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Grouping of Environments for Testing Navy Bean in Ethiopia

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በተለያዩ የቦሎቄ አብቃይ አካባቢዎች በወጥነት ከፍተኛ ምርት የሚሰጡ የቦሎቄ ዝርያዎችን ለመምረጥ በ14 ነጭና ድቡልቡል የዘር ቅርፅ ያላቸው የቦሎቄ ዝርያዎች ላይ ሙከራ ተካሂዷል፡፡ ሙከራው የተሰራው እ.ኤ.አ. በ2010 እና 2011 የሰብል ዘመን በመልካሳ፣ ዓለም ጤና፣ ሀሮማያ፣ ሲሪንቃ፣ ጅማ፣ ፓዌ፣ አረካና አሶሳ ምርምር ማዕከላት ነበር፡፡ ዝርያዎችን እርስ በእርስ በማወዳደር ሂደት የከባቢ ሁኔታዎች ተፅዕኖ ከፍተኛ ሆኖ በሚገኝበት ጊዜ የመረጣ ሥራውን አዳጋች እንዲሆን ያደርገዋል፡፡ የከባቢ ሁኔታዎችና የሰብል ዝርያዎች መስተጋብር ከፍተኛ ሆኖ የዝርያ መረጣን በሚያውክበት ጊዜ ከሚወሰዱት የመፍትሄ አማራጮች አንዱ በአፈር እና አየር ንብረት ሁኔታቸው ተመሳሳይነት ያላቸውን አካባቢዎች አንድ ላይ በመመደብ፤ ለየምድቡ ምርታማ የሆነ ዝርያን መምረጥ ነው፡፡ በከባቢ ሁኔታቸው ተመሳሳይነት መሰረት የመልካሳ፣ ዓለም ጤና፣ ሀሮማያና፣ ሲሪንቃ ምርምር ጣቢያዎች በአንድ ምድብ ሲመደቡ፤ የባኮ፣ ፓዌና አሶሳ ጣቢያዎች ደግሞ በሌላ ምድብ ተደልድለዋል፡፡ በፍተሻ ላይ ለነበሩት ነጭ የቦሎቄ ዝርያዎች ፍፁም የተለየ ከባቢ ሁኔታ ያለው የጅማ ምርምር ጣቢያ ነው፡፡ በምርታማነት ላይ የተሰራው ስታትስቲካዊ የመረጃ ትንተና እንዳሳየው በ14ቱ ተወዳዳሪ ዝርያዎችና አወዳዳሪ ማነፃፀሪያ መካከል ከፍተኛ ተለያይነት መኖሩ ተረጋግጧል፡፡ ወጥነት ባለው ሁኔታ በአማካይ ከፍተኛ ምርት (23.35 ኩንታል በሄክታር) የሰጠው ዝርያ ICA BUNSI X SXB 405/1C-C1-1C-87 ሲሆን ቀጥሎ ምርታማ የነበረው ICA BUNSI X SXB 405/1C-C1-1C-37 የተባለው ዝርያ ነው፡፡ እነዚህ ዝርያዎች ለዝርያ ማረጋገጫ ቀርበው በተደረገው ግምገማ መሰረት ICA BUNSI X SXB 405/1C-C1-1C-87 በድጋሜ ምርታማነቱን በማረጋገጡና የአርሶ አደሩን የምርጫ መስፈርት አሟልቶ በመገኘቱ አዋሽ 2 የሚባል አገራዊ ስያሜ ተሰጥቶት እንዲለቀቅ ተደርጓል፡፡

Abstract

Common bean variety selection within its production environment is often challenged by the occurrence of significant genotype-by-environment interactions (GEI) in the variety development process. Grain yield performance of 16 navy bean (Phaseolus vulgaris L.) lines was tested in a multi-environment variety trial during 2010 and 2011 main growing seasons of Ethiopia. Field experiments were conducted in Randomized Complete Block Design (RCBD) with three replications in 14 rainfed environments of the major common bean growing areas. The objectives were to assess the line by environment interactions (LEI), determine stable genotypes, and grouping of test environments. Significant differences were found among the lines for grain yield on each environment and combined over environments. The combined analysis of variance across environments indicated that both environment and LE interactions were significantly influenced lines yield. All interactions in relation to L×E showed high significant difference (P<0.01) for grain yield. Statistical methods as AMMI, GGE and some stability *parameters were used to describe the LE interaction and to define stable lines in relation to their yield. The highest yield (2435 kg ha^{-1}) was obtained from the line ICA BUNSI X SXB 405/1C-C1-1C-87. The stability analysis also identified lines ICA BUNSI X SXB 405/1C-C1-1C-87 and ICA BUNSI X SXB 405/1C-C1-1C-37 as the most stable lines. Lines identified as superior differed significantly from the standard varieties and can be recommended for use by farmers in the bean growing areas of Ethiopia. Cluster analysis, based on grouping of locations showed that Melkassa, Alemtena and Haramaya as potential and high yielding, but Jimma, Bako, Pawe, Areka, Assosa and Sirinka as low to medium yielding locations.*

Introduction

Common bean is one of the grain legume crops grown in Ethiopia and is being produced on about *3.4* hundred thousand hectares. It is highly produced from lowland to highland areas and also in the warm humid and sub-humid lowlands. The average total crop production per annum is about 2.5 million metric tons. Navy beans are mainly produced for export market and other market class types, as small reds used for local market and human consumption, mainly as cooked grain, or milled for sauce preparation to be eaten with Enjera (Teshale *et al.*, 2008).

The soil and climatic conditions where beans are growing vary in extremes. The considerable variation in soil and climate has resulted in significant variation in annual yield performance of bean cultivars. The environmental variation affects breeding program as selection of genotypes with improved yield performance and yield stability are based on data generated over a number of environments and years (Teshale *et al.*, 2008). Genotype x environment interaction (GEI), which is associated with the differential performance of genetic materials, tested at different locations and in different years and its influence on the selection and recommendation of genotypes has long been recognized (Lin *et al* 1986, Becker and Leon 1988, Crossa 1990).

A number of parametric and non-parametric statistical procedures have been developed over the years to analyze genotype x environment interaction and especially yield stability over environments. Lin *et al* (1986); Becker and Leon (1988), Zobel *et al* (1986), Crossa (1990) and Huhls (1995) discussed a wide range of methods available for the analysis of GEI and stability. Statistical methods as AMMI (additive main effects and multiplicative interaction) (Gauch, 2006 and Girma Taye *et al.*, 2000) and GGE-biplot (Yan *et al.*, 2000) have been used to analyze the MET data to reveal patterns of GEI. These methods partition the overall variation into G, E and GEI components. GGE-biplot analysis also allowed visual examination of the relationships among the test environments, genotypes and the GEI. The results can be graphically represented in an easily interpretable and informative biplot that shows both main effects and GEI.

AMMI and GGE-biplot model have been used extensively with great success over the past years to analyze and understand genotype x environment interaction in various crops. (Crossa 1990, Gauch & Zobel 1996, Gauch 2006). Therefore, the objectives of this study were: (i) to evaluate navy bean lines (mean performance and stability) under different growing conditions to identify superior lines, (ii) to evaluate the relationships among testing environments, and (iii) to group test locations into mega-environments.

Materials and Methods

The trial was carried out during the main cropping seasons of 2010 and 2011 in nine locations (Melkassa, Alemtena, Areka, Haramaya, Jimma, Bako, Pawe, Sirinka and Assossa), which have diverse agro-ecological characteristics such as annual rainfall, temperature and altitude as indicated in Table 1.

Table 1. Descriptive information of the environments with their codes and climatic characteristics

Environment code*	Description	Altitude (m)	Growing season temperature (^{0}C)		Growing season rainfall (mm)	Soil type
			Mean Min	Mean Max		
E1	Melkassa in 2010	1550	14.6	28	728.6	Andosol
E2	Melkassa in 2011	1550	13.8	28.6	810.1	Andosol
E3	Alemtena in 2010	1700	12.9	29.8	728	Andosol
E4	Alemtena in 2011	1700	13.1	30	788	Andosol
E5	Jimma in 2010	1750	11.5	26.3	1576	Nitosol
E6	Jimma in 2011	1750	10.5	26.1	1510	Nitosol
E7	Pawe in 2010	1120	18.8	30.8	1685.1	Nitosol
E8	Pawe in 2011	1120	17.1	32.7	1743.2	Nitosol
E9	Sirinka in 2010	1850	13.3	26.5	1185.6	Vertisol
E10	Sirinka in 2011	1850	13.4	26.4	815.2	Vertisol
E11	Areka in 2011	1800	15.3	28.1	1635	Nitosol
E12	Bako in 2011	1620	13.5	27.3	1413.9	Nitosol
E13	Assossa in 2011	1600	16.5	31	1567	Nitosol
E14	Haramaya in 2011	2050	8.1	24.5	1002	Fluvisol

* Environment here indicates location by year combination

Sixteen navy bean lines including two released varieties were used in this study. The lines were developed from our crossing program and passed a series of selection procedures to be taken as unique uniform lines. The 16 lines were coded as a sequence of the numbers 1 to 16. Description on the codes is given in Table 2. A randomized complete block design with three replications was used at each location. Each plot consisted of 6 rows of 4m long with total area of 9.6 square meters. The rows in each plot were spaced 40 cm and spacing among bean plants within the row was 10 cm. Recommended agronomic and cultural practices were kept and non-experimental variable applied to all plots. Data were collected from central four rows (6.4 square meters area) as grain yield per plot from which grain yield per hectare was adjusted to 14% moisture content.

Table 2. Descriptive information on the name and codes of the 16 navy bean lines

Line Code**	Line Name
L1	ICA Bunsi x S x B 405/1C-C1-1C-1
L2	ICA Bunsi x S x B 405/1C-C1-1C-3
L3	ICA Bunsi x S x B 405/1C-C1-1C-13
L4	ICA Bunsi x S x B 405/1C-C1-1C-14
L5	ICA Bunsi x S x B 405/1C-C1-1C-23
L6	ICA Bunsi x S x B 405/1C-C1-1C-30
L7	ICA Bunsi x S x B 405/1C-C1-1C-37
L8	ICA Bunsi x S x B 405/1C-C1-1C-51
L9	ICA Bunsi x S x B 405/1C-C1-1C-58
L10	ICA Bunsi x S x B 405/1C-C1-1C-69
L11	ICA Bunsi x S x B 405/1C-C1-1C-70
L12	ICA Bunsi x S x B 405/1C-C1-1C-80
L13	ICA Bunsi x S x B 405/1C-C1-1C-87
L14	ICA Bunsi x S x B 405/1C-C1-1C-88
L15	Awash - 1
L16	Awash Melka

** Represent varieties

Statistical analyses: Before conducting combined analyses of variance and AMMI analysis, the data were subjected to the logarithmic and square root transformations to fix failures of assumptions of ANOVA such as normality and homogeneity of error variances among the different environments. Bartlett's (1974) test was used to determine the homogeneity of variances between environments to determine the validity of the combined analysis of variance on the data. After the transformation, it was found that square root transformation fixes the problem of the assumption of homogeneity of variance reasonably.

The grain yield data were subjected to AMMI and SREG model analysis using GenStat statistical package (GenStat 15th Ed, 2013). In the analysis, a total of fourteen environments, a combination of location by growing season was treated as an environment.

The AMMI model used for the data was:

$$\bar{y}_{ij.} = \mu + \tau_i + \delta_j + \sum_{k=1}^{t} \lambda_k \alpha_{ik} \gamma_{jk} + \bar{\varepsilon}_{ij.}$$

And the SREG linear – bilinear model was:

$$\bar{y}_{ij.} = \mu + \delta_j + \sum_{k=1}^{t} \lambda_k \alpha_{ik} \gamma_{jk} + \bar{\varepsilon}_{ij.}$$

Where; $\bar{y}_{ij.}$ is the mean of ith genotype in the jth environments; μ is the overall mean; τ_i is the genotypic effect; δ_j is the environment effect; λ_k $(\lambda_1 \geq \lambda_2 \geq \cdots \lambda_t)$ are scaling constants (singular values) that allow the imposition of orthonormality constraints on the singular vectors for the genotypes, $\alpha_{ik} = (\alpha_{1k}, \ldots, \alpha_{gk})$ and environments, $\gamma_{jk} = (\gamma_{1k}, \ldots, \gamma_{ek})$, such that $\sum_i \alpha_{ik}^2 = \sum_j \gamma_{jk}^2 = 1$ and

$\sum_i \alpha_{ik}\alpha_{ik'} = \sum_j \gamma_{jk}\gamma_{jk'} = 0$ for k≠k; α_{ik} and γ_{jk} for k = 1,2,3, …, are called "primary", "secondary", "tertiary", . . . etc effects of genotypes and environments, respectively; $\bar{\varepsilon}_{ij.}$ is the residual error assumed to be normally and independently distributed (0 , σ^2/r) (where σ^2 is the pooled error variance and r is the number of replicates). List squares estimates of the multiplicative (bilinear) parameters in the kth bilinear term are obtained as the kth component of the deviations from the additive (linear) part of the model. In the AMMI model, only the GEI term is absorbed in the bilinear terms; whereas in the SREG model, the main effects of genotypes (G) plus the GEI are absorbed in the bilinear terms.

The results of the AMMI model analysis were interpreted on the basis of two AMMI graphs: (a) the graph that showed the main and first multiplicative term (PC1) of both genotypes and environments; and (b) the biplot that used scores of environments and genotypes PC1 against scores of environments and genotypes of the second multiplicative axis term (PC2). The GGE biplots were constructed from the first two principal components (PC1 and PC2) derived by subjecting the environment centered yield data (which contains G and GE) to singular valued composition (SVD) (Yan, 2002 and Yan et al., 2000). GGE biplots were used to: (a) understand the existence of mega-environments (defined as a group of locations that consistently share the best set of genotypes over years (Yan and Rajcan, 2002), (b) relationships between testing environments based on the angels between the vectors of the environments, (c) ranking of genotypes on the basis of yield and stability.

The parametric and univariate non-parametric stability statistics for grain yield were computed by GenStat statistical package (GenStat 15th Ed, 2013). Of the parametric stability estimates, cultivar superiority measure (Pi) of Lin and Binns (1988a) was used. Pi associates stability and productivity and defines a superior genotype as the one with near the maximum in various environments. The smaller the Pi estimate, the more superior the new genotype is.

Among the univariate non-parametric stability statistics rank-based stability parameters Si^2, Si^3, Si^6 of Nassar and Huhn (1987) were computed. Non-parametric measures for stability are handy for breeders because they are rank based on absolute data and free from stringent statistical assumptions. The non-parametric $Si^{(2)}$ statistics measures the variance among the ranks over environments. $Si^{(3)}$ and $Si^{(6)}$ represent mean rank of each genotype. The lowest value for each of the statistics represents high stability (Flores *et al.*, 1998; Asrat *et al.,* 2009).

The AMMI Stability Value (ASV) described by Purchase (1997) was use to further investigate the stability of the varieties. The AMMI model does not make provision for a quantitative stability measure, such a measure is essential in order to quantify and rank genotypes according to their yield stability. The following measure was proposed by Purchase (1997):

AMMI Stability Value (ASV) $= \sqrt{\left[\frac{IPCA1SumofSquares}{IPCA2SumofSquares}(IPCA1score)\right]^2 + \left[IPCA2score\right]^2}$

In effect the ASV is the distance from zero in a two dimensional scatter gram of IPCA 1 scores against IPCA 2 scores. Since the IPCA 1 score contributes more to G x E sum of squares, it has to be weighted by the proportional difference between IPCA 1 and IPCA 2 scores to compensate for the relative contribution of IPCA 1 and IPCA 2 to the total G x E sum of squares.

Results and discussion

Mean yield performance: The relative performance of lines based on the mean grain yield over years and locations is presented in Table 3. The general mean yield in the tests ranged from 700 $kgha^{-1}$ to 4278 $kgha^{-1}$, indicating rather divergent conditions for the lines, due to geographical differences between the sites of evaluation (Table 1). In the combined analysis, all effects were significant, indicating the presence of variability among lines, environments and also a differential response of lines to environments (Table 4). In terms of mean yield of lines, line 13 and line7 were the most productive, followed by line12 and line8 (Table 3). As indicated in table 3 one of the standard checks, Awash-1 was the least performer.

Table 3. Mean yield performance (kg ha^{-1}) of 16 navy bean lines evaluated at 14 environments for the two periods, 2010 and 2011

Lines	**Environments**														**Mean**
	MK10	**MK11**	**AT10**	**AT11**	**JM10**	**JM11**	**PW10**	**PW11**	**SK10**	**SK11**	**AK11**	**BK11**	**AS11**	**HM11**	
Line1	3283	3286	2732	1851	2019	2665	780	1415	1345	1479	1030	1425	2324	3029	**2047**
Line2	3106	3360	2430	1930	2357	2961	784	1289	1324	1473	1014	1470	2134	3300	**2067**
Line3	2572	3857	2668	1369	2373	3249	700	1211	1232	1221	1086	1500	2343	2859	**2017**
Line4	3108	4278	3061	2181	1347	2180	984	1500	1568	1733	1321	1444	2237	3199	**2153**
Line5	3280	3528	2249	1790	2387	3220	1043	1649	1545	1896	1291	1234	2115	2865	**2149**
Line6	3426	3372	2750	2130	1741	2348	849	1460	1426	1630	1070	1387	2212	3191	**2071**
Line7	3152	4100	2346	2714	2323	2874	1106	1355	1638	1904	1298	1657	1853	4134	**2318**
Line8	3135	4107	2901	2497	1516	2140	924	1323	1514	1661	1190	1567	2076	3699	**2161**
Line9	3197	3405	3005	1806	2108	2744	747	1372	1327	1331	1036	1622	2535	3114	**2096**
Line10	2683	4067	2216	1944	2179	2983	873	1218	1386	1606	1171	1343	1826	3324	**2059**
Line11	3476	3713	2704	1977	1593	2457	1068	1756	1618	1972	1339	1177	2212	2758	**2130**
Line12	3183	3414	2380	1834	2739	3420	931	1469	1445	1630	1171	1522	2263	3212	**2187**
Line13	3328	4125	2972	2402	2376	3043	1167	1614	1723	1845	1441	1852	2461	3741	**2435**
Line14	2938	3637	2765	1609	2201	2983	769	1349	1319	1371	1098	1492	2386	2935	**2061**
Awash-1	2372	4222	1643	1590	2101	3151	883	1213	1343	1750	1213	899	1425	2820	**1902**
A/melka	3223	3904	2512	2512	1549	2174	957	1362	1521	1821	1170	1346	1826	3603	**2106**
Mean	**3091**	**3773**	**2583**	**2009**	**2057**	**2787**	**910**	**1410**	**1455**	**1645**	**1184**	**1434**	**2139**	**3236**	**2122**

AMMI analysis: The combined analysis of variance (ANOVA) of the 16 navy bean lines over the 14 environments is presented in Table 4. AMMI model was used as it gave the best fit for this data set. The ANOVA indicated highly significant differences (*P<0.01*) for environments, lines and line by environment interaction for grain yield data. The IPCA 1 and IPCA 2 axes were also highly significant (*P<0.01*) (Table 4). Variance components of the sum of squares, ranged from 1.79% for lines, 87.98% for environments and 10.23% for LEI. This indicated the overwhelming influence that environments have on the yield performance of navy bean lines in Ethiopia. The importance of the environment component comes from climatic and biological factors as rainfall, temperature, altitude and disease incidence which can result in conditions unique to each year by location combination and that the bean lines respond differently to these conditions. It is important that the L x E variation is five times the variation of lines as main effect (Gauch, 2006 and Girma Taye *et al.*, 2000). The IPCA 1 and IPCA 2 axes explained 39.32% and 24.53% of the total interaction term, respectively.

Table 4. AMMI ANOVA of grain yield for 16 navy bean lines at fourteen environments during 2010 – 2011 main crop seasons

Sources of Variation	Degree of freedom	Sum of Squares	Mean Squares	F value	Explained percent of GEI SS
Treatment	223	522867290	2344696	16.96**	
Environments	13	460020679	35386206	80.88**	
Reps within Environment	28	12250577	437521	3.16**	
Line	15	9379070	625271	4.52**	
Variety x Environment	195	53467541	274193	1.98**	
Interaction PCA 1	27	21025671	1060538	5.63**	39.32
Interaction PCA 2	25	13113741	773422	3.79**	24.53
Residuals	143	19328128	135162	0.98^{ns}	36.15
Pooled error	420	58068413	138258		9.79

** - stands for 1 probability levels; ns – non significant

AMMI biplot*:* Figure 1 is AMMI biplot where lines and environments are depicted as points on a plane. The abscissa showed the main effects and the ordinate showed the first multiplicative axis term (IPCA1). The horizontal line showed the interaction score of zero and the vertical line indicated the grand mean yield. Displacement along the vertical axis indicated interaction differences between lines and between environments, and displacement along the horizontal axis indicated difference in line and environment main effects. The lines with IPCA1 scores close to zero expressed general adaptation whereas the larger scores indicated more specific adaptation to environments with IPCA1 scores of the same sign (Gauch, 2006). The IPCA scores of a line in the AMMI analysis are an indication of adaptation over environments. The greater the IPCA scores, negative or positive, the more specifically adapted is a line to certain environments. The more the IPCA scores approximate to zero, the more adapted the line is over all the environments sampled.

Looking at the environments it is clear that there is significant variation in the different environments sampled, they are spread from the lower yielding environments in quadrants I and IV to the high yielding environments in quadrants II and III (Figure 1). Most of the higher yielding environments are in quadrants II and III. The high yielding environments are Melkassa and Alemtena, in the Central Rift Valley areas and Haramaya in the eastern zone. Pawe, Bako, Areka and Sirinka are lower yielding environments. Sites representing the south and north-western locations, Jimma and Assossa, respectively were the moderate yielding sites. The lines showed considerably less variation around the mean yield of 2122 kg ha^{-1} than the environments. Line 13 and line 7 are adapted to almost all environments (Figure 1). Considering only the IPCA 1 scores line 4, line 8, line 12 and the check Awash Melka were the most unstable lines, and also adapted to the higher yielding or more favorable environments.

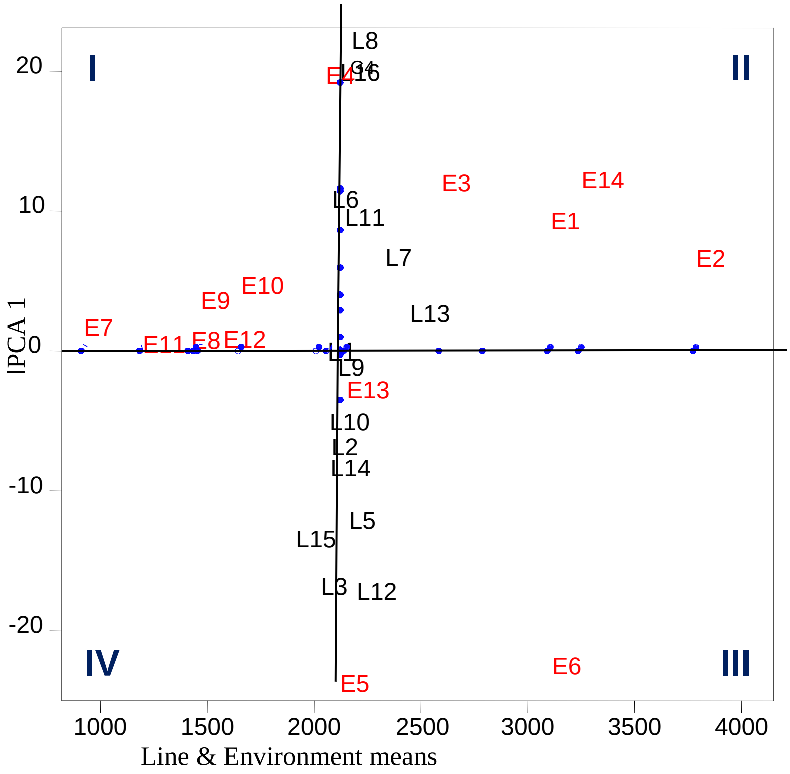

Figure 1. IPCA 1 scores for both genotypes and environments plotted against the mean yield for genotypes and environments.

Figure 2 cross-validated the interaction pattern of the 16 bean lines with 14 test environments. The distances from the origin (0,0) are indicative of the amount of interaction that was exhibited by bean lines either over environments or environments over lines. Among environments Melkassa and Alem tena locations in both years (2010 and 2011) Haramaya University in 2011 had higher values for both IPCA's, depicting high discrimination power and strong role of these locations for the GEI. Similarly, bean lines such as L6, L7, L11 and the check variety Awash melka were also plotted close to these environments (Figure 2) had high values of IPCA1 and IPCA2; and showed high performance in these environments. Assossa is the other location with high IPCA2 score, which specifically contributed to the GE interaction. Bean lines as L1, L9, L10, L14 and the check variety Awash 1 expressed a highly interactive behavior (positively or negatively), in addition L1 and L9 are specifically adapted to Assossa location.

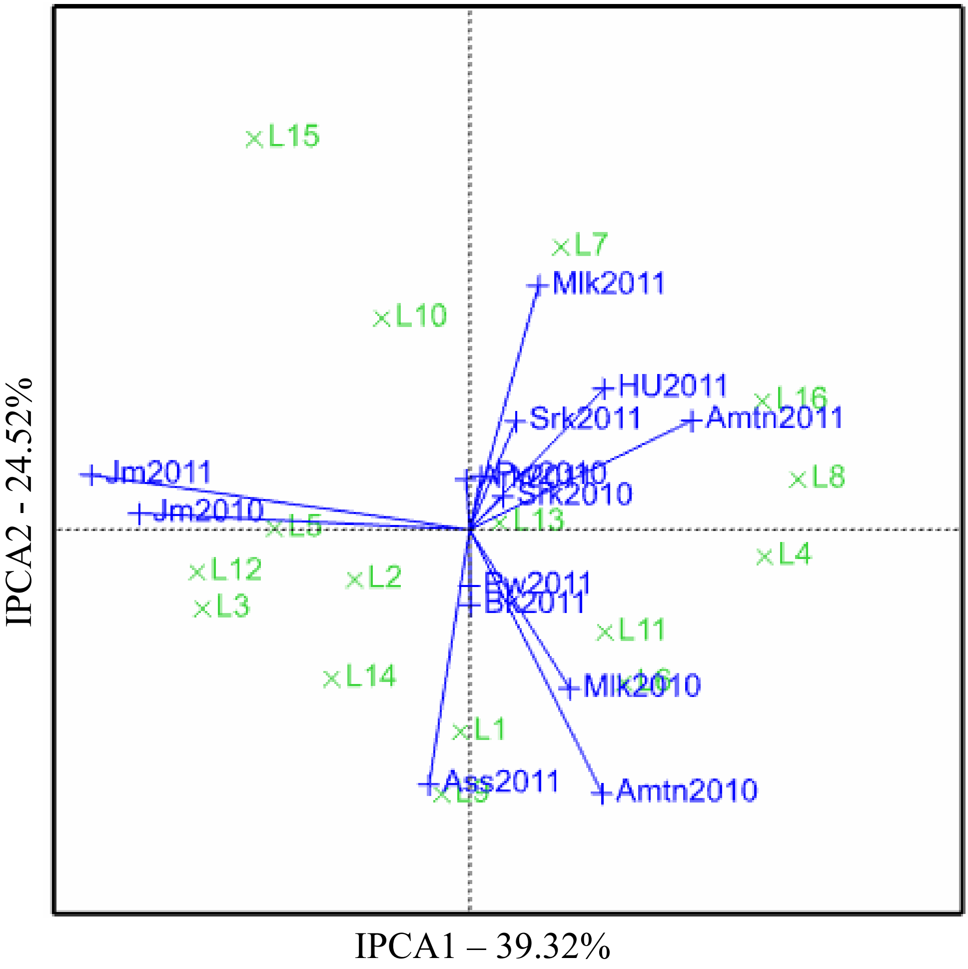

Figure 2. AMMI2 biplot of the first two IPCA scores of both genotypes and environments.

GGE-biplot analysis of Multi Environment Trial data:

The GGE refers to the genotype main effect plus the genotype-by-environment interaction (GE), which are the two sources of the site regression model (Yan *et al.*, 2000, 2007). The biplot from this model is used for assessment of multi-environment data provided that a given data set has a high near-perfect correlation (r = 0.914; P < 0.001) between IPCA1 and genotype main effects

(Crossa *et al.*, 2002). The partitioning of line by environment interaction through GGE biplot analysis showed that IPCA1 and IPCA2 accounted for 49.42% and 32.15% of GGE sum of squares, respectively, and both cumulatively explained 81.57% of the LEI variation. This implies that IPCA scores of GGE-biplot better explained the interaction term in this particular experiment.

Visualization of the "which won where" pattern of MET data is necessary for studying the possible existence of different mega-environments in the target environments (Yan *et al.*, 2000) and figure 3 represented a polygon view of genotypes MET data in this investigation. The polygon view of the biplot indicated the best line(s) in each environment and groups of environments (Yan 2002). The polygon is formed by connecting the markers of the lines that are furthest away from the biplot origin such that all other lines are contained in the polygon. The perpendiculars to the sides of the polygon form sectors or mega-environments of lines and sites (Yan 2002, Yan *et al* 2007). The term mega-environment analysis defines the partition of a crop growing region into different target zones (Gauch and Zobel 1996). The major mega-environments for navy bean testing are enclosed by convex-hull as shown in figure 3. The vertex lines were L3, L4, L8, L9, L12, L13, L15 and L16 and these lines were the best or the poorest yielding lines in some or all of the environments. Among the extreme lines, line 4 and 8 as well as line 3 and 12, respectively were located in pairs indicating their similar response pattern. As indicated in Figure 3, eight sectors of which five had environments and most of the environments fell into two of the sectors or mega-environments. Two small sectors which are located in quadrants I and II, respectively are without environments. And the other big sector with no environments enclosed in it is found in quadrant IV (Figure 3). Four environments, Assossa 2011, Bako 2011, Pawe 2010 and Pawe 2011 fell into a sector found in quadrant II. The highest yielding lines for these four environments are line 13 and Line 9. The second major mega-environment which consisted of environments Melkassa 2010, Melkassa 2011, Alem tena 2010, Alem tena 2011 Sirinka 2010, Sirinka 2011 and Haramaya 2011 was found in a sector located in quadrant III. The third and fourth mega-environments included a single testing site in each, Areka and Jimma locations respectively. The meg-environment which included Jimma environments combined the two sectors in quadrant I. The vector genotypes in these sectors are line 3 and line 12, respectively and they gave the highest yield in Jimma both in 2010 and 2011 (Figure 3, Table 3). And hence, Jimma could be considered as separate mega-location for navy bean evaluation and recommendation.

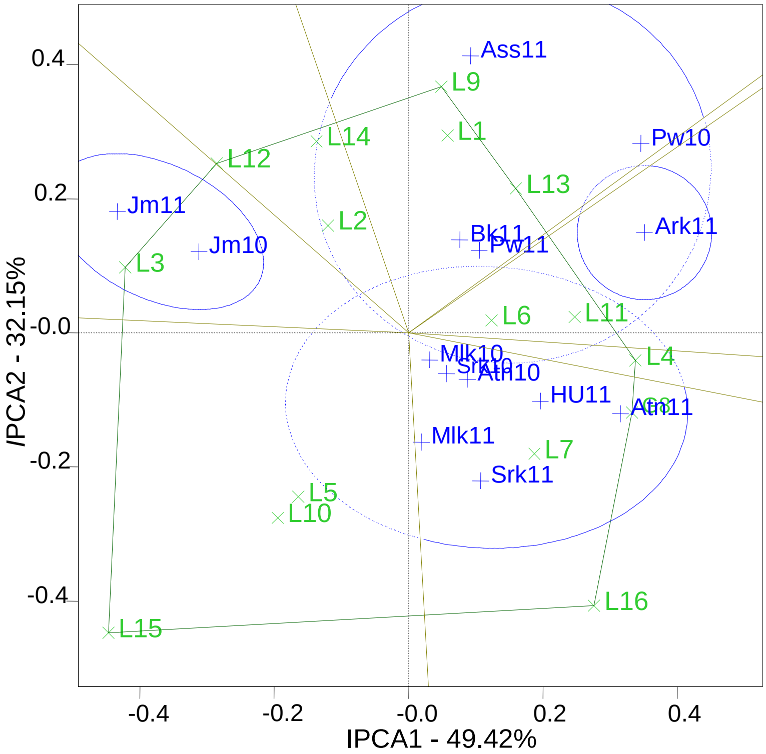

Figure 3. Polygon views of the GGE biplot based on symmetrical scaling for which-won-where pattern for genotypes and environments. for clustering environments

Relationship among test environments:

Another GGE-biplot, which was based on environment-focused scaling, was depicted to estimate the pattern of environments (Figure 4). Environment IPCA1 and IPCA2 scores had both positive and negative scores which give rise to the crossover non-crossover GEI, leading to disproportionate genotypes yield differences across environments (Yan *et al.,* 2000). A genotype may have large positive interactions with some environments, while it has large negative interactions with some others. Test environments Environment IPCA1 scores correlated with environment yield means (r = 0.849; P < 0.01; Table 5). Taking into account such a correlation more than 50% 0f the environments (like Mk11, Atn11, HU11, Jm10, Jm11, etc.) discriminated sufficiently and they are more representative (Yan *et al.,* 2001). Those environments with short environmental vectors were not discriminated sufficiently because of the incidence of biotic factors (diseases and insect pests) and unpredictable climatic features (distribution and amount of rainfall, high temperature and drought) (Kaya *et al*., 2006; Kassaye *et al*., 2013).

Figure 4 provides the summary of the interrelationships among the test environments. The lines that connect the biplot origin and the markers for the environments are called environment vectors. The angle between the vectors of two environments is related to the correlation coefficient between them. The cosine of the angle between the vectors of two environments approximates the correlation coefficient between them (Yan, 2001). Acute angles indicate a positive correlation, obtuse angles a negative correlation and right angles no correlation (Yan and Kang, 2003). The angle between the vectors of two environments is related to its correlation coefficient (Kaya *et al*., 2006). The correlation coefficients among the 14 environments are presented in table 5. Of the 91 correlation coefficients contained in table 5, 47 of them exhibited significant difference. Based on the angles between environment vectors, the highest correlation coefficient observed was between Jm10 and Jm11 which represent the same site (Jimma) in the different years. Jimma location, in general observed loose associations (negative or positive) with most of the environments and negative intermediate relationships with few others (Table 5). Melkassa, Alem tena, Haramaya and Sirinka locations were positively and strongly correlated among each other with high correlation coefficient values. Assosa, Bako, Pawe and Areka locations were also showed strong positive relationships among each other with strong correlation coefficients. Assossa was the other specific location which had loose negative associations with Melkassa, Haramaya and Shrink locations.

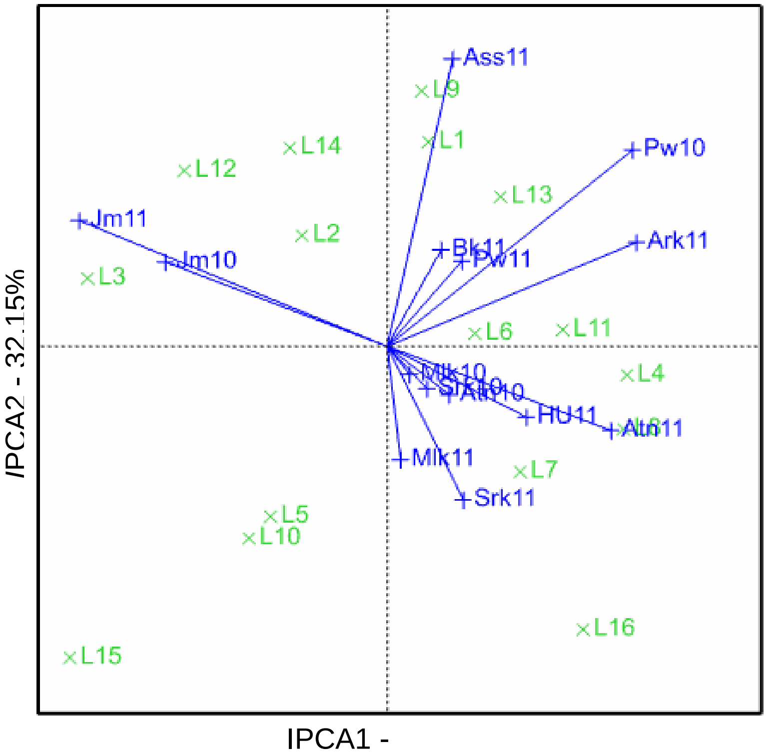

Figure 4. GGE-biplot which shows the relationships among the 14 test environments.

Correlation between environments may be used to investigate indirect response to selection (Cooper and Delacy, 1994; Cooper et al., 1997). For example, Melkassa location significantly correlated with Alem tena, Haramaya and Sirinka locations. In the same manner, strong positive associations were observed among Pawe, Bako and Assossa locations (Table 5) Such significant correlation coefficients among locations suggest that indirect selection for grain yield can be practical across locations. For instance, lines adaptable or higher yielding in Melkassa may also show similar responses in Alem tena, Sirinka and Haramaya s well.

Mean yield and stability performance of lines

Cultivar performance measure (Pi): In terms of mean yield of lines, line 13 and line 7 were the most productive, followed by line12 (Table 6). However, performance stability of the lines was analyzed by cultivar performance measure. According to the method of Lin & Binns (1988b) cultivar performance measure (*Pi*) in which lines with the lowest *Pi* values are considered as the most stable lines. From this analysis, the most stable cultivar ranked first for *Pi* and mean yield was line 13 followed by line 7 (Table 6). Others with low *Pi* values and high ranking for mean yield were lines 12 and 8. The ranks of the *Pi* measure and mean yield are in agreement (Table 6) and this indicated that the *Pi value* as one of good performance measure in stability analysis (Helton *et al* 2009). The most unstable lines according to this analysis were Awash-1, line 3 and line 11 (Table 6).

Table 5. Correlation coefficients among test environments.

Envts	Ark11	Ass11	Atn10	Atn11	Bk11	HU11	Jm10	Jm11	Mlk10	Mlk11	Pw10	Pw11	Srk10	Srk11
Ark11	1	0.588	0.377	0.715	0.712	0.603	-0.557	-0.587	0.189	-0.105	0.958	0.812	0.260	0.106
Ass11	0.588*	1	-0.177	-0.106	0.854	-0.165	0.184	0.203	-0.097	-0.551	0.785	0.798	-0.177	-0.573
Atn10	0.377	-0.177	1	0.791	0.357	0.915	-0.099	-0.208	0.941	0.878	0.160	0.447	0.986	0.905
Atn11	0.715**	-0.106	0.791**	1	0.275	0.970	-0.672	-0.748	0.545	0.521	0.485	0.432	0.676	0.743
Bk11	0.712**	0.854**	0.357	0.275	1	0.297	0.186	0.146	0.423	-0.044	0.792	0.985	0.360	-0.072
HU11	0.603*	-0.165	0.915**	0.970**	0.297	1	-0.487	-0.580	0.728	0.699	0.361	0.437	0.833	0.857
Jm10	-0.557*	0.184	-0.099	-0.672**	0.186	-0.487*	1	0.994	0.242	0.102	-0.406	0.030	0.068	-0.227
Jm11	-0.587*	0.203	-0.208	-0.748**	0.146	-0.580*	0.994**	1	0.134	0.001	-0.414	-0.018	-0.042	-0.325
Mlk10	0.189	-0.097	0.941**	0.545*	0.423	0.728**	0.242	0.134	1	0.884	0.030	0.458	0.984	0.800
Mlk11	-0.105	-0.551*	0.878**	0.521*	-0.044	0.699**	0.102	0.001	0.884**	1	-0.333	0.014	0.911	0.945
Pw10	0.958**	0.785**	0.160	0.485*	0.792**	0.361	-0.406	-0.414	0.030	-0.333	1	0.850	0.063	-0.166
Pw11	0.812**	0.798**	0.447*	0.432*	0.985**	0.437*	0.030	-0.018	0.458*	0.014	0.850**	1	0.424	0.036
Srk10	0.260	-0.177	0.986**	0.676**	0.360	0.833**	0.068	-0.042	0.984**	0.911**	0.063	0.424	1	0.882
Srk11	0.106	-0.573*	0.905**	0.743**	-0.072	0.857**	-0.227	-0.325	0.800**	0.945**	-0.166	0.036	0.882**	1

*, **: Significant at P = 0.05 and P = 0.01 respectively.

Table 6 Lin & Binns's (1988a) cultivar performance measure (*Pi*), Rank-based stability parameters Si^2, Si^3, Si^6 of Nassar and Huhn (1987) and AMMI stability value (ASV) for 16 navy bean lines tested at 14 environments, for the years 2010-2011

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Line code	**Grand mean**	**Lin and Binns Cultivar Superiority Measure**		**Rank-based stability parameters Si^2, Si^3, Si^6 of Nassar and Huhn (1987)**						**AMMI Stability Value (ASV)**			
				Si^2		**Si^3**		**Si^6**					
		Pi($x10^3$)	**Rank**	**Value**	**Rank**	**Value**	**Rank**	**Value**	**Rank**	**IPCA Score 1**	**IPCA Score 2**	**ASV**	**Rank**
Line1	**2047**	196	10	10.43	14	3.80	2	11.03	2	-0.6274	-13.4028	17.06	5
Line2	**2067**	179	6	10.21	13	4.19	3	13.26	4	-7.6255	-3.3137	10.57	2
Line3	**2017**	248	15	10.50	15	6.19	16	29.50	16	-17.7259	-5.234	23.50	11
Line4	**2153**	198	12	7.36	3	5.35	10	20.71	10	19.5516	-1.8071	24.97	12
Line5	**2149**	173	5	7.71	5	5.43	11	22.68	11	-12.9145	0.062	16.42	4
Line6	**2071**	206	13	9.07	9	4.19	3	13.15	3	10.2217	-10.1807	18.35	7
Line7	**2318**	82	2	5.43	2	5.03	8	19.49	8	6.0611	18.7532	25.06	13
Line8	**2161**	170	4	7.86	6	4.90	7	17.52	7	21.7655	3.3169	28.00	15
Line9	**2096**	191	8	9.43	10	5.85	13	24.88	13	-1.8671	-17.5661	22.46	9
Line10	**2059**	180	7	10.07	12	4.41	6	14.07	6	-5.7894	14.0161	19.28	8
Line11	**2130**	217	14	7.64	4	6.12	15	26.71	15	8.9726	-6.8554	14.36	3
Line12	**2187**	140	3	8.00	7	5.98	14	25.38	14	-18.0517	-2.8073	23.23	10
Line13	**2435**	28	1	3.14	1	2.07	1	3.36	1	1.9774	0.4549	2.58	1
Line14	**2061**	194	9	9.71	11	4.33	5	13.76	5	-9.1268	-9.8879	17.11	6
Awash-1	**1902**	367	16	10.86	16	5.25	9	20.29	9	-14.2426	25.9381	37.63	16
A/melka	**2106**	197	11	8.57	8	5.65	12	22.73	12	19.4211	8.5139	26.97	14

Variances of ranks (Si^2), means absolute differences of pairs of ranks (Si^3) and mean ranks (Si^6): The method of Nassar and Huhn (1987) is a non-parametric stability measure based on the ranks of the lines across locations. This gives equal weight to each location or environment. Lines with less change in rank are expected to be more stable. The mean absolute rank difference (**Si^3**) estimates are all possible pair wise rank differences across locations for each line. The **Si^2** estimates are simply the variances of ranks for each line over environments (Nassar and Huhn 1987, Huhn 1990). According to this procedure line 13 was the most stable, with line 3 and Awash-1 the most unstable one (Table 6). Considering mean yield and **Si^2** of the lines the second high yielding line, line 7 was also exhibited good stability. For **Si^2**, **Si^3** and **Si^6** smaller estimates indicate relative stability as indicated in table 5 but often, **Si^3** and **Si^6** have less power for detecting stability than **Si^2** (Huhn, 1990).

AMMI stability value (ASV): The IPCA scores of lines in AMMI are indicators of the stability of a line over environments (Purchase 1997). The lowest IPCA1 was observed by line1 followed by lines 9 and 13 (Table 6). According to IPCA1 score the three lines were stable but the highest mean yield was exhibited by line 13 (2435 kg ha^{-1}), which is significantly higher than the grand mean (2122 kg ha^{-1}). The highest IPCA1 was recorded by line 8 followed by line 4, Awash Melka, line 12 and line 3. AMMI stability value (ASV) confirms the results of IPCA1 and IPCA2 scores (Table 6). As a result, ASV selected line 13 (ICA Bunsi x SxB 405/1C-C1-1C-87) followed by line 2 (ICA Bunsi x SxB 405/1C-C1-1C-3) with the lowest ASV as stable lines, however only line 13 exhibited the highest mean yield greater than the grand mean (Table 6). Corresponding to ASV, the standard checks (both Awash-1 and Awash Melka), line 8 and line 7 were the most unstable lines although the two lines (7 and 8) had higher mean yield above the grand mean. Helton *et al* (2009) and Karimzadeh and Mohammadi (2010) reported the same result in rainfed lentil yield trials.

Conclusion

Multi-location trials data is crucial to select and recommend high yielding and stable genotypes for farmers. The genotypes studied in this experiment exhibited both crossover and non-crossover types of GEI. The former substantially led to differential rankings of genotypes across test environments, thereby making genotypic selection difficult for navy bean growing environments under Ethiopian conditions. We exploited the AMMI, GGE-biplot and some stability parameters as statistical methods for evaluating experimental navy bean lines performance data. AMMI-ANOVA and stability analyses revealed similar results in selecting the highest yielding and stable navy bean line as well as in identifying the best test environments. The GGE-biplot model summarized patterns and relationships of lines and environments successfully. It is a very successful tool in classifying sites into mega-environments and to study the relationships within and between the clustered sites. The highest yielding lines were ICA Bunsi x SxB 405/1C-C1-1C-87 and ICA Bunsi x SxB 405/1C-C1-1C-37, and the difference for mean grain yield between these lines and the other lines was significant according to the F test result. Besides, ICA Bunsi x SxB 405/1C-C1-1C-87 was stable line as depicted in the AMMI biplot figures and stability parameters.

In the case of test environments, we found four possible mega-environments for navy bean testing and therefore, bean improvement program will surely focus on them to foster yield-based selection in multi-environment yield trials. Indirect selection among test environments might also be employed to reduce the number of test environments by eliminating those that are highly correlated with each other thereby economizing and optimizing the conduct of multi-environment yield trials. On the other hand, a low H value might suggest that genotype performance trials should be conducted in a number of population of environments sampled from the target region.

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