Evaluation and Stability Analysis of Climbing Bean (*Phaseolus vulgaris* L.) Genotypes in High Potential Areas of Ethiopia

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Abstract

*Climbing bean (*Phaseolus vulgaris L.*) is an important pulse crop to ensure food and nutritional security in Ethiopia. However, its productivity is below its potential due to use of low yielding local varieties, biotic and abiotic stresses in different growing environments. Limited research was done on climbing bean and a few varieties were developed so far. This study is therefore undertaken to evaluate and identify high yield potential and stable performance. The trial was conducted at Jimma, Metu, Haru, Bako and Pawe during 2019-2020 main crop seasons using randomized complete block design with three replications. The combined analysis of variance showed highly significant difference ($P\leq 0.01$) among genotypes (G), locations (L), year (Y) and their interaction (G x LxY) for most of the traits. Based on mean grain yield performance of the genotypes over environments, Genotype NUV-54 (G1) scored maximum grain yield (2.67 tha^{-1}) followed by GenotypeNUV-76 (G15) (2.57 tha^{-1}), which exhibited a yield advantage of (23.61% and 18.14) and (18.98% and 13.72%) from the checks Dandesu (2.16tha^{-1}) and Tibe (2.26 tha^{-1}), respectively. Stability view of GGE biplot showed that G1 and G15 exhibited the first and the second-highest mean grain yield and relatively ideal genotypes and moderate stability to stable across environments, respectively. These genotypesG1 and G15 are characterized by small seed size with red and white seed color, respectively. Fast cooking time is the other major attributes of outstanding varieties G1 (83 minute) and G15 (88 minute).The performance of these two genotypes also showed resistance to common bacterial blight; angular leaf spot and floury leaf spot. These two promising genotypes were promoted to verification plot for official release. Based on the gain yield performance, disease resistance and quality, the National Variety Release Committee (NVRC) approved the release of the first candidate varieties NUV-54 (G1) for commercial production since June 2022.The variety is recommended for Southwest, West and other similar agro ecologies with high rainfall areas of the country.*

Keywords: Climbing bean, Yield, GGE, NUV 54

Introduction

Common bean is an important pulse in terms of production and area coverage in Ethiopia. The national area coverage and production is estimated as 311,583.58hectares and 552, 564.074tons, respectively(CSA, 2021).The production and utilization of common bean has increased due to the rising of global demand and the expansion hunger particularly in vulnerable subset of small holder farmers in the country. Nutritionally, common bean is rich in dietary protein, source of vitamins and essential minerals such as iron and zinc (which are key elements for mental development) and B-vitamins. It plays a critical role in cropping systems and soil fertility improvement *via* nitrogen fixation (Beebe *et al.*, 2000)..

Common bean is classified into four major groups by CIAT, depending on their growth habit. Class I has a determinate growth habit (bush type bean) while class II-IV has an indeterminate growth habit. Classes IIIb and IV are referred to as climbing beans or pole beans. Climbing beans originated from medium to high-altitude regions of the Andes and Central America (Voysest, 2000). The most outstanding characteristic of climbing beans is their high yield potential: up to 4 to 5 tonha^{-1} versus 3 tonha^{-1} for bush beans under optimal conditions (CIAT, 2004). The nature of their growth habit and yield potential allows significant harvests in areas where population pressure is high and arable land is scarce (Sperling and Muyaneza, 1995). Climbing beans are grown in East and Central African countries, including: Rwanda, Central Kenya highlands, Western Kenya, Burundi, and Eastern Democratic Republic of Congo and Southern, southwestern and Western mid-highlands of Ethiopia (Ramaekers *et al.*, 2013; Raphaël, 2013; CGIAR, 2018; Berhanu *et al.*, 2019). The majority of these regions are characterized by high rainfall, high population density and land scarcity. Climbing beans are more common on altitudes of 1750-2300 meters above sea level (Woolley *et al.*, 1991).

Climbing bean in Ethiopia is mainly produced around homestead gardens, along the fences and sometimes intercropped with maize/pigeon peas. It can also be planted in the production fields, but it requires providing supporting sticks (Berhanu *et al.*, 2019). Therefore, climbing beans which have high grain yield can provide the best option for intensification and production where arable landholdings are diminished due to population pressure. Despite the potential of climbing beans to maximize income per unit area for small holder farmers, limited number of climbing bean varieties were released as compared to bush type beans. Hence, this study was conducted to evaluate the stability of high yielding climbing bean genotypes along with disease resistance and acceptable quality across different testing locations and thereby to identify and advance elite genotypes to variety verification trial and release..

Materials and Methods

The experiment was conducted in Jimma, Metu, Haru, Bako and Pawe during 2019-2020 cropping season.

The description of experimental locations is presented in Table1. A total of 17 climbing bean genotypes including two checks (Dandesu and Tibe) were evaluated as a national variety trial across five locations during 2019-2020 except at Pawe where the experiment was conducted in 2020 only(Table 2). The tested materials were introduced from International Centre for Tropical Agriculture (CIAT). The genotypes were arranged in randomized complete block design with three replications.

Planting was done in a plot of four rows with 4m length with regular spacing of 10 cm between plants and 50cm between rows. Fertilizer NPS at the rate of 121kgha^{-1} was applied at planting. The plants were supported with sticks starting from one month after planting and hands weeding along with manual digging were done to control weeds. Harvesting and threshing were done manually after physiological maturity.

Two candidate climbing bean varieties; namely, NUV-54 and NUV-76 along with two checks Dendesu and Tibe were tested under verification plot. The verification plot was planted at Jimma, Metu Bako and Pawe research stations and on two farmers field surrounding each research center. The trial was planted in a 10m X 10m single plot. All cultural practices for climbing were carried out as stated above. The verification plots were evaluated by variety release technical committee.

Table1. Description of experimental locations

Location	Altitude	Latitude	Longitude	Temperature		Annual rainfall
				Min(°C)	Max(°c)	
Jimma	1754	7°46'N	36°00'0"E	11.6°c	26.3°c	1572mm
Metu	1558	8°19' 0" N	35°35' 0"E	12.7°c	28.9	1829 mm
Haru	1252	8°59' 0" N	35°47' 0"E	16°c	27°c	1227mm
Bako	1650	9°6' 0" N	37°9' 0" E	13.3°c	28°c	1238mm
Pawe	1120	11°19' 0"E	36°24' 0"E	16.3 °c	32.6°c	1587mm

Table 2. Climbing bean genotypes tested at nine environments (at five locations for two years)

Genotype code	Genotype name	Location	Year	Environment code
1	NUV 54	Jimma	2019	JM19
2	NUV 27		2020	JM20
3	NUV20	Metu	2019	MT19
4	NUV 31		2020	MT20
5	NUV 40	Haru	2019	HR19
6	HUV219-9		2020	HR20
7	NUV 100	Bako	2019	BK19
8	NUV 115		2020	BK20
9	NUV 102	Pawe	2020	PW20
10	NUV 30			
11	NUV 90			
12	NUV42			
13	NUV 173			
14	NUV 56			
15	NUV 76			
16	Check 1(Dandesu)			
17	Check 2(Tibe)			

Agronomic characters such as days to flowering, days to maturity, plant height (cm), number of pods per plant, number of seeds per pod, number of seeds per plant, hundred seed weight (gm), yield per plant(gmplant^{-1}), and yield per hectare (Kgha^{-1}) were recorded. Disease such as common bacterial blight, angular leaf spot, and floury leaf spot were also recorded. The scoring system was 1-9 scale (1=immune, 9=Susceptible, then 1-3=resistant,4-6=moderately resistant and 7-9 = susceptible (Shrestha and Mishra, 1994). All the data including grain yield were collected from the middle two harvestable rows. All the data were subjected to combined analysis of variance (ANOVA) using SAS software. The data analyses for interpreting genotype by environment interaction were done by GGE stability analysis in R software.

The following ANOVA models have been used to test the performance of genotypes at each and combined locations, respectively (Singh and Ceccarelli 1996) as indicated below.

$Y_{ij} = \mu + G_i + B_j + e_{ij}$ and $Y_{ijk} = \mu + G_i + E_j + GE_{ij} + Bk_{(j)} + e_{ijk}$.

Where, Y_{ij}= observed value of genotype i in block j, Y_{ijk}= observed value of genotype i in block k of environment j, μ = grand mean of the experiment, G_i =the effect of genotype i, B_j= the effect of block j, $Bk_{(j)}$ = the effect of block k in environment j, e_{ij}= error effect of genotype i in block j,E_j= environment effect, GE_{ij}= the interaction effect of genotype i with environment j, e_{ijk}= error (residual) effect of genotype i in block k of environment j. The stability of the tested genotypes was performed using GGE Biplot of GUI package in Rsoftware.

Results and Discussion

The result from the combined analysis of variance across the five locations is presented in Table 3. The pooled analysis of variance revealed that mean squares due genotype was significant ($P \leq 0.01$) for most of the traits except pod per plant and common bacterial blight, indicating genotypes were responded differently for each trait. Mean squares due to location was significant ($P \leq 0.01$) for all the traits considered, indicating the distinct nature of the five test locations. Mean square due to years differed significantly ($P \leq 0.01$with respect to all the traits indicating that climate changes were observed during the study.

Mean squares due to location x genotype were significant for most of traits except pod per plant, seed per pod and seed per plant, meaning that genotypes exhibited different relative performance in each location. Non-significant genotype x year was observed for most of the traits except days to flowering, days to maturity, floury leaf spot, hundred seed weight and yield hectare^{-1}, indicating that genotypes showed consistent performance for most of traits in each year. Location x year interaction revealed significant effect for all traits, meaning the location of genotypes performance varied in the two years, suggesting that climbing bean genotypes performed differently in every location in each year. Means squares due to genotype x location x year interaction found significant effect for days to flowering, floury leaf spot and hundred seed weight. Generally, the result for yield and related traits indicated that phenotypic variability for these traits is dependent on genetic factors, environmental variables and the interaction between genotypes and environment.

Based on the combined mean performance of the genotypes over environment, G1 scored maximum grain yield (2.67 t/ha) followed by G15 (2.57 t/ha), which exhibited a yield advantage of (23.61% and 18.14) and (18.98% and 13.72%) from the check Dandesu (2.16 tha^{-1}) and Tibe (2.26 t/ha), respectively (Table4). The performance of the tested genotypes also showed resistance to common bacterial blight, angular leaf spot and floury leaf spot. Highest plant height was recorded from genotype, G5 (291.37 cm) followed by G14 (269.88 cm), while the lowest was recorded from genotype G4 (213.57 cm). Separate analysis for each of the test environments showed consistently large variation among test genotypes for grain yield. Generally, based on the combined mean yield and other agronomic traits over 9 environments, G1 was relatively top-ranking genotype followed by G15. Moreover, G1 had also showed the highest yield across most of the environments than the two check varieties. Thus, G1 and G15 are the first and the second candidate varieties promoted for variety verification trial.

Table 3. Mean squares values of combined analysis of variance for yield and related characters of 17climbingbean genotypes evaluated at nine environments during 2019-2020.

Source	DF	DTF	DTM	PH(cm)	NPP	NSD	SPP	CBB	ALS	FLS	HSW (gm)	YLD$_{pl}$ (gm/plant	YLD$_{ha}$ (t/ha)
yr	1	24350.7**	9676.9**	17817.4**	1664.3**	58.4**	65156.4**	9.7**	19.9**	23.5**	161.5**	3452.0**	196.1**
loc	4	8934.0**	21564.3**	1139**	5696.1**	90.7**	111505.7**	145.3**	49.0**	32.0**	8585.6**	5054.6**	104.6**
Geno	16	55.3**	118.8**	8493.9**	139.7ns	15.7**	3404.2**	1.3ns	1.6*	1.4**	903.1**	127.2**	1.3**
Loc*rep	10	22.5**	28.4*	1302.2ns	297.5*	8.1ns	14249.6**	4.7**	0.6ns	0.3ns	31.4ns	30.3ns	1.7**
Geno*yr	16	21.2**	26.5*	18.1ns	159.1ns	6.1ns	1596.2ns	1.0ns	1.1ns	1.8**	111.9**	23.9ns	0.6*
yr*loc	3	22986.5**	10192.8**	59697.0**	502.1*	21.0*	22690.5**	5.2**	9.5**	23.5**	2107.4**	5516.7**	96.5**
Geno*loc	64	15.1**	25.0**	2018.7**	136.2ns	7.7ns	1134.3ns	1.7**	2.5**	1.7**	79.9**	65.5**	0.8**
yr*geno	16	24.3**	20.7ns	1874.5ns	203.3ns	6.5ns	1603.1ns	1.0ns	1.0ns	1.5**	103.0**	16.2ns	0.6*
geno*yr*loc	48	12.9*	15.3ns	1602.4ns	151.8ns	7.8ns	1415.6ns	0.6ns	0.8n5	1.1**	60.3**	20.6ns	0.5ns

Where, * = significant at (P≤0.05) and **= significant at (P≤ .01), yr=year,loc=location, Geno=genotype, DF=degree of freedom, DTF = days to 50% flowering, DTM = days to 95% pod maturity, PH = plant height, NPP =pod per plant, NSD=seed per pod, NSP= seed per plant, CBB=common bacterial blight, ALS= angular leaf spot,FLS=floryleaf spot, HSW=hundred seed weight, YLD$_{pl}$=yield per plant, YLD$_{ha}$= yield ha$^{-1.}$

Table 4 . Mean grain yield performance (t ha-1) of 17 climbing bean genotypes evaluated in five locations in 2019 and2020 cropping season

		2019				2020					
No.	Genotype	Jimma	Metu	Haru	Bako	Jimma	Metu	Haru	Bako	Pawe	Overall mean (tha-1)
1	NUV 54	2.07	1.83	2.92	1.77	5.74	2.07	5.00	1.21	1.48	2.67
2	NUV 27	0.77	1.53	3.37	1.90	4.27	1.55	4.38	1.21	1.28	2.25
3	NUV20	1.30	1.23	2.73	2.06	4.82	1.99	3.96	1.62	0.94	2.30
4	NUV 31	0.37	1.50	2.47	1.37	3.06	1.82	3.75	1.13	1.35	1.87
5	NUV 40	1.17	1.28	2.01	1.05	4.96	1.97	3.13	1.44	1.71	2.08
6	HUV219-9	0.97	1.50	2.49	2.17	5.05	1.59	3.96	1.26	1.05	2.23
7	NUV 100	0.73	1.54	3.08	1.91	3.86	1.69	3.54	0.88	1.70	2.10
8	NUV 115	0.40	0.84	2.35	1.35	5.19	1.68	4.17	0.98	1.40	2.04
9	NUV 102	0.87	0.97	2.73	1.88	5.12	1.81	5.42	0.78	1.67	2.36
10	NUV 30	0.77	1.45	1.72	1.36	4.14	1.63	4.58	1.44	1.36	2.05
11	NUV 90	0.77	1.49	3.41	1.57	5.46	1.77	4.58	1.08	1.09	2.36
12	NUV42	0.47	0.92	2.17	1.48	3.41	1.58	3.96	0.90	1.54	1.82
13	NUV 173	0.43	1.51	3.19	1.46	5.64	1.89	5.75	1.13	1.65	2.52
14	NUV 56	0.43	1.31	2.07	1.06	3.81	2.23	3.75	1.08	1.70	1.94
15	NUV 76	0.60	1.91	3.28	1.80	5.90	2.03	5.71	0.70	1.21	2.57
16	Dandesu	0.57	1.14	2.83	1.70	5.52	1.48	4.42	0.83	0.97	2.16
17	Tibe	1.37	1.23	2.25	1.96	5.57	1.53	3.58	1.25	1.63	2.26
	mean	0.83	1.36	2.65	1.64	4.80	1.78	4.33	1.11	1.4	2.21
	CV	42.70	22.04	15.33	19.45	13.54	32.56	27.17	33.37	14.2	26.92
	LSD	0.59	0.50	0.68	0.53	1.08	ns	Ns	ns	0.33	0.32

Table 5. Mean grain yield performance (ton ha-1) and other growth parameters of 17 climbing bean genotypes evaluated in five locations for the period 2019-2020

geno	Name	DF	DM	PH	NPP	spd	SPP	CBB	ALS	FLS	HSW	Yld(gm/plant)	Yld(t/ha)
1	NUV 54	56.63	105.85	256.77	15.17	4.97	68.43	3.07	2.41	1.44	29.34	17.80	2.68
2	NUV 27	52.15	101.26	240.36	12.89	5.55	68.55	2.85	2.67	1.37	29.36	16.07	2.25
3	NUV20	52.19	101.81	235.42	13.93	5.23	69.22	2.89	2.70	1.52	28.62	14.83	2.30
4	NUV 31	52.19	99.00	213.57	14.39	4.64	58.54	2.67	2.26	1.74	41.29	13.32	1.87
5	NUV 40	54.70	105.48	291.37	11.21	4.81	53.60	2.48	2.07	1.81	34.91	15.50	2.08
6	HUV219-9	54.37	99.59	253.37	13.43	7.10	83.52	2.74	2.48	1.15	25.31	15.95	2.23
7	NUV 100	52.41	100.26	221.85	13.59	6.79	69.98	3.04	2.70	1.15	28.56	13.71	2.10
8	NUV 115	53.37	101.59	246.78	10.57	5.21	52.65	2.70	2.56	1.22	29.35	13.61	2.04
9	NUV 102	54.44	100.22	246.43	15.17	5.55	74.99	2.44	2.44	1.00	26.32	17.75	2.36
10	NUV 30	52.22	102.48	245.23	10.45	5.00	46.00	2.70	1.96	1.52	42.43	15.34	2.05
11	NUV 90	52.70	100.81	256.23	14.00	6.08	79.34	2.89	2.48	1.22	24.47	15.30	2.36
12	NUV42	52.48	101.52	249.52	13.14	5.07	68.65	2.67	2.15	1.52	33.95	14.26	1.82
13	NUV 173	52.89	98.07	244.77	11.43	5.90	64.09	2.81	2.15	1.44	25.84	17.70	2.52
14	NUV 56	55.81	103.22	269.88	10.85	5.23	53.92	2.56	2.15	1.74	40.08	15.43	1.94
15	NUV 76	53.59	99.48	238.24	13.00	7.21	82.64	2.67	2.07	1.00	25.55	16.30	2.57
16	Dandesu	54.67	99.67	263.27	14.29	6.23	78.23	3.11	2.56	1.15	27.39	20.50	2.16
17	Tibe	53.85	100.07	256.88	21.55	5.64	78.75	2.81	2.67	1.00	29.76	21.29	2.26
	mean	53.57	101.20	248.82	13.47	5.66	67.71	2.77	2.38	1.35	30.74	16.16	2.21
	CV	5.64	3.76	14.50	89.88	48.23	57.75	31.59	37.4	51.72	15.71	31.21	26.92
	LSD	1.62	2.04	19.31	NS	1.46	20.94	NS	0.48	0.37	2.58	2.70	0.32

GGEBiplot and stability analysis of the test genotypes across environments

The GGE biplot method consists of a set of biplot interpretation methods to evaluate genotype and test-environment (Yan, 2007). The analysis showed that genotype G1 performed best at Jimma and Metu followed by G15. The check Tibe (G17) better performed at Jimma and Pawe. Pawe. Genotype G4, G7, G14, and G12 did not perform best in any of the environments (Figure 1). Mean vs. Stability" view of GGE biplot is an efficient tool to compare genotype based on mean performance and stability across environments within a mega environment (Yan *et al*., 2007). Mean vs. stability view of GGE biplot is presented in Figure 2. G1 showed higher mean grain yield but had less stability across environment. Genotype-15 scored the second-highest mean grain yield performance and relatively stable across environments. Besides according to Yan and Hunt (2001), the GGEBiplot explains a small portion of the total variation that can contribute to this discrepancy.

The "which-won-where" view of the GGE biplot is an effective feature for mega-environment analysis (Yan *et al*., 2007). Therefore, in this study based on the mean yield performance of climbing bean genotypes, all environments and genotypes fall into a four sector (figure 3). The Biplot contains a polygon drawn on genotypes that are furthest from the biplot origin so that all other genotypes are contained within the polygon and these genotypes located on the vertices of the polygon performed either the best or the poorest in one or more environments (Yan, 2006). Environments within the same sector share the same winning genotypes and environments in different sectors have different winning genotypes while, the genotypes within the polygon and nearer to origin were less responsive than vertex genotypes (Yan and Tinker, 2006).Besides the high fluctuation in the performances of the genotypes, the significant interaction effect was observed over year by location. Yan and Tinker (2006) indicated the genotypes in the corner of the polygon are the best performing one in each set of environments within the angle of the polygon formed by the broken lines. In this assumption, the G1, G5, G4, and G13 performed best in their respective environments. Genotypes 1 performed well in JM19 and JM20 and moderately adapted to MT19, MT20, and BK20.Three vertex genotypes, G5, G4, and G13 had the highest yield in their vertex environments (MT20, PA20and BK20), (PW20), and (BK19,HR19 and HR20 and, respectively. The other thirteen genotypes were fallen in sectors with their respective environment markers.

The ideal genotype is located in the first concentric circle in the bi-plot. An ideal genotype has the highest mean yield and stable across environments (Farshadfar*et al*., 2012). Genotype near to the concentric circle is G15 which can be desirable and benchmarks for evaluation of climbing bean genotypes followed by G11, G9, and G17 (figure 4).

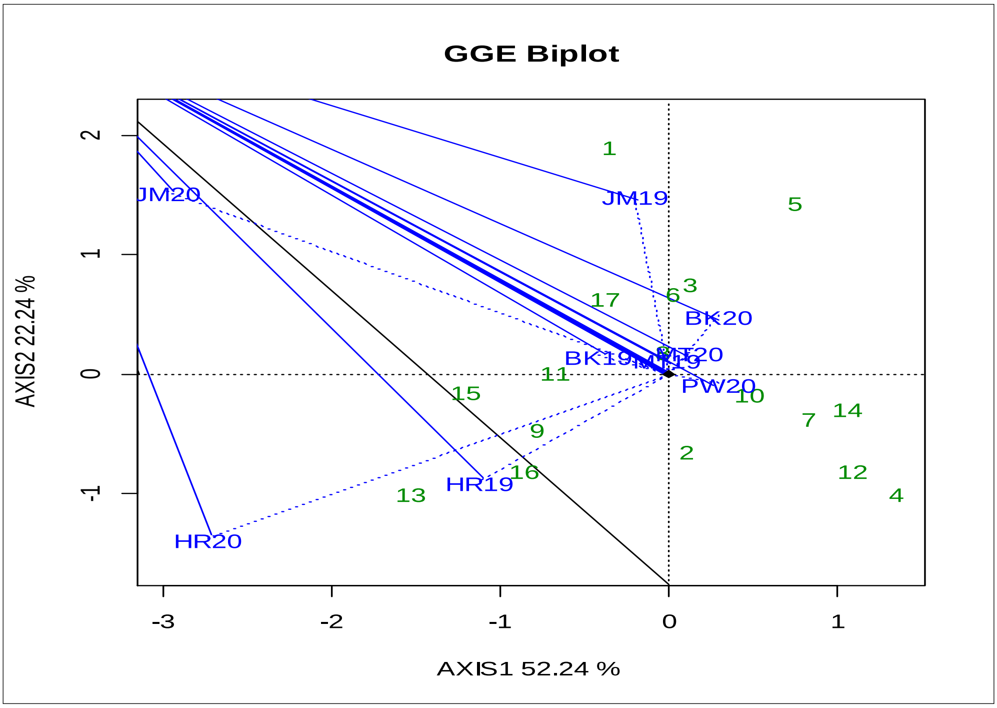

Figure 1. Mean grain yield performance and stability of genotypes based on the G × E data

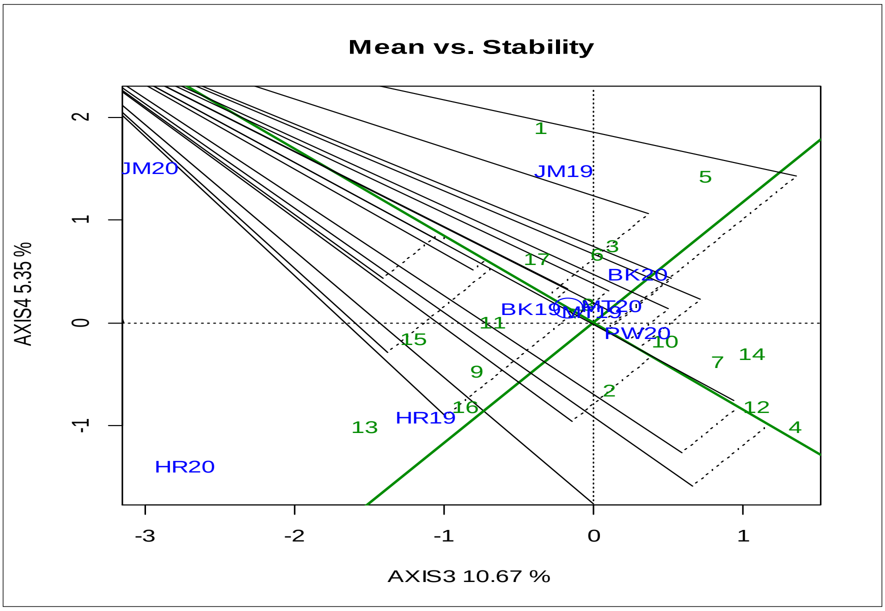

Figure 2. Mean grain yield performance and stability of genotypes based on the G × E data

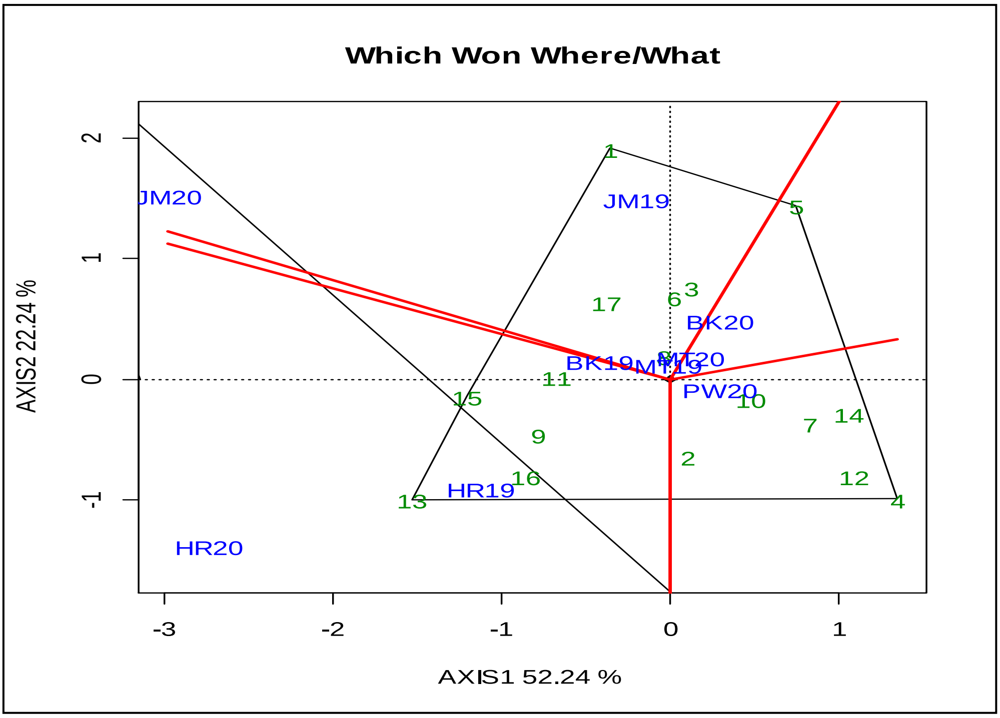

Figure 3. GGE bi-plot on genotypes using symmetrical scaling for mean lint yield and stability of 15climbingbean genotypes
Tested across seven environments

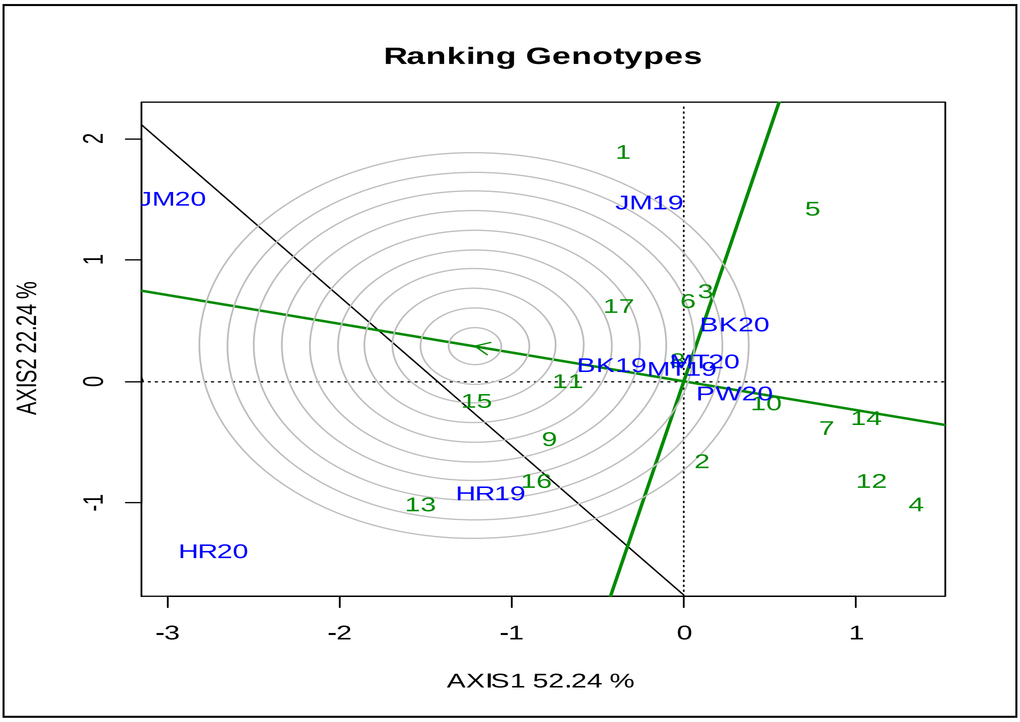

Figure 4. The average- environment view to rank genotypes to ideal genotypes

Important seed Characteristics and cooking time of candidate varieties

The candidate varieties NUV-54and NUV-76 are characterized by small seed size with red and white seed color, respectively. Fast cooking time is the other major attribute of outstanding candidate varieties NUV-54 (83 minutes) and NUV-76 (88 minutes). Whereas, check varieties; Dandesu and Tibe were characterized by red seed color, medium and small seed size with their acceptable cooking time (87 and 85 minutes), respectively (Table 6). Therefore, these two genotypes were promoted to variety verification trial and submitted to variety releasing committee as candidate varieties and evaluated by the technical committee in the 2021 cropping season. Finally, based on the gain yield performance, disease resistance/tolerance and acceptable quality, the national variety release standing committee approved the release of the first candidate varieties NUV-54 (G1) for commercial production purposes since June 2022.

Table 6. Seed Characteristics and cooking time of climbing bean Candidate and check varieties

No.	Variety	Seed color	Seed size	Cooking time (minute)	Decision of the committee (NVRC)	Year of release
1	NUV-54 (candidate1)	white	small	83	released	2022
2	NUV 76(candidate2)	red	small	88	rejected	-
4	Dandesu(check1)	red	medium	87	check	2012
5	Tibe (check2)	red	small	85	check	2004

Conclusion and Recommendation

The combined analysis of variance showed highly significant ($P \leq 0.01$) due to genotypes, location, year and their interaction for most traits. The mean yield performance of the genotypes showed that G1 (NUV 54) scored maximum grain yield (2.67 tha^{-1}) followed by G15 (NUV76) (2.57 tha^{-1}), which exhibited a yield advantage of (23.61% and 18.14) and (18.98% and 13.72%) from the standard check Dandesu (2.16 t/ha) and Tibe (2.26 t/ha), respectively. The performance of the genotypes also showed resistance to foliar disease. These genotypes G1 and G15 are characterized by small seed size with red and white seed color, respectively. Fast cooking time is the other major attribute of outstanding varieties G1 (83 minutes) and G15 (88 minutes).Generally, G1showed higher mean grain yield value than the other test genotypes and had moderate stability for some environments. GenotypeG15 scored the second-highest mean grain yield and relatively a good stable candidate across environments. Therefore, based on the gain yield performance, disease resistance and acceptable quality, the national variety release standing committee approved the release of the first candidate varieties NUV-54 (G1) for commercial production since June 2022. The variety is recommended for Southwest, West and other similar agro-ecologies with high rainfall areas of the country.

Acknowledgments

The author acknowledges Jimma Agricultural Research Center, Ethiopian Institute of Agricultural Research and National Lowland Pulse Research Program of Melkasa Agricultural Research Center for availing the resources and facilities for conducting the research. Special appreciation also goes to collaborative center Viz, Metu and Haru Agricultural Research Sub-Center, PaweAgricultural Research Center and Bako Agricultural Research Centerfor their cooperation in conducting trial, field management and data exchange.

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