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Research Article

Evaluation and stability analysis of recently released mesoamerican red-colored common bean (*Phaseolus vulgaris* L.) varieties in the Southern Ethiopia region

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Abstract - The small red *Phaseolus vulgaris* L. varieties were tested at three sites from 2022 to 2023 (six environments, E1 to E6) to evaluate and select superior and stable varieties. A randomized complete block design was used to evaluate six varieties with four replications. The varieties were planted in six rows per plot; the space between rows, plants, plots, and reps were 0.4m, 0.1m, 0.8m, and 1m, respectively. ANOVA showed significant differences ($P < 0.01$) for seed yield ($kgha^{-1}$), days to 50% flowering, days to 90% maturity, plant height (cm), seed per pod, and pod per plant both at individual environments and in the combined analysis. The GEI (Genotype by Environment Interaction) was significant ($P < 0.01$) for the measured traits. The mean seed yield in the three sites was 2397.5$kgha^{-1}$. The superior varieties were SER 119 and SER 125 with a mean seed yield of 2846 and 2639 $kgha^{-1}$ respectively; however, the most stable genotype identified by AMMI and GGE bi-plots was SER 125. The AMMI ANOVA showed that environments, genotypes, and their interaction were significant; and their magnitude was 31.85%, 14.75%, and 27.75% respectively of the total variation. Besides, the study identified discriminating (Bolosso Bombe and Areka) and undiscriminating (Gofa) environments. Hence, this study recommended that SER 125 and SER 119 common bean varieties could be produced in the tested locations and areas with similar agro ecological zones.

Keywords: Common bean, evaluate, select, stable, varieties

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1. Introduction

The common bean (*Phaseolus vulgaris* L.) belongs to the legume family Leguminosae; it originated and domesticated from Central and South America (Pachico, 1989; Elisa et al., 2014). Those originated from Central America are known as the Mesoamerican gene pool whereas those from South America are termed as Andean gene pool (Debouck et al., 1993), and the classification was based on DNA analysis (Beebe et al., 2000), seed size (Evans, 1980) (the Andean gene pool is with the large seed size whereas the Mesoamerican gene pool is the small seed size), and morphological traits (Singh et al., 1991).

The common bean accounts for 85% of global bean production (Machiani et al., 2019) and it is the most widely grown and important legume in the world (HarvestPlus, 2009), with an annual yield surpassing 27 million tons cultivated across 29 million hectares worldwide (Gepts et al., 2008). In 2020, global dry bean production reached 27.5 million metric tons, with 34.8 million hectares harvested. Since 1990, dry bean production has risen by approximately 60%, while the harvested area has expanded by 36% over the same period (FAO, 2022). The production of common beans is concentrated in Latin America and Africa due to their protein, mineral content, soil fertility improvement, home consumption, and income source (Salcedo, 2008).

The common bean is a significant crop across various regions of Africa, particularly in Eastern Africa; serving as a crucial food source for people across all income levels, it holds particular significance for those with limited resources, providing essential dietary protein (Wortman et al., 2004). It is cultivated across over four million hectares annually in Africa, serving as a crucial grain legume. It plays a vital role in providing daily dietary to over 300 million individuals residing in the world (Mark A. et al., 2022). Eastern Africa boasts the highest annual per capita bean consumption globally, ranging between 50 to 60 kilograms, according to ISAR (2011). Across African regions, bean products are consumed at various stages of plant growth, ensuring a continuous and diverse food supply that includes leaves, green pods, fresh grain, and dry grains (Buruchara et al., 2011).

It is one of the lowland pulse crops produced in the lowland agro-ecology of Ethiopia. It has been known as an export crop for a long period contributing to the foreign exchange earnings (EAA, 2021). It is also grown as a food crop because the dry bean is being used in traditional dishes such as nifro (boiled grain), mixed with sorghum or maize and *wet* (local soup), and with *kocho.* Besides, fresh beans (mature, completely non-dried grain) are popular for their taste and crack ability (EAA, 2021). Nutritionally, it is rich in protein (lysine), minerals (Fe, Zn, Mg, Cu, K), and vitamins. The current average yield of common bean is 1.72 tons per hectare in the country. In the 2021/22 production year, 584,157.96 tons, 143,203.92 tons, and 27,372.35 tons of common bean were produced in Ethiopia, SNNPRE, and Wolaita zones, respectively (CSA, 2021/2022).

Having the immense importance of the crop in the world, Africa, and Ethiopia, the stability of the released common bean varieties across production areas is still a challenge. Besides, the improved common bean varieties released for various important traits surpassed 83 until 2022 in Ethiopia (EAA, 2022); however, most of these varieties were not yet being used in the production system of farmers, among many reasons, one could be the weak structural linkage between organizations working on an agricultural system of the country, the access of varieties is low (Witcombe et al., 1996; Courtois et al., 2001). Hence, the research was done to evaluate the performance and select the superior common bean varieties using the comparison parameters of yield and yield-associated traits. In line with evaluating their performance, the seed yield stability of the varieties was also analyzed.

2. Materials and methods

2.1 Description of the study areas

The field experiment was done in the south Ethiopia region of Areka and Gofa stations and Bolosso Bombe districts during the 2022 to 2023 cropping seasons. The description of the study areas is displayed in (Table 1).

Table 1. Description of the study locations in South Ethiopia during the 2022 to 2023 main seasons.

Study sites	Altitude (masl)	Annual Rain Fall (mm)	Soil type	Temperature (^{0}C)		Global positioning	
				Max	Mini	Latitude (N)	Longitude (E)
Gofa station	1297.00	1338	Acrisols	29.4	17.6	609‘36°′′	3759‘12°′′
Areka station	1780.00	1438	Alisols	26.2	14.2	797‘06°′′	3772‘69°′′
Bolosso Bombe	1513.25	1400	Nitisols	25.0	12.6	7^{0}15′16′′	37^{0}58′44′′

* NB: masl = meter above sea level,

2.2 Experimental designs and treatments

The field experiment was laid out by randomized complete block design (RCBD) with four replications using five released common bean varieties, and a local check at Areka and Gofa stations, and Bolosso Bombe districts. The common bean varieties included in the experiment are described in (Table 2). The number of rows per plot was six 4 meters long; the space between row and plant was 0.4m and 0.1m, respectively. During planting, one row and one meter were left between plots and replications, respectively. The gross (total area) and net plot size (harvestable area) were 9.6m^{2} and 6.4m^{2}, respectively.

Using tools for land preparation, including rakes, hoes, raw markers, and strings, the experimental field was evenly leveled to reduce variation among the plots. During the field layout process, planting materials or crop varieties were prepared separately for each plot. Seeds were then planted in six rows per plot, following the randomization of each replication. Before planting, artificial fertilizer was applied to the plot rows at a 122 kg/ha rate. The fertilizer was lightly covered with soil to avoid direct contact with the seeds, and the seeds were subsequently planted. The experiment relied on rainwater for both planting and growth. Since this was an adaptation trial for crop varieties, no chemicals were used to control insects or weeds.

Table 2. The Mesoamerican gene pool common bean varieties used for the study during the 2022 to 2023 cropping seasons in South Ethiopia Region

S.N.	Variety name	Released year	Maintaining center	Seed size & color
	SCR 26 (Sekia)	2017	Hawassa ARC	Small red bean
	SER 119	2014	Melkassa ARC	Small red bean
	SER 125	2014	Melkassa ARC	Small red bean
	Hawassa Dume (SNNPR-120)	2008	Hawassa ARC	Small red bean
	Local check	Not registered	Farmers	Small red bean
	SCR 15 (keyyo)	2019	Melkassa ARC	Small red bean

NB: ARC = Agricultural Research Center,

Source: Adopted from Crop variety register. Issue no. 24. Addis Ababa, Ethiopia.

3. Data collection and analysis

3.1 Data collection

During the implementation of the experiment, data were collected on both plant and plot basis. The data collected on the plant basis were plant height (cm), number of pods per plant, and number of seeds per pod whereas days to 50% flowering, days to 90% maturity, and seed yield (kgha^{-1}) were collected in plot basis (IBPGR, 1983).

Plant height (cm) was estimated from the average height of five sampled plants measured from the ground surface to the tip of the main stem in cm (centimeter) when more than 90% of plants matured.

The number of pods per plant was estimated by counting the fertile pod /pod with at least one seed/ number of five sample plants.

The number of seeds per pod was determined from the average number of seeds per 10 pods from five sampled plants.

Days to 50% flowering were determined considering the number of days from emergence to the stage when 50% of the plants of each genotype have begun to flower.

Days to 90% maturity were determined considering the number of days from emergence until 90% of the pods are mature.

Seedyield(g): among six rows per plot, four central rows were harvested and threshed from each plot, and seeds obtained from them were weighed to obtain the seed yield in gram plot^{-1}and the values were converted into kgha^{-1}.

3.1 Data analysis

Homogeneity of error variance was tested before combined analysis using Bartlett's test (Bartlett, 1973). The data collected on a plant and plot basis were subjected to ANOVA by using the GLM (General Linear Model) procedure of SAS software version 9.2 (SAS, 2008) for individual and combined environments. Besides, genotypes' yield stability analysis was scrutinized by using GenStat version 17.1 (GenStat, 2014).

4. Result and discussion

4.1 ANOVA for seed yield and related traits

Significant differences ($P < 0.01$) were observed among common bean varieties across different sites, as indicated in (Table 3), in terms of seed yield (kgha $^{-1}$), days to 50% flowering, days to 90% maturity, plant height (cm), seed per pod, and pod per plant. The mean values for these traits were 2397.13 kgha^{-1}, 40.57 days, 83.91 days, 63.93 cm, 5.06 seeds per pod, and 13.99 pods per plant, respectively. Notably, compared to the national average for common bean in 2021/2022, which stood at 17.27 kgha^{-1} (CSA, 2021/22), the mean yield from the tested varieties showed a substantial increase of 98.56%. Several researchers (Kwabena et al., 2016; Demelash, 2019; Gobeze et al., 2023) have previously documented this significant trait disparity among common bean varieties.

Table 3. ANOVA of yield and related traits of Mesoamerican Common bean varieties in Areka, Gofa & Bombe districts of South Ethiopia from 2022 to 2023.

Source of Variation	DF	Mean square values					
		YLD	DTF	DTM	PH	SDPPD	PDPPT
Yr.	1	6971800*	413.04*	2782.5*	16405*	14.69*	0.34*
Yr. (Loc)	3	4325872.78*	628.74	2620.12*	8127.62*	21.52*	28.04*
rep (Loc)	9	620295.44 *	1.07*	2.92*	280.08 *	0.264*	4.424*
Loc	2	4293033.38*	1202.76*	4135.01*	15223.2*	21.59*	98.14*
Yr.*Loc	2	3002909.09*	736.38*	2538.89*	3988.76*	24.93*	41.88*
V	5	1996431.26**	98.88**	91.43**	530.53**	0.74*	11.16**
Loc *V	10	832201.58*	10.45*	5.86*	191.95*	1.57*	27.29*
Yr.*V	5	670723.56**	1.76**	1.18**	341.32**	0.63*	9.124**
Yr.*Loc*V	10	723750.62**	26.89**	15.46**	259.52**	1.98*	10.32**
Error	114	117638.61	3.26	2.943	109.53	0.46	394.21
CV (%)		11.29	2.45	1.65	12.14	10.76	11.29
Mean		2397.13	40.57	83.91	63.93	5.06	13.99
LSD		287.76	1.0319	1.44	5.98	0.5	1.0634

NB: Loc = location, V = variety, Yr. = year, CV = Coefficient of variation, LSD = Least Significant Difference, YLD = Yield in Kgha^{-1}, DTF = Days to 50% flowering, DTM = Days to 90% maturity, PH = plant height, SDPPD = Seed per pod, PDPPT = Pod per plant, * = significant at ($P < 0.05$), ** = significant at ($P < 0.01$)

4.2 The mean performance of the common bean varieties

(Table 4) presents the tested common bean varieties' mean seed yield (kgha^{-1}). Among these, SER 119 and SER 125 demonstrated superior performance with mean yields of 2846 and 2639 kgha^{-1}, respectively. Comparatively, the local check yielded 2323 kgha^{-1}, ranking third among the tested varieties. SER 119 outperformed SCR-26 by 15.93% in mean yield, although SCR-26 is a more recent release than SER 119 and SER 125 (Table 1). The recently released variety was anticipated to exhibit higher yield potential than the older ones. Besides, in the 2022 cropping season in Ethiopia, the national average yield for common beans stood at 17.27 tons per hectare (CSA, 2021/2022). However, all tested varieties surpassed this average, indicating the suitability of the test sites for Mesoamerican common bean varieties. Previous studies (Alemayehu & Rahel, 2015; Buno & Gebre, 2022; Masreshaw et al., 2022) have also reported on the mean yield performance of released varieties in common bean crops.

Table 4. The mean of seed yield (kgha-1) performance of Mesoamerican common bean varieties at Gofa, Areka, and Bolosso Bombe sites during the 2022 to 2023 cropping seasons

Varieties	2022			2023			Mean yield	Rank
	Gofa	Areka	Bombe	Gofa	Areka	Bombe		
SCR-26	2029	1522	1331	1702	3199	2600	2064	6
SER 119	2157	2728	3602	2406	3023	3159	2846	1
SER 125	1937	2017	3393	2613	2961	2912	2639	2
Hawassa Dume	2301	1449	1795	2060	2807	3082	2249	5
Local check	2099	2605	1995	1939	3044	2253	2323	3
SCR-15	1841	1667	2722	1667	2872	2813	2264	4
CV	13.6	26.2	14	13.56	12.19	16.1		
GM	2060	1998	2472	2064	2984	2803	2397.5	

NB: GM = Grand Mean, and CV = Coefficient of Variation

The seed yield and traits of common bean varieties are summarized in (Table 5), showing significant differences in yield performance for most varieties except Hawassa Dume, Local check, and SCR 15. Varieties SCR 26, SER 119, and SER 125 did not differ significantly in days to 50% flowering. In terms of days to 90% maturity, SER 125, Hawassa Dume, Local check, and SCR 15 showed significant differences, while SCR 26 and SER 119 did not. Plant height varied significantly between SCR 26 and SER 125, but other comparisons showed no difference. SER 125 had significantly different seeds per pod compared to most varieties. SER 119 showed differences in pod per plant when compared to Hawassa Dume and Local check. Similar studies on legumes, such as common bean (Alemayehu & Rahel, 2015), and soybean (Masreshaw et al., 2022) also showed differences in yield traits.

Table 5. The Seed yield and related traits mean performance of Mesoamerican common bean varieties tested in 2022 to 2023

Variety	Mean values of related traits of each variety					
	YLD	DTF	DTM	PH	SDPPD	PDPPT
SCR 26 (Sekia)	2063.92d	38.58d	81.50d	67.75ab	4.87b	14.0abc
SER 119	2845.58a	38.96d	82.37d	64.46bc	4.96b	13.27c
SER 125	2638.63b	39.29d	83.67c	58.96c	5.37a	13.29bc
Hawassa Dume (SNNPR-120)	2248.71c	42.25b	84.92b	60.08c	5.08ab	14.29ab
Local check	2322.46c	43.67a	87.042a	70.96a	4.95b	15a
SCR 15 (keyyo)	2263.50c	40.67c	83.96bc	61.33c	5.08ab	14.2abc
LSD	287.76	1.032	1.44	5.98	0.38	1.064
CV (%)	11.29	2.45	1.65	12.14	10.76	11.29

NB: YLD =Yield in Kgha^{-1}, DTF = Days to 50% flowering, DTM = Days to 90% maturity, PH = plant height, SDPPD = Seed per pod, PDPPT = Pod per plant, LSD = Least Significant Difference, CV = coefficient of variation

4.3 The stability of the common bean varieties

The stability of Mesoamerican common bean varieties was assessed using multivariate stability models, namely the GGE (Genotype and Genotype by Environment) bi-plot (Yan et al., 2007) and AMMI (Additive Main Effects and Multiplicative Interaction) (Gauche & Zobel, 1988). In AMMI analysis, the impact of genotype (G) and environment (E) is depicted as additive main effects, with GEI represented as a multiplicative component, which is then subjected to principal component analysis (PCA) (Zobel et al., 1988). Conversely, GGE bi-plot analysis serves as a robust tool for multi-location analysis, genotype assessment (average performance and stability), and environmental evaluation (ability to differentiate among genotypes in specific environments), such as identifying "which-won-where" patterns (Yan et al., 2007).

4.4 ANOVA for seed yield of AMMI model

ANOVA analysis for AMMI revealed significant differences among Genotype (G), Environment (E), and Genotype by Environment Interaction (GEI), indicating varied performance among genotypes (Table 6). The distribution of E, G, and GEI toward the total Sum of Squares (SS) amounted to 31.85%, 14.75%, and 27.94%, respectively. Notably, the substantial proportion of E (31.85%) underscored its pivotal role in causing performance disparities among genotypes, closely followed by GEI. The prevalence of GEI (27.94%) surpassing that of genotypes (14.75%) emphasized the complexity it introduces to selecting superior and adaptable varieties. These results align with previous findings in studies on common beans (Girum et al., 2022; Demelash, 2019). Within the AMMI ANOVA Table, IPCA 1 and IPCA 2 emerged as significant and sufficient in elucidating GEI, jointly constituting 91.30% of the total GEI SS, leaving the remaining IPCAs at 8.69%. The consensus among various authors, such as in common bean (Kwabena et al., 2016), and cowpea (Tesfaye et al., 2022) studies, supports these findings.

Table 6. AMMI ANOVA table for Mesoamerican common bean seed yield of six genotypes tested at six environments

SV	DF	SS	MS	Pr.	% SS	% GEI
TRT	35	50452787	1441508*	<0.001		
Genotype	5	9982141	1996428*	<0.001	14.75	
ENV	5	21558542	4311708*	<0.001	31.85	
Block	18	10638412	591023*	<0.001		
GEI	25	18912105	756484*	<0.001	27.94	
IPCA 1	9	12436190	1381799*	<0.001		65.76
IPCA 2	7	4831139	690163*	<0.001		25.54
IPCA3	5	933730	186746*	0.0332		4.94
IPCA4	3	663943	221314*	0.0338		3.51
IPCA5	1	47102	47102^{ns}	0.4248		0.25
Residuals	0	0	0			
Error	90	6593469	73261			
Totals	143	67684668	473319			

NB: - IPCA = Interaction Principal Component Analysis, ENV = Environment, GEI = Genotype by Environment Interaction, SV = Source of Variation, DF = Degree of freedom, SS = sum of square, MS = Measure square

From (Table 7), the environments with relatively higher IPCA 1 scores, whether positive or negative, such as B/Bombe 2022 (34.73), Areka 2023 (-15.55), and Gofa 2022 (-16.68), were considered as potential environments. In these environments, SER 119 (G2) emerged as the top-ranked variety, followed by SER 125 (G3), consistently across all tested environments.

This finding is consistent with previous stability studies conducted on cowpeas (Tesfaye et al., 2022; Yasin al., 2022), and common beans (Demelash, 2019; Girum et al., 2022), suggesting the reliability and validity of the selection process.

It is a promising indication that SER 125 (G3) consistently performs well across different environments, which could be valuable for future cultivation and breeding efforts in common bean production.

Table 7. Table of the first four common bean genotype AMMI selections per test environment

Environments	Designation	Mean	IPCA 1 Score	The first four AMMI selections			
				1	2	3	4
E1	Gofa 2022	2060	-16.68	G4	G2	G1	G5
E2	Gofa 2023	2064	0.31	G2	G3	G4	G6
E3	Areka 2022	1998	2.67	G2	G5	G3	G6
E4	Areka 2023	2984	-15.55	G2	G5	G4	G1
E5	B/Bombe 2022	2473	34.73	G2	G3	G6	G5
E6	B/Bombe 2023	2803	-5.49	G3	G2	G4	G6

NB: G1 = SCR-26, G2 = SER 119, G3 = SER 125, G4 = H/Dume, G5 = L/Check, and G6 = SCR-15, IPCA = Interaction Principal Component Analysis, E = Environment

(Figure 1) displays the IPCA1 versus IPCA 2 graph, illustrating six environments and three locations over two years. In the IPCA1 versus IPCA 2 AMMI plot, genotypes or locations with low IPCA 1 scores are positioned near the axis origin, indicating stability across tested locations (Gauche & Zobel, 1988; Gauche, 1988; Zobel et al., 1988). Conversely, genotypes or environments positioned to the right of the origin are deemed superior and promising (Gauche & Zobel, 1988). Therefore, SER 119 and SER 125 were identified as superior genotypes, while Bolosso Bombe (in 2022 & 2023) and Areka (in 2023) were deemed potential environments; Gofa (in 2022 & 2023) and Areka (in 2022) were classified as less discriminating (Figure 1). Various authors, such as those studying common bean (Kwabena et al., 2016; Demelash, 2019; Girum et al., 2022), and cowpea (Tesfaye et al., 2022; Yasin et al., 2022) drew similar conclusions.

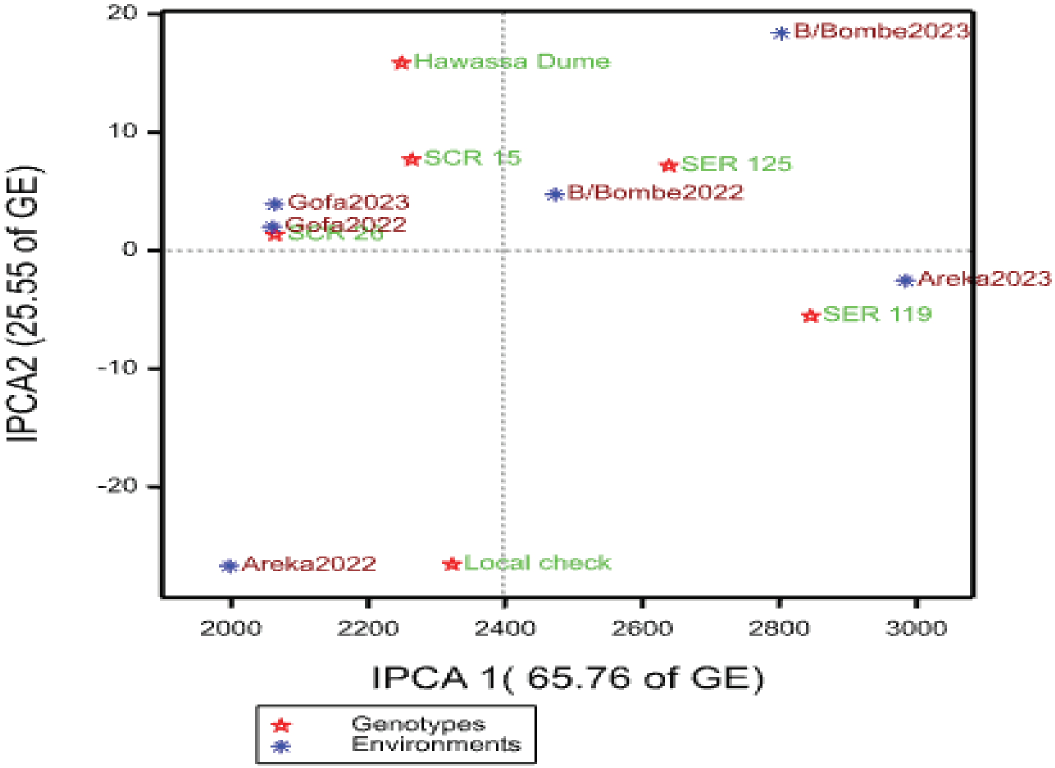

Figure 1. AMMI bi plot of IPCA 1 versus IPCA 2 graph of common bean genotypes tested at six environments in South Ethiopia, 2022 to 2023

4.5 Genotype plus genotype by environment (GGE) bi-plot analysis

The GGE bi-plot comparison graphs for common bean varieties (Figure 2) and environments (Figure 3) are presented below. Movement of genotypes away from the Average Environment Coordinate (AEC) and bi-plot origin indicates greater Genotype × Environment Interaction (GEI) effects. Consequently, SER 125 and SER 119 demonstrated stability, whereas others did not. Furthermore, genotypes positioned to the right of the axis origin are considered superior; thus, SER 125 and SER 119 emerged as the top performers (Figure 2). Similarly, environments moving away from AEC and the bi-plot origin indicate significant GEI effects (Figure 3); Gofa exhibited stability as it closely aligned with AEC, resulting in similar yields across genotypes. Conversely, Areka and Bolosso Bombe were identified as discriminating or unstable environments due to their distance from AEC. Notably, SER 119 and SER 125 excelled in Bolosso Bombe and Gofa, while different varieties performed better in Areka. These findings corroborate previous studies on common bean by Demelash (2019), Girum et al. (2022), Kwabena et al. (2016), as well as cowpea research by Tesfaye et al. (2022) and Yasin et al. (2022) highlighting promising production environments in Ethiopia.

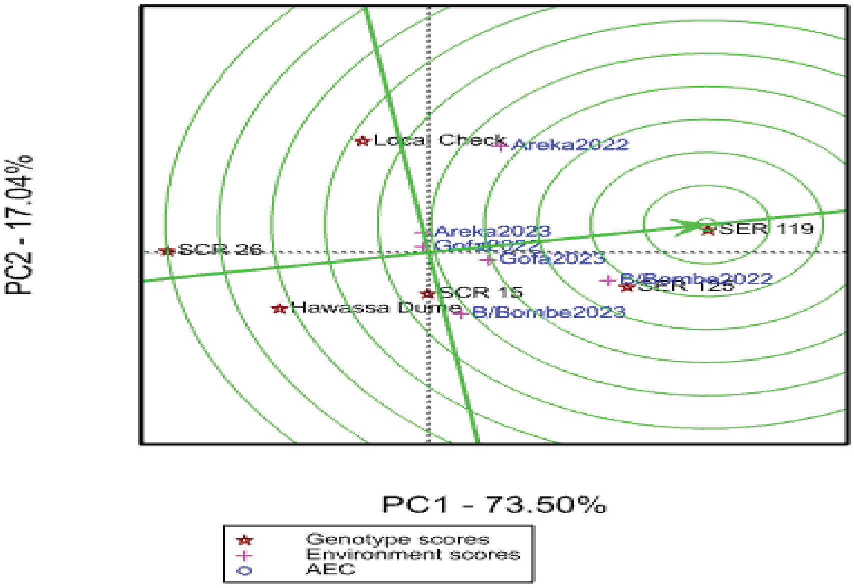

Figure 2. The GGE comparison of tested genotypes with ideal genotype based on mean seed yield performance across tested environments

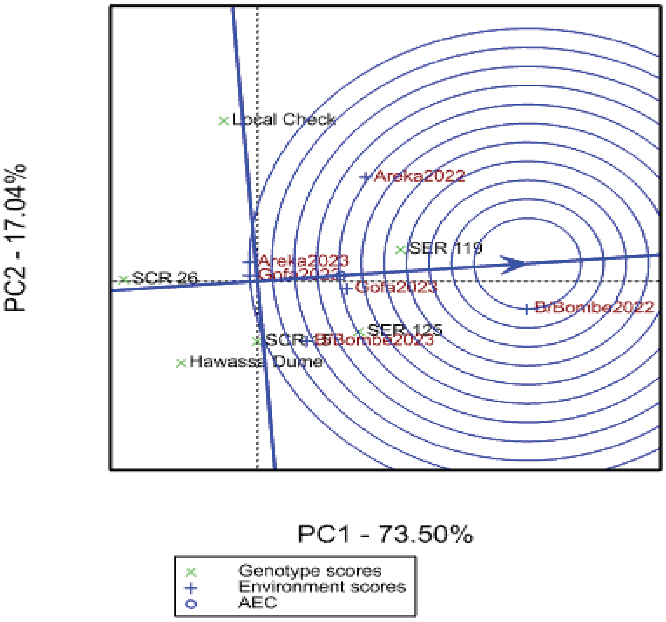

Figure 3. The GGE comparison of test environments with ideal environment for 2022 to 2023 cropping seasons

5. Conclusion

For two years, six common bean varieties were tested at Gofa, Areka, and Bombe locations. SER 125 and SER 119 exhibited average yields of 2639 kgha^{-1} and 2846 kgha^{-1}, respectively, with SER 125 demonstrating greater stability across the three locations. The average yields for SCR-26, Hawassa Dume, Local check, and SCR-15 were 2064 kgha^{-1}, 2249 kgha^{-1}, 2323 kgha^{-1}, and 2264 kgha^{-1}, respectively. All varieties surpassed the national average yield of 1727 kgha^{-1}, suggesting that these locations are well suited for common bean cultivation despite differences in their ability to discriminate between varieties. Specifically, Bombe and Areka were found to be discriminating locations, while Gofa was not. Given its high stability and yield, the SER 125 variety is recommended for large-scale production, with SER 119 also suitable for the tested locations and similar agroecological zones.

Artificial intelligent declaration

The authors utilized the Chat GTP tool and GRAMMARLY application for rewriting and language editions in the preparation of this work. Subsequently, the author conducted a thorough review and editing process, taking full responsibility for the content of the publication.

Human/animal ethics declaration

No human or animal ethics declaration needed.

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