

Seed Yield and Its Related Traits Performance of Common Bean (Phaseolus vulgaris L.) Varieties in Dawro Zone, Southwest Ethiopia

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Abstract
Poor addressing of all potential areas and slow turnover of old cultivars for more than 15-30 years are serious bottlenecks limiting production and productivity of common bean in Ethiopia. Farmers in the study area, Dawro zone, had been cultivating common bean landraces for about five centuries and Red wolaita for about 30 years. Red wolaita is low seed yielding and poor in quality due to loss of its genetic identity because of mixing up with landraces, genetic drift, and natural out crossing. Hence, thirteen newly released common bean varieties reported for their higher seed yield potential and Red wolaita were evaluated at seven locations for seed yield and its related traits performance using RCBD design with three replications in Dawro zone, southwest Ethiopia, in the 2010 main cropping season to select higher seed yielding and broadly adapted varieties. Analysis of variance (ANOVA) and additive main effects and multiplicative interaction (AMMI) models were used to analyze the data. The analysis of variance revealed presence of highly significantly difference ($P < 0.01$) between varieties for seed yield and its related traits performance. Combined AMMI model analysis of variance partitioned the variability in seed yield performance of varieties with the largest effect of location (50.27%) followed by variety effect (28.81%) and then variety by location interaction (GLI) effect (20.92%) indicating highly significant complication of GLI in selecting high seed yielding and broadly adapted varieties with greater influence of location. AMMI 1 biplot analysis enabled identification of higher seed yielding and broadly adapted varieties, Zebra-90, GobeRasha, Roba-1, Nasir, and Omo-95. Higher seed yielding varieties were earlier to flower, but latest to mature. Longer plant height, and higher number of primary branches per plant, pods per plant, and seeds per pod had better contributed to higher seed yield performance. Generally, since broadly adapted varieties were the winners with rank change within themselves at all locations and no variety had performed specifically well, Zebra-90, GobeRasha, Roba-1, Nasir, and Omo-95 were recommended for production in the Zone and now Nasir, which has similar seed color with the old and low seed yielding cultivar in the Zone, Red wolaita, has got wider acceptance and at popular production in the Zone.
Keywords: AMMI, Broad adaptation, Dawro Zone, GLI, Seed yield, Variety, Yield related traits

INTRODUCTION

Common bean (*Phaseolus Vulgaris* L.) is becoming one of the most important cash crops and source of protein for farmers in many lowlands and mid-altitude agro-ecologies in Ethiopia in the face of climate change and variability by over taking areas cultivated to vulnerable crops [30]. It is highly preferred by Ethiopian farmers because of its: (i) fast maturing characteristics that made it quick source of cash and food by filling hunger gap and securing households food needs after the failure of main season crops or shortage of their produce, (ii) better tolerance to drought, low fertile soils, and shade in intercropping, (iii) nutritional composition (high lysine, folate, Fe, Zn, Ca, Cu, Mg, and Mn), (iv) adaptability to areas with altitudes ranging from 650 meter to 2500 meter [31]. In recent years, it is becoming important export earnings of the country. Its export earning estimated to be over 85% of export earnings from pulses [26]. It ranks third as an export commodity next to coffee and sesame and contributing about 9.5% of total export value from agriculture in the country [10].

There is general belief that common bean was introduced to Ethiopia in the 16th century by the Portuguese traders [17]. In Ethiopia, it is grown suitably in areas with an altitude ranging between 1200 - 2200m above sea level with optimum temperature range of 16 - 28°C and a rainfall of 350-500 mm well distributed over the growing season. It performs best on deep, friable and well aerated soil with good drainage, reasonably high nutrient content and pH range of 5.8 to 6.5 [23, 23].

Both area coverage and production of common bean has been increasing in Ethiopia since 2002 in response to economic reforms of the 1990s [19, 20]. It had area coverage of 244,012.80 hectares and production of 3,628,903 quintals in 2010 in Ethiopia.[7] However, its average national yield was estimated at 1487kg ha^{-1}, which is still low as compared to attainable yield of 2000- 3000 kg ha^{-1} from improved varieties under good management condition [2, 6, 9, 15, and 21]. Its average yield in the study area is 1231 kg/ha[7], which is again very low compared to the attainable yield indicated above.

The low seed yield of common bean in Ethiopia in general and in the study area, Dawro Zone, in particular is attributed to several production constraints which include lack of improved varieties for the different agro-ecological zones, poor cultural practices, drought, low soil fertility, diseases (common bacterial blight, anthracnose, halo blight, rust, angular leaf spot, fusarium wilt, bean common mosaic virus, and bean golden mosaic virus) and insect pests (bean fly or bean stem maggot and bruchids).

In Ethiopia, since 1973 to 2010, thirty seven common bean varieties had been developed and released for cultivation from national and regional Agricultural Research Centers [23]. None of these improved varieties had introduced into the study area except, Red Wolaita, which was introduced into the Zone before 30 years. This is due to nothing, but less focus given to the crop's multifaceted importance mentioned above and the potential of the crop to increase production and productivity in the Zone given climate change and variability. Farmers in the study area had been cultivating landraces for about five centuries and Red wolaita for about 30 years. Red Wolaita is now low seed yielding and poor in quality due to loss of its genetic purity because of mixing up with landraces, genetic drift, and partly due to natural out crossing. Therefore, introduction of newly released high yielding, well adapted, and preferred market quality common bean varieties is required. However, when genotypes are introduced into new and diverse production environments, occurrence of significant genotype x environment interaction is common and complicates selection for broad adaptation [4]. In this case, means averaged over locations are misleading and simultaneous consideration of mean performance and stability is necessary [30]. Several biometrical methods had been developed and used to analyze stability/adaptability. But, recently AMMI biplot models are preferred tools for simultaneous analysis of mean performance and stability [11]. Therefore, this research was conducted to evaluate seed yield and its related traits performance of common bean varieties in Dawro Zone growing condition and to select higher seed yielding and broadly adapted varieties for production in the Zone.

MATERIALS AND METHODS

The experiment was conducted during the 2010 main cropping season at seven representative locations in the beans growing areas of Dawuro zone. Dawro zone, in South Nations Nationalities and People Regional (SNNPR) State, is located in the southwestern part of Ethiopia 507km from Addis Ababa through Wolaita Sodo at 6^{o}52\`N to 7$^o$13\`N latitude and 37^{o}07\`E to 37$^o$26\`E longitudes. The characteristics of experimental locations are given in Table 1. Farmers in the Zone, particularly in two of its districts (Loma and Gena Bosa) had been cultivating common bean landraces in sole or relaying with maize, sorghum, sweat potato, cassava, coffee, banana, sugarcane, yam, and taro for about five centuries, but the only cultivar improved by modern plant breeding and introduced into the Zone before 30 years is Red wolaita. It is preferred by local farmers not only for its nutritiousness, but also due to its ability to impart red color to maize in a boiled blend recipe of bean and maize that makes consumers to feel as if they were eating the nutritious bean recipe when they are actually eating the blend recipe.

Table 2. Characteristics of the test locations

Locations	Altitude (m. a.s.l.)	Soil texture	Latitude	Longitude	Temperature (^{o}C)		Rainfall (mm)
					Minimum	Maximum	
Turi	1773	Clay	7^{o}06169"N	37^{o}11'733"E	12.0	27.0	1645
Tarcha	1342	Clay loam	7^{o}9'210"N	37^{o}10'365"E	16.5	32.0	1405
Yalo	1270	S. clay loam	6^{o}56'990"N	37^{o}20'551"E	15.0	28.0	1400
Duga	1760	S. clay loam	7^{o}05'180"N	37^{o}20'096"E	13.0	25.0	1700
Wara	1465	Clay loam	7^{o}10'065"N	37^{o}03'783"E	14.0	25.0	1340
Bero	1800	S. clay loam	7^{o}52'075"N	37^{o}08'640"E	14.0	23.0	1560
Gendo	1860	Clay	6^{o}58'760"N	37^{o}22'075"E	14.0	26.5	1465

m. a.s.l. = Meters above sea level, mm = Millimeter and S.clay loam = Sandy clay loam.

Experimental materials were 14 common bean varieties constituting of 13 new introductions to the study area and one check, Red wolaita (Table 2). At all locations, RCBD with three replications was used. The plot size was 1.6m x 4m (6.4m^2) with four rows of spacing 40cm between rows and 10cm between plants. The net harvested area was 3.2m^2, the middle two rows. Two seeds per hill were sown on rows with manual drilling to ensure germination and good stands of the bean varieties and then were thinned to one plant per hill 12 days after emergence to achieve 160 plants per plot. Recommended DAP fertilizer rate of 100 kg ha-^{1} was applied to each plot during sowing. Land preparation, sowing and other cultural practices were followed as per recommendations for common bean.

Data were collected on:

- **Days to 50% flowering (DF):** Counted as the number of days from planting to the stage when 50% of the plants in a plot had at least one open flower.
- **Days to maturity (DM)**: The number of days from planting to 50% of plants in a plot had at least one of their pods dried.
- **Seed yield (GY):** The seed yield in grams of the plants that were harvested from the central two rows of the plot adjusted for 12% seed moisture using seed moisture meter and then converted to

kilogram per hectare. The equation used for adjusting seed yield to the specific moisture content was[16]:

$$Y_{adj} = \left[\left(\frac{100-MC}{100-12}\right) * Y\right]$$

Where; Y_{adj} was moisture adjusted yield, Y was unadjusted yield, and MC measured moisture content (%).

- **100 seeds weight (HSW):** Weight (gm) of 100 seeds was estimated by weighing 100 seeds randomly taken from the seed yield of each plot.
- **Plant height (PH):** The average height in centimeters of ten randomly pre-tagged plants in the central two rows was measured from the soil surface to the top of the canopy of the plant.
- **Number of primary branches per plant (NPBPP):** The number of branches on the main axis of ten randomly pre-tagged plants was counted and averaged.
- **Number of pods per plant (NPPP):** The number of pods on ten randomly pre-tagged plants was counted and averaged.
- **Number of seeds per pod (NSPP):** The seeds of five randomly taken pods from each of ten randomly pre-tagged plants was counted and averaged.

Table 2. Experimental varieties and some of their agronomic traits.

No	Varieties	Code	Seed color	Seed size	Year of release	Seed source
1	Gofta	G1	Cream	Medium	1997	MARC
2	GobeRasha	G2	Red speckled	Large	1999	MARC
3	Beshbesh	G3	Cream	Small	1998	MARC
4	Zebra-90	G4	Carioca	Small	1999	MARC
5	Mexican 142	G5	White	Small	1973	MARC
6	Roba - 1	G6	Cream	Small	1990	MARC
7	Awashmelka	G7	White	Medium	1999	MARC
8	Tabor	G8	Cream	Small	1999	HARC
9	Dimitu	G9	Red	Small	2003	MARC
10	Nasir	G10	Red	Small	2003	MARC
11	Red wolaita (check)	G11	Red	Small	1974	MARC
12	Ibbado	G12	Red speckled	Large	2003	AARC
13	Omo-95	G13	Red	Small	2003	AARC
14	Hawassa dume	G14	Red	Medium	2008	AARC

MARC = Melkassa Agricultural Research Center, HARC = Hawassa Agricultural Research Center, and AARC = Areka Agricultural Research Center.

The analysis of variance for separate locations was done using SAS software version 9.2 [28] to observe the differences among varieties in their performance for yield and its related traits. Comparison of treatment means was done using Tukey's Studentized Range test (HSD). The AVOVA model of fixed effects varieties for individual location was:

$$y_{ij} = \mu + \alpha_i + \beta_j + \bar{e}_{ij}$$

Where; y_{ij} is the observed response of i^{th} variety in the j^{th} replication, μ is the mean across replicates, α_i is effect of i^{th} variety, β_j is the effect of j^{th} replicate, and $\bar{e}_{ij}$ is the random error assumed to be normally and independently distributed as mean zero and variance equal to σ^2.

The AMMI model combined analysis of variance and its biplot stability/adaptability analysis was done using Genstat statistical software package version 17. The AMMI model [31] used was:

$$y_{ij} = \mu + \alpha_i + \beta_j + \left(\sum_{1}^{n} k_n U_{in} V_{jn}\right) + Q_{ij} + \epsilon_{ij}$$

Where: y_{ij} *is* the mean yield across replicates of the i^{th} variety in the j^{th} location, μ is the grand mean, α_i is the additive effect of i^{th} variety, β_j is the additive effect of j^{th} location, k_n is the singular value of the IPCA axis n, U_{in} and V_{jn} are scores of variety i and location j for the IPC axis n, respectively, Q_{ij} is residual for the first n multiplicative components, and $\bar{\varepsilon}_{ij.}$ is the residual error assumed to be normally and independently distributed as $(0, \sigma^2/r)$ (where σ^2 is the pooled error variance and r is the number of replicates).

RESULTS AND DISCUSSION

Analysis of Variance

The mean squares of analysis of variance for seed yield and yield related traits are presented in Table 3. The analysis revealed that common bean varieties evaluated were highly significantly different ($p < 0.01$) in days to 50% flowering, days to maturity, height, number of pods per plant, number of seed per pod, hundred seeds weight, and seed yield at all test locations. The analysis showed statistically no significant difference between varieties for number of primary branches per plant performance at Yalo and Gendo. Similar findings were reported by [27] from evaluating 31 common bean genotypes for the same traits. Similarly, [3] compared 26 genotypes at Jimma and reported similar findings for number of pods per plant, 100 seeds weight and seed yield performance.

Table 3. Mean squares, coefficient of variation, and coefficient of determination for yield and yield related traits of 14 common bean varieties evaluated at seven locations of Dawro zone in the 2010 main cropping season.

		Locations						
Trait	Mean square components	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo
DF	Rep.MS	5.02*	2.00**	3.52^{ns}	1.60**	0	6.50**	0.50^{ns}
	G.MS	114.38**	4.55**	7.94**	16.15**	24.07**	11.52**	21.96**
	E.MS	0.92	0.15	1.14	0.26	0.44	0.86	0.32
	CV	1.97	0.96	2.76	1.15	1.63	2.11	1.16
	R^2	0.98	0.94	0.79	0.97	0.97	0.88	0.97
DM	Rep.MS	0.50^{ns}	1.50*	26.17**	0.02^{ns}	0.45^{ns}	2.00^{ns}	0.21^{ns}
	G.MS	24.30**	20.40**	28.37**	18.06**	24.70**	26.00**	50.14**
	E.MS	0.68	0.32	2.27	0.36	0.25	0.77	0.32
	CV	1	0.74	1.78	0.67	0.59	1.07	0.62
	R^2	0.95	0.97	0.88	0.96	0.98	0.94	0.99
PH	B.MS	174.12^{ns}	1240.21**	208.67^{ns}	20.65^{ns}	44.14^{ns}	93.26*	64.99^{ns}
	G.MS	742.93**	755.70**	439.30**	652.85**	190.02**	609.07**	232.82**
	E.MS	139.73	71.9	78.24	19.37	26.39	18.91	72.83
	CV	12.88	10.6	11.32	6.9	5.94	6.9	12.03
	R^2	0.73	0.87	0.75	0.94	0.79	0.94	0.63
	Rep.MS	0.07^{ns}	1.28**	0.02^{ns}	0.07^{ns}	0.5**	0.06^{ns}	0.44*
	G.MS	1.11**	0.34**	0.13^{ns}	0.49*	0.33**	0.32**	0.18^{ns}
NPBPP	E.MS	0.09	0.18	0.14	0.18	0.07	0.06	0.09
	CV	9.19	15.12	12.49	19.7	8.46	11.23	11.56
	R^2	0.87	0.59	0.33	0.58	0.74	0.73	0.57
NPPP	Rep.MS	20.35*	50.9**	3.87^{ns}	0.26^{ns}	23.41**	10.17**	4.34^{ns}
	G.MS	18.25**	27.54**	11**	4.79**	21.76**	4.98**	5.25*
	E.MS	5.6	4.34	2.43	1.16	2.69	1.48	1.97
	CV	14.93	14.79	8.84	8.36	9.22	10.27	9.08
	R^2	0.66	0.8	0.71	0.68	0.82	0.69	0.6
NSPP	Rep.MS	0.81**	0.04^{ns}	0.08^{ns}	0.04^{ns}	0.04^{ns}	0.14^{ns}	0.5*
	G.MS	1.05**	0.95**	0.71**	0.71**	0.99**	0.62**	0.62**
	E.MS	0.07	0.06	0.09	0.11	0.08	0.09	0.12
	CV	5.08	4.3	5.06	5.77	4.87	5.34	5.98
	R^2	0.89	0.89	0.81	0.76	0.87	0.78	0.75
HSW	Rep.MS	0.34^{ns}	7.18*	0.39^{ns}	2.178^{ns}	0.04^{ns}	0.77^{ns}	0.37^{ns}
	G.MS	340.48**	219.82**	282.34**	310.74**	240.83**	213.63**	312.00**
	E.MS	1.483	2.025	0.886	182.49	78.07	149.71	51.57
	CV	5.25	5.67	3.87	5.58	3.98	5.33	3.25
	R^2	0.99	0.98	0.99	0.99	0.99	0.99	1.00
GY	B.MS	10911.6^{ns}	145290.2**	59496.9^{ns}	6282.0^{ns}	88419.8^{ns}	30304.9*	25929.0^{ns}
	G.MS	238708.3**	148889.8**	708152.7**	416262.7**	1025464.1**	353164.8**	506175.0
	E.MS	3775.2	21287.5	39336.3	3920.6	59233.7	8898.4	16492.4
	CV	3.63	6.31	7.79	3.33	9.02	5.86	6.27
	R^2	0.97	0.8	0.9	0.98	0.9	0.95	0.94

* and ** = Significant at 0.05 and 0.01 level of probability respectively, ns = Non significant, Rep. MS = Replication mean square, G. MS = Genotype mean square, E. MS = Error mean square, CV = Coefficient of variation, R^2 = Coefficient of determination, DF = Number of days to flowering, DM = Number of days to maturity, PH = Plant height in cm, NPBPP = Number of primary branches per plant, NPPP = Number of pods per plant, NSPP = Number of seeds per plant, HSW = Hundred seed weight, and GY = Seed yield (kg/ha

Variety x Location Interaction (GLI) Analysis

The variety x location interaction (GLI) analysis of variance using AMMI model is presented in Table 4. The analysis showed that the variety (G), location (L), and GLI effects were highly significant ($p < 0.01$). This showed the diversity of locations and presence of highly significant genetic differences among the varieties for seed yield performance. The explained percentage of variability due to variety, location, and GLI were 28.81%, 50.27%, and 20.92%, respectively, indicating largest effect of location followed by variety. Similar findings were reported by [2, 22, and 29] for common bean cultivars performance and their growing environments in Ethiopia. The significant GLI also indicated dissimilarity of the relative performance of varieties across locations and called for adaptability analysis.

The AMMI model analysis partitioned the GEI into the first two significant IPCAs with contributions of IPCA1 (39.25%) and IPCA2 (29.88%). The remaining residuals were not significant (Table 4). Therefore, IPCA1 and IPCA2 alone were adequately predicted the variation in this data structure, but as the data were from one season trials, GLI couldn't be exploited and should be minimized by selecting for broad adaptation, the overall pattern of varieties' interaction with locations was interpreted using AMMI1 biplot, Figure 1.

Table 4. AMMI model ANOVA for seed yield (kg/ha) of 14 common bean varieties evaluated at seven locations of Dawro Zone in the 2010 main cropping season.

Sources	DF	SS	MS	Explained % from SS	Explained % from GLI
Varieties	13	8527223	655940**	28.81	
Locations	6	14880890	2480148**	50.27	
GLI	78	6192316	79389**	20.92	
IPCA 1	18	2430298	135017**		39.25
IPCA 2	16	1850341	135017**		29.88
IPCA 3	14	867813	135017ns		
Residuals	30	1043864	34795		

** = Significant at 0.01 level of probability, ns = non significant, GLI = Variety by location interaction, DF= Degree of freedom, SS= sum of squares, MS=Mean sum of squares, IPCA1, IPCA2, and IPCA3 are interaction principal component axis 1, 2, and 3, respectively.

Performance of Varieties

Seed yield performance

The mean seed yield of varieties averaged over locations ranged from 2622.3 kg/ha (Zebra-90) to 1200.8 kg/ha (Mexican-142) (Table 5). Most varieties performed above the overall mean except Mexican-142, Tabor, Awashmelka, and Gofta. [2, 6, 15, 22] reported seed yield performance of common bean genotypes in the range 1098 to 3000 kg ha^{-1}. Comparing means averaged over locations, varieties evaluated were grouped into five for seed yield performance and the highest yielding variety, Zebra-90, showed significantly different performance than others.

The locations' mean seed yield averaged over varieties ranged from 2698.7 kg/ha at Wara to 1609.3 kg/ha at Bero (Table 5). Thus, Wara is ideal location for commercial production of common bean as it has highest seed yield potential while Bero and Turi were the least yielding locations.

Wider range in seed yield performance (2338.5kgha^{-1}) among varieties was observed at the highest yielding location, Wara. The observed performance of varieties was consistent with the reports of [2, 6, 15, and 22] in most locations except for Mexican-142 which performed far below the level reported by other investigators. This revealed that most test locations are not suitable for Mexican-142 production.

Rankings of the varieties were different for seed yield performance across locations (Table 5). The highest yielding variety, Zebra-90, showed higher seed yield performance in four of the test locations (Tarcha, Duga, Wara, and Gendo). GobeRasha, Omo-95, and Gofta won at Turi, Yalo, and Bero, respectively. This showed presence of crossover genotype x variety interaction (GLI) and called for GLI and stability analysis before selection of superior varieties based on only mean seed yield performance averaged over locations.

Table 5. Mean seed yield of (kgha^{-1}) of 14 common bean varieties grown at seven locations of Dawro zone in the 2010 main cropping season.

Genotypes	Locations							Mean
	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	
Gofta	1452.9^{g}	2259.8^{bcd}	2404.7^{cde}	1746.5^{f}	2405.1^{d}	**2135.6^{a}**	1733.1^{b}	2019.7^{ef}
Goberasha	**2023.0^{a}**	2251.4^{bcd}	3065.8^{ab}	2269.9^{b}	2485.6^{cd}	1596.1^{de}	2228.5^{b}	2274.3^{b}
Beshbesh	1640.7^{ef}	2499.8^{ab}	2497.0^{bcde}	1958.1^{de}	3392.8^{ab}	1426.8^{ef}	2105.4^{b}	2217.2^{bcd}
Zebra-90	1978.2^{ab}	**2828.7^{a}**	2611.6^{abcde}	**2553.6^{a}**	**3474.1^{a}**	1973.5^{ab}	**2936.8^{a}**	**2622. 3^{a}**
Mex.142	1074.6^{h}	2122.8^{bcd}	1353.4^{f}	974.5^{g}	1135.6^{e}	751.9^{g}	993.0^{c}	1200.8^{g}
Roba-1	1703.1^{def}	2353.3^{bcd}	2908.3^{abc}	2018.5^{cd}	2667.6^{bcd}	1817.8^{bcd}	2279.4^{b}	2249.7^{bc}
A.melka	1777.2^{cde}	1936.6^{d}	2392.1^{cde}	1821.9^{ef}	2543.8^{cd}	1814.6^{bcd}	2275.4^{b}	2080.3d^{ef}
Tabor	1209.6^{h}	2289.4^{bcd}	2200.9^{de}	1674.2^{f}	2506.6^{cd}	1661.2^{cde}	1960.6^{b}	1929.0^{f}
Dimitu	1758.7^{cde}	2228.5^{bcd}	2782.2^{abcd}	1683.3^{f}	3077.2^{abcd}	1492.3^{ef}	1941.5^{b}	2137.7^{bcde}
Nassir	1899.5^{abc}	2472.5^{abc}	2065.8^{e}	1699.8^{f}	2999.3^{abcd}	1536.3^{de}	2157.1^{b}	2118.6^{cde}
Red wolaita	1839.8^{abcd}	2504.8^{ab}	2281.4^{de}	2178.0^{bc}	2423.8^{d}	1699.9^{bcde}	2009.2^{b}	2133.8^{bcde}
Ibbado	1836.0^{bcd}	2053.7^{cd}	3007.5^{ab}	1814.7^{ef}	3044.2^{abcd}	1232.2^{f}	1998.7^{b}	2141.0^{bcde}
Omo-95	1553.5^{fg}	2187.3^{bcd}	**3117.7^{a}**	2187.9^{bc}	2446.2^{d}	1895.3^{abc}	1943.5^{b}	2190.2^{bcd}
H. dume	1921.4^{abc}	2386.0^{bc}	2969.5^{abc}	1705.3^{f}	3180.1^{abc}	1497.1^{ef}	2113.4^{b}	2253.3^{bc}
Mean	1690.6^{f}	2312.5^{c}	2547.0^{b}	1877.6^{e}	**2698.7^{a}**	1609.3^{f}	2048.3^{d}	2112
CV (%)	3.63	6.31	7.79	3.33	9.02	5.86	6.27	7.00
HSD(0.05)	184.86	438.98	188.38	188.38	732.23	283.8	570.75	155.08

Mex.142 = Mexican-142, Amelk-90 = Awashmelka, R. wolaita = Red Wolaita, H.dume = Hawassa dume. Means followed by similar letters down columns for varieties and variety means and across columns for location means are not significantly different at the 0.05 probability level based on Turkey's Studentized Range (HSD) test. Bolded values are highest mean seed yields at each test locations. HSD value for location means is 96.17.

Seed yield related traits performance

Days to flowering and maturity

When averaged across locations, days to flowering of varieties ranged from 39.8 days for Gofta to 47 days for Awashmelka (Table 6). [3, 18] reported flowering periods of common bean genotypes in the ranges of 33-52 days and 45-52 days, respectively. Depending on mean separation test, Awashmelka was significantly latest to flower than other varieties. Beshbesh, Roba-1, Tabor, Dimitu, and Nassir had taken statistically similar number of days to flower, but greater than the overall mean indicating relative lateness in flowering. The highest and medium seed yielding varieties (Zebra-90, GobeRasha, Hawassa dume, and Red Wolaita) had taken statistically similar number of days to flower, which is lower than the grand mean. Under rainfed condition, [1] reported shorter period from sowing to first flowering for adapted cultivars of common bean. Thus, present finding matched with this report and this phenological plasticity has contributed for high seed yield performance of these varieties.

Longer average number of days to 50% flowering was recorded at locations Gendo and Turi which have higher elevations and lower average daily temperatures whereas the shortest average number of days to 50% flowering was recorded at location Yalo with lower elevation and higher average daily temperature (Tables 6 and 1). Similarly, [14] reported decrease in period from sowing to 50% flowering with higher average daily temperature under optimal soil water and other conditions in common bean.

Rankings of the varieties were changed across locations for the number of days taken for 50% flowering. The latest flowering variety, Awashmelka, was the latest at five locations. Nassir, Tabor, and Mexican-142 were latest at Turi, Yalo, and Wara, respectively. However, at all locations, Gofta was earliest to flower except at Yalo where Ibbado was earliest to flower (Table 6). [9] reported 61.67, 60.67, and 50.33 average days to 50% flowering for Awashmelka, Mexican-142, and Red Wolaita, respectively, whereas [3] reported 50, 49, and 49 days to 50% flowering for the same varieties, respectively.

Mean days to maturity of varieties ranged from 81.4 days for Omo-95 to 88.6 for GobeRasha (Table 6). Maturity periods of common bean genotypes in the ranges 66-90, and 85-106 days, respectively, were reported by [5, 18], respectively. Therefore, present finding was in line with these reports and the slight variation in ranges could be due to differences in environments and varieties included in the test set.

The higher yielding variety (GobeRasha) had taken significantly the longest average number of days to mature than all other varieties. Therefore, it is the latest maturing variety for the study areas and good for production in areas where rain falls for at least three months. This report matched with the report of [6]. White varieties, Mexican-142 and Awashmelka, had taken statistically similar average number of days to mature among each other, but above the grand mean. Thus, they are again late maturing varieties at test environments. This finding was similar with the findings reported by [3, 9]. Six varieties, Roba-1, Tabor, Dimitu, Nassir, Ibbado, and Hawassa dume, had also taken statistically similar number of days to mature among one another, but significantly different than others. It is similar report with the reports of [6, 15]. Variety Omo-95 had taken significantly the lower average number of days to mature than other varieties. Thus, it is an ideal early maturing variety for the study area and can be used in breeding for early maturity.

Performance of varieties for maturity period was not consistent with seed yield performance. Some high yielding varieties (GobeRasha and Zebra-90) matured late while other high yielding varieties (Ibbado and Hawassa dume) matured early. Again the low yielding variety (Mexican-142) matured late. Under optimal condition, [14] reported strong and positive correlation of seed filling period with seed yield performance. Thus, the present finding was not agreed with this report for some of the varieties. This complicated correlation between days to maturity and seed yield performance could be due to differential reaction of varieties to test environments.

When averaged over varieties, the longest average number of days to maturity was recorded at Gendo with highest elevation and cooler air temperature, but the shortest average number of days to maturity was recorded at Tarcha with higher elevation and warmer air temperature than Yalo (Tables 1 and 6). [14] Reported inverse relationship between seed filling period and air temperature in common bean. Thus, the present finding was in agreement with this report. The rankings of varieties were also changed for number of days to maturity performance across locations (Table 6). Mexican-142 was latest to mature at four locations (Tarcha, Yalo, Duga, and Wara) whereas GobeRasha was latest at three locations (Turi, Bero, and Gendo). Omo-95 was consistently earlier to mature at most locations. This rank change revealed differential reaction of varieties with locations for maturity period and emphasized importance of considering GLI while selecting for early or late maturity among the varieties.

Table 6. Mean number of days to 50% flowering and maturity of 14 common bean genotypes grown at seven locations of Dawro zone in the 2010 main cropping season

	Days to 50% flowering								Days to maturity							
Genotypes	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean
Gofta	39.3^{e}	39.0^{g}	38.3^{abc}	41.0^{h}	36.3^{f}	41.7^{c}	43.0^{f}	39.8^{g}	78.7^{g}	76.3^{de}	84.7^{abcd}	86.3^{e}	84.7^{de}	82.7^{bc}	86.3^{e}	82.8^{ef}
Goberasha	43.7^{cd}	41.3^{bcd}	37.0^{bc}	44.7^{cde}	39.7d^{e}	42.0^{c}	47.3^{d}	42.2^{de}	**88.7**^{a}	77.3^{bcd}	88.3^{ab}	91.3^{ab}	88.7^{b}	**87.0**^{a}	**98.7**^{a}	**88.6**^{a}
Beshbesh	56.0^{a}	42.3^{ab}	40.0^{ab}	48.0^{a}	39.0^{e}	42.3^{c}	50.7^{abc}	45.5^{bc}	80.0^{fg}	74.7^{ef}	83.3^{cd}	90.0^{bc}	82.7^{fg}	78.0^{f}	90.0^{d}	82.7^{f}
Zebra-90	45.3^{c}	40.3^{def}	37.7^{abc}	41.7^{gh}	40.0^{de}	44.0^{bc}	45.0^{e}	42.0^{de}	84.0^{c}	78.3^{bc}	**88.7**^{a}	86.7^{e}	86.3^{c}	81.0^{cde}	87.0^{e}	84.6^{c}
Mexican-142	48.3^{b}	40.7^{de}	40.3^{ab}	45.3^{bcd}	**46.3**^{a}	42.0^{c}	50.0^{bc}	44.7^{c}	83.3^{cd}	**81.0**^{a}	**88.7**^{a}	**92.7**^{a}	**90.7**^{a}	85.7^{a}	90.3^{cd}	87.5^{b}
Roba-1	54.0^{a}	41.0^{cde}	40.0^{ab}	46.3^{b}	42.7^{b}	44.0^{bc}	51.0^{abc}	45.6^{b}	81.3^{def}	71.3^{g}	80.3^{de}	90.3^{bc}	86.0^{cd}	81.7^{cd}	96.7^{b}	84.0^{cd}
A. melka-90	54.7^{a}	**42.7**^{a}	39.3^{abc}	**48.3**^{a}	45.3^{a}	**47.0**^{a}	**52.0**^{a}	**47.0**^{a}	86.7^{ab}	76.7^{cd}	86.7^{abc}	91.3^{ab}	87.3^{bc}	85.0^{ab}	96.0^{b}	87.1^{b}
Tabor	54.7^{a}	42.3^{ab}	**41.0**^{a}	46.0^{bc}	42.0^{bc}	46.0^{ab}	51.3^{ab}	46.2^{b}	80.3^{efg}	78.7^{b}	84.0^{bcd}	89.7^{bcd}	80.3^{h}	81.3^{cde}	91.0^{cd}	83.6^{de}
Dimitu	55.0^{a}	41.3^{bcd}	40.0^{ab}	46.0^{bc}	40.7^{cde}	46.0^{ab}	51.3^{ab}	45.8^{b}	80.0^{fg}	78.7^{b}	83.0^{cde}	88.0^{de}	84.0^{ef}	79.0^{ef}	97.0^{ab}	84.2^{cd}
Nassir	**56.7**^{a}	42.0^{abc}	39.7^{ab}	45.7^{bc}	41.0^{bcd}	46.0^{ab}	50.3^{abc}	45.9^{b}	82.7^{cde}	76.7^{cd}	83.3^{cd}	89.7^{bcd}	82.3^{g}	81.0^{cde}	92.0^{c}	84.0^{cd}
Red wolaita	45.0^{c}	40.7^{de}	38.0^{abc}	44.0^{def}	39.0^{e}	43.0^{c}	49.3^{c}	42.7^{de}	80.7^{efg}	73.0^{fg}	84.7^{abcd}	86.7^{e}	86.3^{c}	80.0^{def}	89.3^{d}	83.0^{ef}
Ibbado	41.3^{de}	39.0^{g}	36.0^{c}	41.7^{gh}	36.7^{f}	42.0^{c}	46.3^{de}	40.4^{f}	84.3^{bc}	75.7^{de}	78.7^{e}	86.3^{e}	82.3^{g}	86.3^{a}	90.3^{cd}	83.4^{de}
Omo-95	44.0^{cd}	40.0^{efg}	36.7^{bc}	42.7^{fg}	39.0^{e}	42.0^{c}	47.3^{d}	41.7^{e}	80.0^{fg}	73.0^{fg}	81.3^{de}	89.3^{cd}	82.0^{g}	78.3^{f}	86.0^{e}	81.4^{g}
Hawassa dume	43.7^{cd}	39.3^{fg}	36.7^{bc}	43.3^{ef}	40.3^{cde}	46.0^{ab}	50.0^{bc}	42.8^{d}	81.3^{def}	76.7^{cd}	86.0^{abc}	84.0^{f}	84.7^{de}	81.0^{cde}	90.3^{cd}	83.4^{de}
Grand mean	48.7^{a}	40.9^{d}	38.6^{e}	44.6^{b}	40.6^{d}	43.9^{c}	**48.9**^{a}	43.7	82.3^{d}	76.3^{e}	84.4^{c}	88.7^{b}	84.9^{c}	82.0^{d}	**91.5**^{a}	84.3
CV (%)	1.97	0.96	2.76	1.15	1.63	2.11	1.16	1.85	1	0.74	1.78	0.67	0.59	1.07	0.62	0.99
HSD(0.05)	2.89	1.18	1.54	1.54	1.99	2.79	1.7	0.85	2.48	1.7	1.8	1.8	1.5	2.64	1.7	0.88

Locations HSD (0.05) are 0.53 and 0.55 for days for flowering and maturity, respectively. Means followed by similar letters down columns and for grand mean across columns are not significantly different at the 0.05 probability level based on Turkey's Studentized Range (HSD) test. Bolded values are highest mean number of days to flowering and maturity at each test locations.

Plant height and primary branches per plant

Over all mean plant height of varieties was 76.3cm and mean height ranged from 91.9cm for Zebra-90 to 56.2cm f~~or Ibbado (Tab~~le 7). The reported height of common bean varieties ranging from 54.2cm -121cm, by [5] was in line with present finding. Overall locations' mean plant height averaged over varieties ranged from 91.8cm at Turi to 63cm at Bero. The shortest height for varieties observed at Bero was attributed to its infertile soils.

Varieties were grouped into three as with indeterminate prostrate (Gofta, Zebra-90, Mexican-142, Tabor and Omo-95), indeterminate bush (Beshbesh, Roba-1, Awashmelka, Dimitu, Nassir, Red Wolaita and Hawassa dume), and determinate bush (GobeRasha and Ibbado) growth habits for plant height performance with rank change across locations. This also indicated presence of cross over GLI for plant height performance.

The overall mean number of primary branches per plant was 2.7 and mean performance averaged over locations ranged from 3.0 for Roba-1 and Tabor to 2.3 for Gofta, Zebra-90, and Omo-95 (Table 7). The reported mean primary branches per plant performance of common bean genotypes in the range from 1.5 to 3.2 by [24] were similar to this report.

Varieties had produced maximum average number of primary branches per plant at high yielding location (Wara) and minimum at low yielding location (Bero) indicating good contribution of branching for seed yield performance. When averaged over locations, varieties evaluated were grouped into two categories for primary branch performance with rank change across locations (Table 7). This was similar performance with that of [9] except for Red Wolaita which branched more in this study.

Table 7. Mean pant height and number of primary branches per plant of 14 common bean varieties grown at seven locations of Dawro Zone in the 2010 main cropping season.

	Plant height (cm)								Primary branches per plant							
Genotypes	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean
Gofta	**118.3^{a}**	100.8^{ab}	76.2^{ab}	**85.3^{a}**	94.6^{ab}	75.5^{bc}	73.2^{ab}	89.1^{a}	2.1^{d}	2.7^{a}	2.8^{a}	1.5^{b}	2.7^{c}	2.2^{ab}	2.3^{a}	2.3^{dc}
Goberasha	64.5^{c}	70.5^{def}	56.2^{b}	39.6^{g}	77.0^{cd}	43.3^{gh}	58.6^{b}	58.5^{d}	4.0^{a}	2.8^{a}	**3.3^{a}**	2.4^{ab}	3.5^{abc}	2.3^{ab}	**2.9^{a}**	**3.0^{a}**
Beshbesh	87.0^{abc}	62.2^{ef}	76.9^{ab}	53.9^{ef}	91.3^{abc}	52.5^{fgh}	70.9^{ab}	70.7^{c}	3.4^{abc}	2.3^{a}	2.7^{a}	1.8^{ab}	3.2^{abc}	**2.5^{a}**	2.8^{a}	2.7^{abc}
Zebra-90	109.5^{ab}	99.7^{abc}	95.4^{a}	78.3^{ab}	94.3^{ab}	76.9^{abc}	**88.9^{a}**	**91.9^{a}**	2.3^{d}	2.7^{a}	3.2^{a}	1.5^{b}	2.9^{bc}	1.4^{c}	2.1^{a}	2.3^{d}
Mexican-142	106.8^{ab}	**105.3^{a}**	78.8^{ab}	79.0^{ab}	88.2^{abcd}	79.3^{ab}	78.0^{ab}	87.9^{a}	3.2^{abc}	2.9^{a}	2.8^{a}	2.3^{ab}	2.8^{bc}	2.4^{ab}	2.9^{a}	2.7^{ab}
Roba-1	92.6^{abc}	69.9^{def}	81.7^{ab}	48.7^{fg}	82.7^{bcd}	54.6^{efg}	62.6^{b}	70.4^{c}	**4.1^{a}**	3.3^{a}	3.0^{a}	2.3^{ab}	3.1^{abc}	2.4^{ab}	2.9^{a}	**3.0^{a}**
Awashmelka-90	95.0^{abc}	76.4^{bcde}	72.5^{ab}	63.5^{cde}	94.3^{ab}	67.6^{bcde}	72.5^{ab}	77.4^{bc}	3.4^{ab}	2.7^{a}	3.0^{a}	2.6^{ab}	3.2^{abc}	2.3^{ab}	2.5^{a}	2.8^{ab}
Tabor	108.1^{ab}	83.9^{abcde}	**98.9^{a}**	72.4^{abc}	**99.7^{a}**	69.9^{bcd}	83.2^{ab}	88.0^{a}	3.7^{a}	3.2^{a}	3.0^{a}	2.2^{ab}	**3.8^{a}**	2.4^{ab}	2.6^{a}	**3.0^{a}**
Dimitu	82.6^{bc}	70.0^{def}	81.2^{ab}	55.8^{ef}	90.3^{abc}	54.6^{efg}	70.4^{ab}	72.1^{c}	3.2^{abc}	3.1^{a}	2.6^{a}	2.0^{ab}	3.4^{abc}	2.1^{ab}	2.6^{a}	2.7^{ab}
Nassir	86.9^{abc}	78.7^{bcde}	81.0^{ab}	56.6^{def}	82.3^{bcd}	65.4^{cdef}	69.8^{ab}	74.4^{c}	3.5^{ab}	**3.4^{a}**	2.9^{a}	1.8^{ab}	3.2^{abc}	2.3^{ab}	2.7^{a}	2.8^{ab}
Red wolaita	93.3^{abc}	74.2^{cdef}	74.5^{ab}	69.4^{bcd}	78.3^{cd}	59.4^{def}	74.9^{ab}	74.9^{c}	3.6^{a}	3.2^{a}	3.0^{a}	2.2^{ab}	3.6^{abc}	2.2^{ab}	2.7^{a}	2.9^{a}
Ibbado	66.8^{c}	49.6^{f}	55.6^{b}	46.0^{fg}	76.7^{cd}	40.4^{h}	58.2^{b}	56.2^{d}	3.3^{abc}	2.5^{a}	3.2^{a}	**2.9^{a}**	3.3^{abc}	**2.5^{a}**	2.8^{a}	2.9^{a}
Omo-95	95.3^{abc}	93.7^{abcd}	88.1^{a}	85.1^{a}	74.8^{d}	**89.4^{a}**	69.9^{ab}	85.2^{ab}	2.5^{cd}	2.5^{a}	2.8^{a}	1.7^{ab}	2.7^{a}	1.7^{ab}	2.4^{a}	2.3^{dc}
Hawassa dume	78.0^{bc}	85.4^{abcde}	77.0^{ab}	59.1^{def}	86.5^{abcd}	53.4^{fgh}	62.3^{b}	71.7^{c}	2.7^{bcd}	2.5^{a}	3.2^{a}	1.7^{ab}	3.1^{abc}	1.9^{abc}	2.3^{a}	2.5^{bcd}
Grand mean	**91.8^{a}**	80.0^{c}	78.2^{c}	63.8^{e}	86.5^{b}	63.0^{e}	71.0^{d}	76.3	**3.2^{a}**	2.8^{c}	3.0^{bc}	2.1^{e}	3.2^{ab}	2.2^{e}	2.6^{d}	2.7
CV (%)	12.88	10.6	11.32	6.9	5.94	6.9	12.03	10.24	9.19	15.12	12.49	20.7	8.46	11.23	11.56	12.53
HSD(0.05)	35.56	25.51	13.24	13.24	15.46	13.08	25.68	8.20(5.08)	0.89	1.29	1.28	1.28	0.81	0.74	0.91	0.36(0.22

(5.08) and (0.22) are locations HSD values for plant height and number of primary branches per plant, respectively. Means followed by similar letters down columns and for grand mean across columns are not significantly different at the 0.05 probability level based on Turkey's Studentized Range (HSD) test. Bolded values are highest mean number of primary branches and height at each test locations.

Pods per plant and seeds per pod

When averaged over locations, number of pods per plant performance of varieties ranged from 17.3 for Beshbesh to 12.4 for GobeRasha with rank change across locations (Table 8). Number of pods per plant performance of common bean varieties in the range from 10.7 to 27.8 was reported by [25]. Thus, the present finding was in line with this report and the difference in the ranges might be due to the variation in environments and number and type of varieties evaluated. Varieties produced maximum number of pods per plant at high yielding location (Wara) and minimum number of pods at low yielding location (Bero) indicating that number of pods per plant is the main seed yield determining trait. Similar performance of common bean genotypes for number of pods per plant was reported by [3, 18, and 27].

The overall mean number of seeds per pod averaged over all varieties and locations was 5.7. The varietal mean number of seeds per pod averaged across locations ranged from 6.3 for formerly introduced variety (Red Wolaita) to 4.7 for GobeRasha again with rank change across locations revealing presence of GLI (Table 8). [3, 18, 24, 25] reported number of seeds per pod for common bean varieties in the ranges 6.5-1.8, 6.0-2.9, 6.0-3.3, and 5.5-4.7, respectively.

Table 8. Mean number of pods per plant and seeds per pod of 14 common bean genotypes grown at seven locations of Dawro Zone in the 2010 main cropping season.

	Number of pods per plant							Number of seeds /pod							
Genotypes	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean
Gofta	11.7^{bcd}	15.9^{abc}	10.5^{b}	13.7^{e}	11.1^{ab}	15.2^{ab}	13.1^{efg}	4.8^{cde}	5.3^{dc}	5.4^{bcd}	5.0^{bc}	5.4^{bcd}	5.7^{ab}	5.3^{bcd}	5.3^{f}
Goberasha	10.2^{cd}	14.6^{bc}	10.9^{b}	14.7^{de}	9.9^{ab}	13.3^{b}	12.4^{g}	4.1^{e}	4.8d^{e}	5.0^{cd}	4.8^{c}	4.9^{cd}	4.9^{bc}	4.8^{d}	4.7^{g}
Beshbesh	14.6^{bcd}	19.4^{a}	13.3^{ab}	**23.5^{a}**	13.5^{a}	**18.0^{a}**	**17.3^{a}**	**6.0^{a}**	6.2^{a}	6.0^{ab}	6.2^{a}	6.2^{ab}	**6.2^{a}**	6.1^{abc}	6.1^{a}
Zebra-90	13.4^{bcd}	**20.2^{a}**	13.5^{ab}	19.6^{abcd}	11.5^{ab}	15.0^{ab}	15.4^{bcd}	5.5^{abc}	5.6^{abc}	5.8^{abc}	5.8^{ab}	5.8^{ab}	5.9^{a}	5.8^{abcd}	5.7^{cd}
Mexican-142	13.5^{bcd}	13.8^{c}	12.5^{ab}	15.7^{bcde}	12.6^{ab}	15.0^{ab}	14.3^{def}	5.0^{cd}	5.5^{bcd}	5.5^{bcd}	5.5^{abc}	5.5^{bcd}	5.4^{abc}	5.5^{abcd}	5.4^{ef}
Roba-1	15.2^{abcd}	18.0^{abc}	13.6^{ab}	16.9^{bcde}	12.4^{ab}	17.0^{ab}	16.0^{abcd}	**6.0^{a}**	5.9^{abc}	6.2^{ab}	5.8^{ab}	6.2^{ab}	**6.2^{a}**	6.2^{ab}	6.1^{ab}
A. melka-90	13.8^{bcd}	19.1^{ab}	**14.6^{a}**	19.8^{abc}	12.7^{ab}	14.9^{ab}	16.5^{ab}	5.5^{abc}	5.6^{abc}	6.1^{ab}	6.1^{a}	5.7^{abc}	5.7^{ab}	5.8^{abc}	5.8^{bcd}
Tabor	16.6^{ab}	18.2^{abc}	13.7^{ab}	17.3^{bcde}	11.8^{ab}	15.1^{ab}	15.4^{bcd}	5.5^{abc}	**6.3^{a}**	6.0^{ab}	6.1^{a}	6.1^{ab}	6.1^{a}	6.2^{ab}	6.0^{abc}
Dimitu	16.3^{abc}	17.7^{abc}	12.2^{ab}	19.4^{abcd}	12.2^{ab}	16.6^{ab}	15.4^{bcd}	5.0^{cd}	5.8^{abc}	6.2^{ab}	6.1^{a}	5.4^{bcd}	5.5^{abc}	5.6^{abcd}	5.7^{de}
Nassir	**20.9^{a}**	19.2^{ab}	12.7^{ab}	20.3^{ab}	12.7^{ab}	15.8^{ab}	17.0^{ab}	5.3^{abc}	5.9^{abc}	6.0^{ab}	5.9^{ab}	4.7^{d}	5.6^{abc}	5.8^{abcd}	5.6^{de}
Red wolaita	17.0^{ab}	17.3^{abc}	15.0^{ab}	19.1^{abcd}	**13.6^{a}**	17.0^{ab}	16.4^{abc}	5.9^{a}	6.2^{ab}	**6.6^{a}**	**6.4^{a}**	6.3^{a}	**6.2^{a}**	**6.3^{a}**	**6.3^{a}**
Ibbado	9.6^{d}	15.9^{abc}	11.8^{ab}	15.4^{bcde}	9.6^{ab}	13.9^{ab}	12.7^{fg}	4.5^{cd}	4.5^{e}	4.9^{d}	6.1^{a}	4.7^{d}	4.7^{c}	5.1^{cd}	4.9^{g}
Omo-95	13.7^{bcd}	18.3^{abc}	13.2^{ab}	15.3^{cde}	12.2^{b}	15.5^{ab}	14.7^{cde}	5.9^{ab}	**6.3^{a}**	6.2^{ab}	6.3^{a}	**6.4^{a}**	5.9^{a}	5.9^{abc}	6.1^{a}
H. dume	10.9^{bcd}	19.1^{ab}	13.0^{ab}	18.6^{abcde}	9.9^{b}	14.1^{ab}	14.7^{cde}	5.1^{bcd}	6.0^{ab}	5.9^{ab}	5.6^{abc}	5.9^{ab}	5.8^{ab}	5.9^{abc}	5.8^{cd}
Grand mean	14.1^{c}	17.6^{a}	12.9^{d}	**17.8^{a}**	11.8^{d}	15.5^{b}	15.1	5.3^{b}	5.7^{a}	**5.8^{a}**	**5.8^{a}**	5.6^{a}	5.7^{a}	5.7^{a}	5.7
CV (%)	14.79	8.84	8.36	9.22	10.27	9.08	11.14	5.08	4.3	5.06	5.77	4.87	5.34	5.98	5.24
HSD(0.05)	6.27	3.24	3.24	4.94	3.66	4.22	1.76(1.09)	0.81	0.74	1.01	1.01	0.83	0.92	1.03	0.31(0.19)

(1.09) and (0.19) are locations HSD values for number of pods per plant and number of seeds per pod, respectively. Means followed by similar letters down columns and for grand mean across columns are not significantly different at the 0.05 probability level based on Turkey's Studentized Range (HSD) test. Bolded values are highest mean number of primary branches and height at each test location.

Hundred seeds weight

The overall mean hundred seeds weight performance of varieties was 22. 09gm. The varieties mean performance averaged across locations ranged from 45.85gm for variety Ibbado to 13.24gm for variety Mexican-142 (Table 9). [9, 18, 25] reported hundred seeds weight performance of common bean varieties in the ranges 13.8-55gm, 17.6-46.7gm, and 20-51gm, respectively.

The 100 seeds weight performance of varieties was different across locations with mean locations' performance of 22.21gm, 25.11gm, 24.34gm, 24.23gm, 22.18gm, 22.95gm, and 22.09gm, respectively, for locations Turi, Tarcha, Yalo, Duga, Wara, Bero, and Gendo without rank change (Table 9). Large sized varieties were heaviest, medium sized varieties were heavier, and small sized varieties were the lightest in all test locations, but there is change in magnitude of weights. This revealed presence of non crossover GLI. This was similar with the findings reported by [9].

Table 9. Mean hundred seeds weight (gm) of 14 common bean genotypes grown at seven locations of Dawro Zone in the 2010 main cropping season.

	Locations							
Genotypes	Turi	Tarcha	Yalo	Duga	Wara	Bero	Gendo	Mean
Gofta	26.22^{b}	31.2^{c}	29.16^{c}	31.64^{b}	25.6^{c}	30.59^{b}	26.81^{c}	26.81^{c}
Goberasha	45.17^{a}	39.86^{b}	41.75^{b}	45.38^{a}	36.86^{b}	39.13^{a}	42.77^{b}	42.77^{b}
Beshbesh	15.62^{fgh}	18.81^{def}	18.44^{ef}	18.86^{de}	15.94^{fg}	17.82^{ef}	15.11^{ghi}	15.11^{g}
Zebra-90	26.41^{b}	29.39^{c}	26.94^{cd}	27.35^{c}	25.11^{c}	24.72^{c}	26.12^{i}	26.12^{d}
Mexican-142	12.67^{h}	15.02^{f}	13.77^{g}	14.44^{f}	12.95^{h}	13.86^{g}	13.24^{c}	13.24^{h}
Roba-1	15.27^{gh}	18.48^{ef}	18.33^{f}	17.98^{ef}	15.34^{gh}	16.51^{fg}	14.67^{hi}	14.67^{g}
A. melka-90	15.87^{efgh}	19.04^{def}	17.85^{f}	18.26^{ef}	16.52^{efg}	16.82^{efg}	15.85^{fgh}	15.85^{g}
Tabor	17.76^{defg}	22.04^{de}	20.55^{ef}	19.56^{de}	18.48^{def}	19.58^{def}	17.48^{ef}	17.48^{f}
Dimitu	21.6^{c}	21.41^{de}	21.2^{e}	18.55^{de}	19d^{e}	19.71^{def}	17.74^{ef}	17.74^{f}
Nassir	21.17^{cd}	22.95^{d}	19.64^{ef}	19.51^{de}	19.42^{d}	20.22^{de}	16.91^{efg}	16.91^{f}
Red wolaita	19.31^{cde}	21.89^{de}	20.54^{ef}	19.75^{de}	19.38^{d}	19.09^{def}	17.74^{ef}	17.74^{f}
Ibbado	**47.98^{a}**	**45.36^{a}**	**48.47^{a}**	**46.73^{a}**	**45.76^{a}**	**41.84^{a}**	**45.85^{a}**	**45.85^{a}**
Omo-95	18.99^{cdef}	22.92^{d}	19.58^{ef}	18.88^{de}	19.43^{d}	19.44^{def}	18.84^{de}	18.84^{f}
Hawassa dume	20.91^{cd}	23.08^{d}	24.58^{d}	22.36^{d}	20.74^{d}	22^{cd}	20.15^{d}	20.15^{e}
Mean	23.21^{c}	**25.105^{a}**	24.344^{b}	24.232^{b}	22.18^{d}	22.952^{c}	22.091^{e}	22.09
CV (%)	5.25	5.67	3.87	5.58	3.98	5.33	3.25	4.84
HSD(0.05	36.4	42.82	40.64	40.64	26.56	36.81	21.64	11.91(7.38)

(7.38) = HSD value for location means. Means followed by similar letters down columns and for grand mean across columns are not significantly different at the 0.05 probability level based on Turkey's Studentized

Range (HSD) test. Bolded values are highest mean number of primary branches and height at each test location.

Stability Analysis

AMMI biplots are recently preferred biplots to show adaptability and stability of genotypes over test environments (11-13). Thus, in AMMI 1 biplot, Figure 1, G6, G2, G10, G4, and G13 placed relatively close to zero IPCA1 score line and performed above the overall mean were generally adapted to all environments. This is because in AMMI1 biplot, the genotypes with IPCA1 scores close to zero express general adaptation and the larger scores depict more specific adaptation in combination with environments of the same sign IPCA1 scores [8]. Considering specific adaptability, in all locations, no variety had performed better than the broadly adapted varieties (Table 10). This indicated that it is rewarding to cultivate broadly adapted varieties in the Zone without considering replication of the experiment over years. Therefore, farmers in the Zone could cultivate broadly adapted and high seed yielding varieties, Roba-1, GobeRasha, Nasir, Zebra-90, and Omo-95.

Considering locations, Wara, Yalo, and Tarcha exhibited high seed yield performance (Fig. 1). Thus, they are ideal locations for commercial production of common bean varieties broadly adapted to them. Being placed left of the grand mean, Bero, Turi, Duga, and Gendo were low seed yield potential locations.

Table 10. The first four AMMI model selections per location of 14 common bean varieties evaluated for seed yield performance at seven locations of Dawro Zone in the 2010 main cropping season.

No.	Location	Mean	Absolute IPCA 1 Score value	Priority 1st	2nd	3rd	4th
1	Bero	1609	17.61	G4	G13	G1	G6
4	Tarcha	2312	14.04	G4	G11	G10	G3
2	Duga	1878	8.22	G4	G13	G2	G6
5	Turi	1691	1.93	G4	G2	G14	G12
3	Gendo	2048	2.09	G4	G3	G6	G10
7	Yalo	2547	10.17	G2	G13	G12	G14
6	Wara	2699	29.54	G4	G3	G14	G12

IPCA 1 = Interaction principal component axis 1.

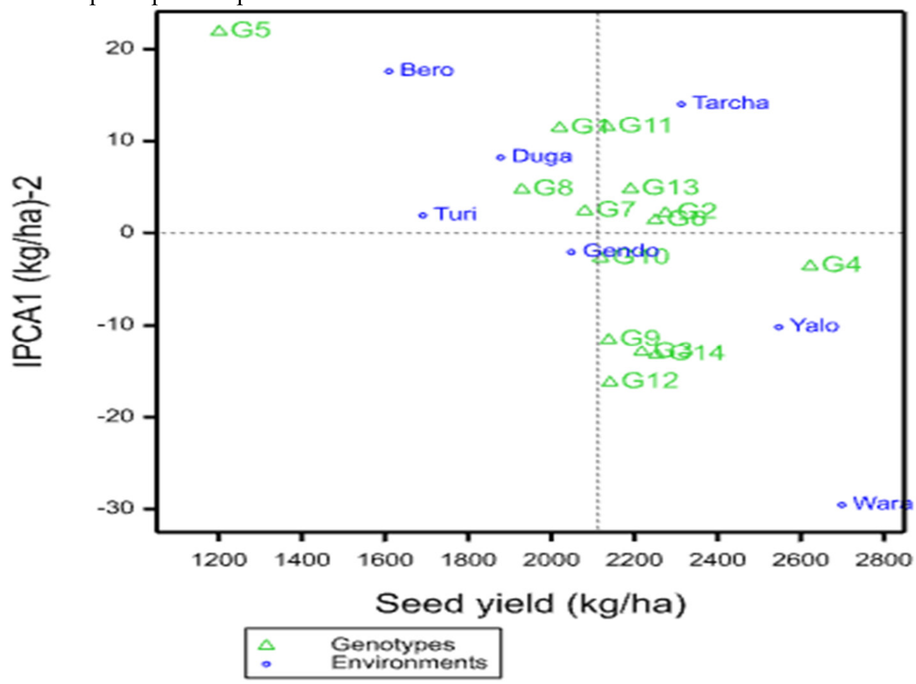

Figure 1. AMMI 1 biplot showing mean seed yield performance and adaptability of varieties over locations

CONCLUSION

The common bean varieties evaluated were highly significantly different for seed yield and its related traits performance. Their seed yield performance of varieties' ranged from 2622.3 kg/ha to 1200.8 kg/ha. Higher seed yielding varieties were earlier to flower, but latest to mature. Longer plant height and higher number of primary branches per plant, pods per plant, and seeds per pod had better contributed to higher seed yield performance. Occurrence of significant GLI complicated selection of higher seed yielding and broadly adapted varieties

AMMI 1 biplot enabled identification of higher seed yielding and broadly adapted varieties, Zebra-90, Roba-1, GobeRasha, Nasir, and Omo-95. Locations, Wara, Yalo, and Tarcha exhibited high seed yield performance and thus, they are ideal locations for commercial production of common bean varieties broadly adapted to them. As at all locations, no variety had performed specifically better than the broadly adapted varieties, it is unnecessary to replicate the experiment over years and farmers in the Zone should cultivate high seed yielding and broadly adapted varieties, Zebra-90, Roba-1, GobeRasha, Nasir, and Omo-95. As a result of this recommendation, now Nasir, which has similar seed color with the old and low seed yielding cultivar in the Zone, Red wolaita, has got wider acceptance and at popular production in the Zone.

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