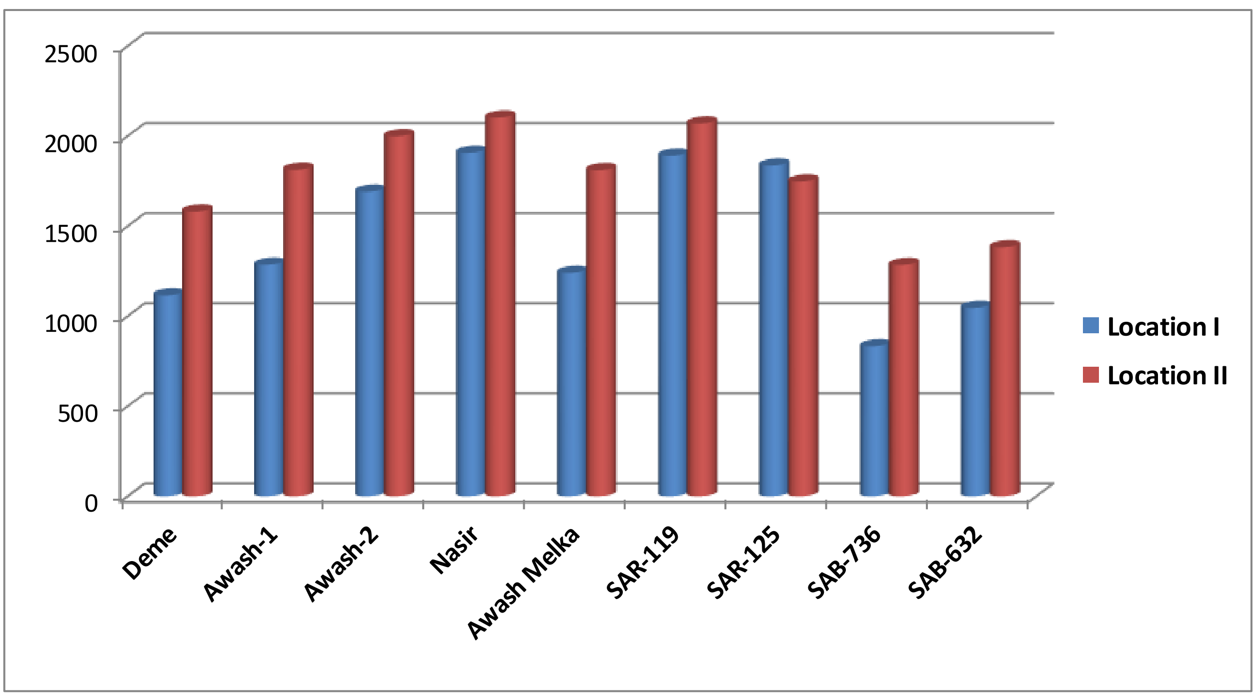

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Fig. 1 Mean performance grain yield (GY) of nine common bean genotypes tested at two locations for three years

Accordingly, based on the phenotypic parameters assessed and mean grain yield performances, the Nasir (G4), SAR119 (G6), Awash 2 (G3) and SAR 125 (G7) are considered as the most stable and adapted varieties because of their slightly consistence mean performance across test environments (Table 4, Graph 1) whether season is favorable or unfavorable. In general, the result from combined mean analysis indicated that, "Nasir (G4) and SAR-119 (G6) are the better performed and stable genotypes for tested environments (Graph 2) with obtained over all mean grain yield of 2004.47 kg/ha and 1979.83 kg/ha, respectively followed by genotypes of Awash-2/G3 (1845.1 kg/ha) and SAR-125/G7 (1791.49 kg/ha) (Table 4). Unfortunately, the variety recommended in the previous study "Nasir" this agro-ecology or Raya valley (Teama et al., 2017), achieved the highest grain yields in this study, which is evaluated only at single location and year. Although this variety recorded with high yielding and recommended as best adapted variety, it is not significantly different from the competent varieties tested with together in this study.

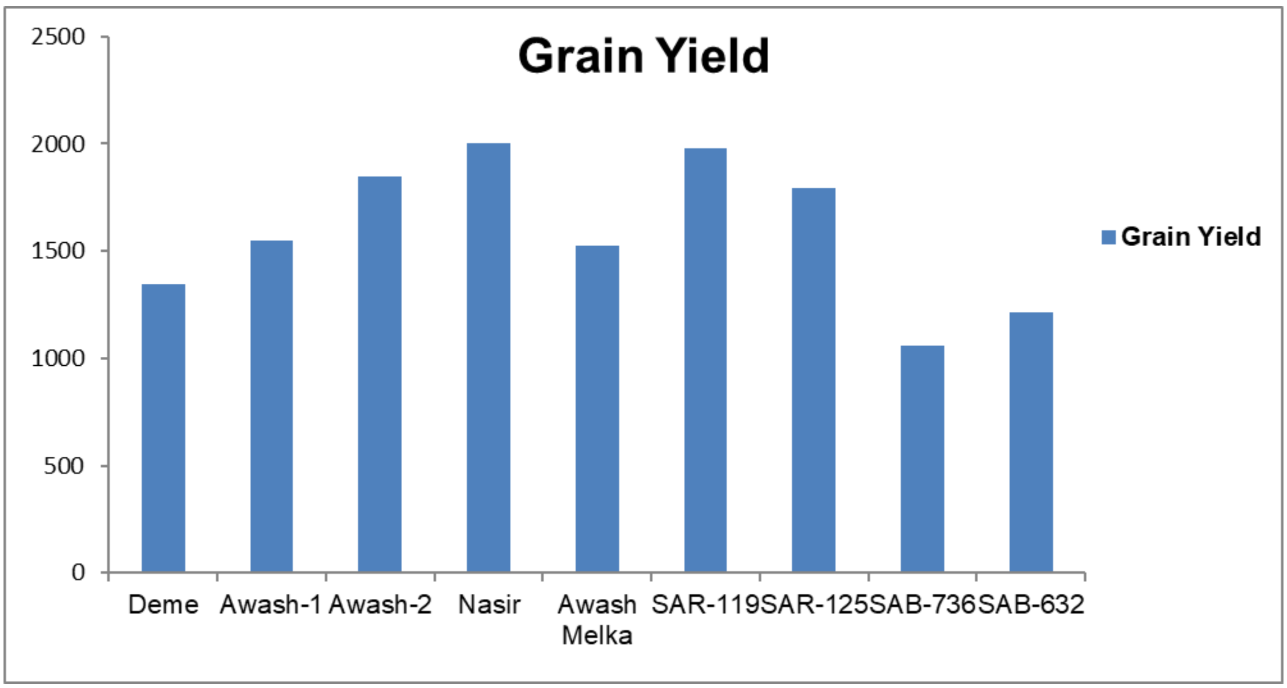

Fig. 2 Combined mean grain yield (GY) of 9 common bean genotypes tested at two locations over three years

Aligned

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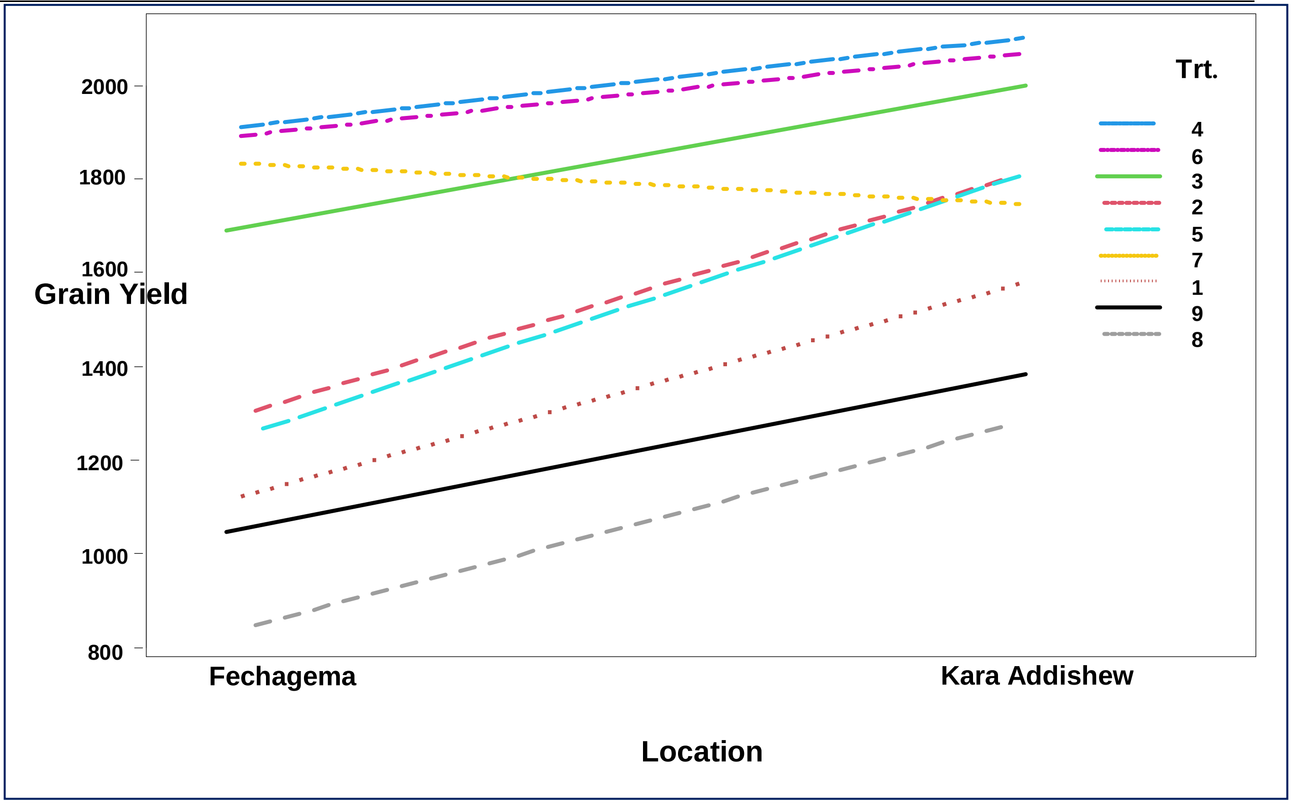

Fig. 3 Favorability of tested environment for the varieties and yield stability across locations

4. SUMMARY AND CONCLUSION

The use of improved varieties contributes to raise yields and yield stability without additional costs for farmers. The reason is that breeders try to combine high yields, wide adaptability and high stability of performance in one genotype. The genotypes with the best combinations of high grain yield, phenotype, wide adaptability, and high performance stability are recommended for cultivation in target environments.

In this study there were nine common bean varieties evaluated for their mean grain yield performance and stability across environments. For the parameter yield stability, the performance of all genotypes was high, except for genotypes Deme (G1), SAB 736 (G8) and SAB 632 (G9), which had low yield stability and adaptability. The genotypes 'Nasir and SAR119' were the only best with adaptability and stability to test environments. On the other hands, the test environments also evaluated for being or not being representative of the target environment and for their power to discriminate among genotypes in a given years. Thus, the one environment (Environment-2) is selected as representative of target environment. Therefore, the common bean breeding programs should contribute to increase the production and productivity depending on the varieties selected for high yield potential at the selection environment.

5. STATEMENTS AND DECLARATION

The authors declare that this study is their reliance work and no funds, grants, or any other support were received during the preparation of this manuscript and also the authors have no relevant financial or no-financial interest to disclose. This manuscript has been submitted as original article in fulfillment of the requirements for publication on Euphytica international journal and is deposited at the open access to be made available to browser under rules of the open access.

All authors contributed to this study. Material preparation, experiment follow up and data collection were done by Betselot Molla and Teama Gereziher. Initiating the experiment, data organize and analyses were performed by Lemma Diriba. The first draft of the manuscript was written by Lemma Diriba and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript."

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