AJAB

Assessing disease resistance and yield components in advanced breeding lines of common bean in different locations of northern Tanzania

Edith L. Kadege^{1*}, Pavithravani B. Venkataramana¹, Teshale Assefa², Joseph C. Ndunguru³, Jean Claude Rubyogo⁴, Ernest R. Mbega¹

¹School of Life Sciences and Bioengineering, The Nelson Mandela African Institution of Science and Technology, Arusha 447, Tanzania

²Crops for Nutrition and Health, International Center for Tropical Agriculture (CIAT), 2704 Arusha, Tanzania ³Department of Research and Innovation, Tanzania Agricultural Research Institute (TARI), Dodoma 1571, Tanzania ⁴Crops for Nutrition and Health, International Center for Tropical Agriculture (CIAT), Nairobi 823-00621, Kenya

Received: October 2, 2023 Accepted: May 11, 2024 Published Online: July 5, 2024

Abstract

Tanzania is the top bean producer in Africa and seventh globally, exporting half of its beans to neighboring nations. This study determines common bean varietal performance in northern Tanzania. Disease infection and yield components of 22 genotypes were evaluated in on-station and on-farm trials. The study used a completely randomized factorial trial design with three replications to explore the individual and combined effects of genotype and environment on disease infection and grain yield in two on-station and six on-farm environments. Data were collected on number of emerging plants; canopy height, canopy width, plant vigor, disease infection levels, plant stands at harvest, number of pods per plant, number of grains per pod, 100-grain weight and grain yield and analyzed using R software. The combined analysis of variance revealed significant differences among genotypes, environment, and genotype by environment interactions. Bean canopy height, canopy width, plant vigor and grain yield were high at on-station trials, compared with on-farm trials. Advanced breeding lines showed 56% higher grain yield than commercial checks across study locations. Additive main effects and multiplicative interaction (AMMI) analysis revealed that, genotype was the dominant factor affecting common bean grain yields at 50.3%, whereas the environmental impacts were 25.7%. NUA 48 and NUA 64 were ideal genotypes showing anthracnose resistance and delivering higher grain yield. VTT 923-23-10 and Sweet Violet varieties were stable across the mega-environment. Therefore, NUA 48, NUA 64, VTT 923-23-10 and Sweet Violet are proposed for further evaluation within Tanzanian bean agroecosystem to identify farmers' preferred varieties.

Keywords: Disease resistance, Yield components, Breeding lines, Bean, Tanzania

How to cite this:

Kadege EL, Venkataramana PB, Assefa T, Ndunguru JC, Rubyogo JC, and Mbega ER. Assessing disease resistance and yield components in advanced breeding lines of common bean in different locations of northern Tanzania. Asian J. Agric. Biol. 2024(4): 2023233. DOI: <u>https://doi.org/10.35495/ajab.2023.233</u>

This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 License. (<u>https://creativecommons.org/licenses/by/4.0</u>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.



*Corresponding author email:

edithkadege@gmail.com

Introduction

Common bean (Phaseolus vulgaris L.) is the main grain legume cultivated and consumed in Tanzania (FAOSTAT, 2021). Common bean production, demand and business opportunities are increasing, while productivity is below 1.4t/ha (FAOSTAT, 2021) compared with a potential grain yield of 2-2.5 t/ha (Binagwa et al., 2020). Despite the release of 49 common bean varieties in Tanzania, farmers' adoption of improved varieties remains limited (14%) (Letaa et al., 2015; Katungi et al., 2019). The reasons for low adoption, among other factors, include disease susceptibility, poor adaptation to farmers' field conditions and poor management practices. factors, disease, specifically Among these anthracnose (Colletotrichum lindemuthianum) plays a crucial role in discouraging adoption of improved varieties. Anthracnose severity increases when temperature is around 17 °C, relative humidity is above 92% and soil pH of 5.8 to 6.5. The disease attacks various parts of the bean plant, including leaves, stems, pods, and seeds leading to development of dark brown necrotic lesions on these plant components. These lesions reduce bean leaf photosynthetic capacity, ultimately leading to a reduction in overall grain yield.

Research on evaluation of common bean for disease resistance and grain yield has focused primarily on research station trials (Shida et al., 2019; Binagwa et al., 2020). Although on-farm research has been conducted (Bucheyeki and Mmbaga, 2013) very little has documented disease infection rates and grain vield. Lack of information reduces farmers' confidence in adopting improved common bean varieties. A particular variety may perform well in one environment and less well in another. This uncertainty limits recommending varieties for different environments and promotes varietal selection by environment. This factor needs consideration when developing any variety for use across a mega-environment, to reduce the chances of introducing new bean varieties that do not perform well across the range of farmers' field conditions, and to prevent rejection of valuable varieties that can perform well on farm. This emphasizes the importance of identification, evaluation and selection of high-performing, stable genotypes with general and specific adaptability within the megaenvironment. Therefore, the aim of this study was to

evaluate the performance of common bean genotypes under on-station and on-farm conditions to allow the selection of varieties for improved productivity, nutrition, and income generation among smallholder farmers in Tanzania.

Material and Methods

Breeding materials and study location

Eighteen germplasm samples were obtained from Tanzania Agricultural Research Institute (TARI – Maruku, Selian and Uyole) and four farmer-selected varieties, frequently cultivated by Tanzania were gathered at random from the study sites. Two onstation trials were established at TARI Selian in Arusha district and at the Tanzania Coffee Research Institute (TACRI) Lyamungo in Moshi district. Six on-farm trials were established, in each of three districts (Karatu, Siha and Lushoto), with two trials per district.

Details of the field trial, planting, and weather condition

All experimental trials were laid out using a completely randomized factorial design with three replications in two on-station and six on-farm environments. Each experimental plot consisted of a single genotype planted in four rows, 2-meter-long. The rows were spaced 50 cm apart, and within each row, holes were spaced 20 cm apart. Two seeds were planted in each of these holes. During planting diammonium phosphate (DAP) were applied at the rate of 100 kg P/ha in each hole (Mushagalusa et al., 2016), then holes covered with a light layer of soil to avoid seed scorching. TARI Selian and Karatu experimental trial sites were planted in March 2022 and harvested in June 2022, while at TACRI Lyamungo, Siha and Lushoto, planting and harvesting were conducted in April 2022 and July 2022, respectively. Firstly, weeding was carried out 3 weeks post-germination (WPG) and second weeding at 7 WPG. Pests and diseases were controlled by spraying SNOW PLUS and chlorothalonil at a rate of 15 ml and 30 ml respectively per 15 l of water using a knapsack sprayer, respectively during third trifoliate (V3), pre-flowering (R1) and pod formation (R5) stages. Rainfall, maximum and minimum temperatures were recorded in trial locations between March and July 2022, and are presented in Table 1.



	TACRI Lyamungo			TARI Selian			ŀ	Karatu			Siha		Lushoto			
Month	Rainfall	Temperature (°C)		Rainfall	Tempo (°	Temperature (°C)		Temperature (°C)		Rainfall	Temperature (°C)		Rainfall	Temperatur e (°C)		
	(mm)	Max	Min	(mm)	Max	Min	(mm)	Max	Min	(mm)	Max	Min	(mm)	Max	Min	
March	29.9	27.7	16.4	193.9	23.4	14.3	213.7	22.2	14.8	31.7	28.4	16.7	19.2	33.1	24.9	
April	287	29.4	15.1	154.9	27.2	16.1	177.2	26.3	15.9	273.2	29.2	15.5	108.7	31.8	24.9	
May	202.8	26.4	15.9	98.7	26.5	17.2	116.3	25.9	16.8	197.8	26.7	16	115.2	31	23.8	
June	196.1	23.9	15.6	87.9	24.1	16.4	93.4	23.1	16.1	148.3	24	15.7	92	29.8	22.4	
July	58.2	21.6	15.1	26.8	21.6	14.1	38.3	22.4	13.9	42.5	21.8	15.4	45.7	28.2	21.3	
Mean	154.8	25.8	15.6	112.8	24.7	15.6	127.8	23.9	15.5	138.7	26	15.9	76.2	30.8	26.5	

Table-1. Weather variables measured during the 2022 common bean cropping season (meteorological stations located at Arusha, Moshi and Tanga). Source: Tanzania Meteorological Authority

Data collection

Disease evaluation was conducted for anthracnose, angular leaf spot, bean common mosaic virus (BCMV), common bacterial blight and leaf rust severity at 3, 5 and 7WPG, using an evaluative scale ranging from 1 to 9, where the scale of 1-3 =resistance -no visible symptoms or very light symptoms respectively, 4-6= intermediate – visible and conspicuous symptoms resulting only in limited economic damage and 7 - 9 = Susceptible – Severe to very severe symptoms causing considerable yield losses or plant death (Schoonhoven and Pastor-Corrales, 1987). Additionally, the data on number of emerging plants; canopy height and width; plant vigor, and number of plant stands at time of harvest were also documented. Five randomly selected bean plants per plot were tagged and assessed for plant vigor, canopy height and width at 8WPG. Canopy height was obtained by measuring plant length from ground soil to plant apex. Canopy width was determined by taking measurements across the entirety of bean plants surface, encompassing the circumference of its leaves. Plant vigor was recorded through visual observation of the plant using a scale from 1 to 5, where 5 corresponds to excellent; 4 to very good; 3 to good; 2 to poor, and 1 to very poor. The number of plant stands at harvest was recorded by counting the number of plants per plot during 2 WPG. The number of pods per plant was recorded by counting the number of pods from five randomly selected plants per plot, and the number of grains per pod was recorded by counting the number of grains per pod from five randomly selected plants per plot. After harvest and grain drying, 100 grains were counted and weighed to obtain 100-grain weight. Grain yield per plot was recorded by measuring all grain from each plot and calculating the total grain yield per hectare.

Statistical analysis

Data on bean growth, disease infection levels and grain yield components were analyzed using R software at a probability level of 5% and the mean separation using Tukey test. Biplot principal component analysis (PCA) was conducted to evaluate the effect of interactions between genotype and environment (GEI). This assesses the ability of different breeding material for its adaptability to different environments and analyses germplasm sample stability across environments. As prescribed by Purchase et al. (2000), an additive main effects and multiplicative interaction model (AMMI) stability value (ASV) was used to estimate and rank the common bean breeding samples according to their yield stability as follows (equation 1):

$$ASV = \sqrt{\left\lfloor \frac{SSIPC1}{SSIPC2} (IPC1) \right\rfloor^2 + (IPC2)^2} \dots (Equation 1)$$

Whereby IPCA1sq is equal to the principal interaction component derived by dividing the sum of squares IPCA 2sq from the AMMI analysis of variance table. The greater the absolute value of IPCA, the greater the adaptability of the breeding material to the specific environment, while lower ASV value indicates greater stability in different environments. The genotype selection index (GSI_i) of individual genotypes was calculated by taking the rank of the mean grain yield of common bean genotype (RY_i) through environments according to the rank of AMMI stability value (RASV_i) (Tadesse et al. (2018) as equation 2)

 $GSI_i = RASV_i + RY_i$ (Equation 2)



Asian J Agric & Biol. 2024(4).

Results

Bean plant growth variation by genotype and environment

The analysis of variance (ANOVA) shows that, except for genotype canopy height, all other growth variables showed highly-significantly differences (P ≤ 0.05) between genotype (G), environment (E) and genotype by environment interactions (GEI) (Table 2). The number of plant stands emerging, and number of plant stands at harvest were high on advanced breeding lines (77.4/69.5) and improved varieties (76.8/68.5) compared with local varieties (70.0/55.7) across the mega-environment (Table 8 Supplementary information). Common bean plant growth varied among and between the two on-station trials and six on-farm trials, where mean canopy height was 44.2 cm and 44.5 cm for TARI Selian and TACRI Lyamungo on-station sites, respectively, while for the on-farm trials, the mean canopy heights ranged from 43.2 cm and 43.4 cm (Table 8 Supplementary information). On-station trials showed a mean canopy width of 15.8 cm, while onfarm trials presented a mean canopy width of 14.2 cm. Using a scale from 1 to 5, where 5 represent excellent; 4 indicates very good; 3 implies good; 2 denotes poor and 1 signifies very poor, the mean plant vigor for on-station trials was 4.6, while for on-farm trials it ranged from 3.8 to 4.1. Furthermore, plant vigor also varied between advanced breeding lines, improved varieties, and farmers' varieties. The mean plant vigor of the advanced breeding lines was 4.8, improved varieties was 4.5 and farmers' varieties was 3.2 (Table 8 Supplementary information).

Common bean disease infection by genotype and environment

A highly-significant difference (P ≤ 0.05) was observed for common bean diseases (anthracnose, angular leaf spot, BCMV, common bacterial blight and leaf rust) among G, E, and GEI (Table 3). Overall, disease infection levels in on-station trials were lower (1.3) than in on-farm trials (1.7) (Figure 1). Study sites at Mwangaza were the most severely affected by common bean diseases (1.92) followed by Matadi (1.76), Upper Kitete (1.72), Mnadani (1.6), Rhotia (1.56), Kwekifinyu (1.52), TACRI Lyamungo and TARI Selian (1.24)Table (1.38)9 Supplementary information.

Anthracnose and BCMV infection were more severe in Upperkitete (3.2 and 1.7) than in other study locations (Mnadani 2.9 and 1.6; Rhotia 2.8 and 1.5; Mwangaza 2.8 and 1.4; Kwekifinyu 2.7 and 1.5; Matadi 2.7 and 1.4) Table 9 Supplementary information. Common bacterial blight was only found at Siha and Lushoto sites, while leaf rust was observed everywhere except for Lushoto (Figure 1). Advanced breeding lines were less susceptible to infection from bean diseases compared to commercial checks across environments (Table 9 Supplementary information). Anthracnose caused by Colletotrichum lindemuthianum scored highest (2.7) followed by angular leaf spot (1.8), common bacterial blight (1.7), leaf rust (1.6), and BCMV (1.4) Table 9 Supplementary information. Anthracnose, as a major common bean disease across locations, was used to identify resistant or susceptible genotypes. NUA 48, NUA 64, Sweet Violet, VTT 923-23-10, RWR 2154, Kipapi, Gloria, KAB 36, COD MLB 0033, , RCB 593, SMC 18, SCR 6, Selian 12, Uyole 18, Calima Uyole, Uyole 03, and Boroto varieties were all resistant to anthracnose, whereas Soya Kijivu, Rose coco, Njano gololi, Lyamungo 90 and Selian 13 varieties exhibited a moderate level of resilience against anthracnose.

Grain yield variation by genotype and environment

The combined analysis of variance reveals that, excluding the grain yield by genotype, there were highly-significant differences ($P \le 0.05$) among G, E & GEI (Table 4) for all other bean yield components. Yields and yield components were higher in onstation trials compared with on-farm trials (Table 5). Grain yields ranged from 1,383 to 2,180 kg/ha under on-station trials and from 1,039 to 1,817 kg/ha under on-farm conditions. Advanced breeding lines (Gloria, Kipapi, Nua 48, Nua 64, Sweet Violet and VTT 923 -23-10) produced 56% higher grain yields than the commercial checks. Some genotypes outperformed under on-station conditions, while on-farm trials under-performed. For instance, under on-station conditions, NUA 48 produced 1,708 kg/ha and 2,180 kg/ha grain yields for TARI Selian and TACRI Lyamungo, respectively. Under on-farm conditions, the grain yields for NUA 48 were 1,397 kg/ha, 1396 kg/ha, 1,465 kg/ha, 1,466 kg/ha, 1,565 kg/ha and 1,611 kg/ha for Mwangaza Siha, Mnadani Lushoto, Matadi Siha, Kwekifinyu Lushoto, Rhotia Karatu and Upperkitete Karatu sites, respectively. The grain yields for NUA 64 were 1,730 kg/ha and 2032 kg/ha TARI Selian and TACRI Lyamungo, for

respectively, while under on-farm conditions, the same variety produced grain yields of 1,390 kg/ha, 1,391 kg/ha, 1,408 kg/ha, 1,444 kg/ha, 1500 kg/ha and 1,663 kg/ha at the six on-farm trial sites. Some genotypes produced higher grain yield values in higher rainfall areas compared with low rainfall areas. For example, at TACRI Lyamungo the grain yields from VTT 923-23-10 and Sweet Violet were 1,847 kg/ha and 1,708 kg/ha, respectively, while at Lushoto the grain yields from VTT 923-23-10 and Sweet Violet

were 1,232 kg/ha and 1,114kg/ha, respectively.

VTT 923-23-10 and Sweet Violet were stable genotypes across study locations. For instance, in areas with high rainfall, the grain yields of VTT 923-23-10 ranged from 1,747 kg/ha to 1,847 kg/ha, while under low rainfall conditions, grain yield ranged from 1,190 kg/ha to 1,231 kg/ha. Sweet Violet grain yields ranged from 1,673 kg/ha to 1,708 kg/ha under high rainfall, while in low rainfall areas grain yields ranged from 1,065 kg/ha to 1,114 kg/ha.

Table-2. Analysis of variance (mean square values) for number of plant stands emerging, canopy height, canopy width, plant vigor and number of plant stands at harvest across eight environments

Source of variation	DF	Plant stand emerging	Canopy height	Canopy width	Plant vigor	Plant stand at harvest
		MS	MS	MS	MS	MS
Environment (E)	7	31.0***	26.8***	37.3***	6.8***	1521.1***
Rep (E)	16	0.71***	0.79***	0.87***	0.17***	0.67***
Genotype (G)	21	198.5***	623.0 ^{ns}	30.2***	3.9***	662.9***
G * E	147	2.0***	3.6***	0.7***	0.3***	15.3***
Error	336	0.512	0.373	0.474	0.115	0.549
CV%		0.94	1.4	4.71	8.23	1.11

***Significant at P \leq 0.001, ns=not significant. DF= Degree of freedom; MSS=Mean of square and CV= Coefficient of variation and MSR= Mean of Square Regression.

Table-3. Analysis of variance (m	nean of square values)) for common bean	disease infection
----------------------------------	------------------------	-------------------	-------------------

Source of variation	DF	Anthracnose	Angular leaf spot	Leaf rust	Common bacterial blight	Bean common mosaic virus
		MS	MS	MS	MS	MS
Environment (E	7	7.95***	7.97***	37.78***	61.38***	0.87***
Rep (E)	16	0.21***	0.56***	0.28***	0.58***	0.38***
Genotype (G)	21	23.57***	21.43***	2.45***	0.87***	5.37***
G * E	147	0.83***	0.62***	0.46***	0.34***	0.33***
Error	336	0.216	0.392	0.189	0.151	0.219
CV%		16.3	13.24	16.46	45.72	12.93

***Significant at P \leq 0.001. DF= Degree of freedom; MSS=Mean of square and CV= Coefficient of variation and MSR= Mean of Square Regression

Table-4. Analysis of variance (mean of square values) for number of pods per plant (NPP), 1	umber of
grains per pod (NGP), 100-grain weight (100GW) and grain yield (GY)	

Source of variation	DE	NPP	NGP	100GW(gm)	GY (kg/ha)
Source of variation	Dr	MS	MS	MS	MS
Environment (E	7	742.6***	8.66***	263.4***	1164697.19***
Rep (E)	16	5.61***	0.28***	0.44***	475.67***
Genotype (G)	21	575.8***	4.45***	402.7***	1829749.03***
G * E	147	39.3***	0.56***	7.8***	53244.23***
Error	336	1.261	0.197	0.96	676.8
CV%		3.49	10.94	2.28	2.23

***Significant at P≤0.001. DF= Degree of freedom; MSS=Mean of square and CV= Coefficient of variation and MSR= Mean of Square Regression



Figure-1. Common bean disease infection mean scores by trial location.

Location	TARI	TACRI	Rhotia Korotu	Upperkitet	Matadi	Mwangaz	Mdadani Luchata	Kwekifiny	Genotype
	Senan	Lyamungo	Karatu	e Karatu	Sina	a Silla	Lushoto	u Lushoto	mean
Bean genotypes	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)	GY (kg/ha)
Gloria	1415.6	1249.5	1163.5	1209.1	1358.1	1370.4	1064.4	1087.5	1239.8
Kipapi	1383	1222.6	1138.5	1201.8	1358.6	1118.6	1039.9	1296.1	1219.9
NUA 48	1708.5	2180.3	1565.6	1611.7	1464.9	1396.3	1396.3	1466.5	1598.8
NUA 64	1730.1	2031.6	1499.6	1663.7	1444	1390.6	1390.6	1408.2	1569.8
Sweet Violet	1516.8	1708.3	1239.5	1756.5	1673.5	1065.7	1065.7	1114.1	1392.5
VTT 923 -23- 10	1421.6	1847.4	1254.4	1817.3	1748.8	1190.2	1190.2	1231.5	1462.7
COD MLB 0033	1529.4	1780.1	1229.1	1380.9	1171.4	1177.8	1138.3	1161.2	1321.0
KAB 36	1563.8	1744.2	1284.7	1345.9 1223.		1215	1184.2	1206	1345.9
RCB 593	1396.3	1568.3	1130.3	1206.5	1088.3	1048.1	1048.1	1078.6	1195.6
RWR 2154	1612.4	1833.8	1312.8	1366.6	1242.4	1164.6	1164.6	1227.9	1365.6
SCR 61	1385.2	1559.5	1131.6	1172.4	1065.8	1037.2	1037.2	1075.9	1183.1
SMC 18	1426.1	1608.4	1169.7	1222.7	1111.6	1072.3	1072.3	1098.3	1222.7
Selian 12	1368.7	1206.2	1140.3	1185.9	1306.5	834.7	834.7	879.2	1094.5
Selian 13	1193.1	1244.5	940.7	1020.7	1513.5	1315	1315	1363	1238.2
Uyole 18	1135.9	1255.1	925.5	1223.4	1500	1094.9	1094.9	937	1145.8
Calima Uyole	1250	1074.2	1020.5	1318.4	971.1	980.8	929.8	950.8	1062.0
Uyole 03	1119.9	1221	1014.1	1198.3	1139.5	1044.1	1044.1	1172	1119.1
Lyamungo 90	838.8	860.9	626.5	655.5	620.4	573.2	573.2	594.6	667.9
Boroto	906.5	1117.6	718.4	747	975.4	962.8	624.5	642.8	836.9
Njano Gololi	851.9	848.4	709.8	743.6	809.3	628.9	628.9	658.6	734.9
Rosecoco	1067.6	929.9	868.2	902	810.9	788.7	788.7	814.2	871.3
Soya Kijivu	709.1	795.2	586.2	622.9	566.2	518.6	518.6	545.2	607.8
Location means	1296.8	1404	1075.9	1207.8	1189.3	1044.9	1006.6	1045.9	1158.9
SD	5.5	2.8	2.8 34.3		27.7	9.2	27.7	5.6	15.3
CV %	0.4	0.2	3.2	0.8	2.3	0.9	2.8	0.5	1.4

Table-5.	Genotype	grain	yield	means	by	environment
		0	•		•	

GY= Grain yield.



AMMI stability value and yield stability index for grain yield

AMMI biplot modelling was used to determine the interaction effects of G and E principal components (PC) (Figure 2). The main effect of G, E, and GEI account for 50.3%, 25.7% and 23.2% of grain yield, respectively (Table 6). Genotypes on the right-hand side of the biplot (Figure 2) show a superior grain yield performance compared with genotypes on the left-hand side. Genotypes close to or on the vertical axis are the most stable across the mega-environment compared to genotypes that are distant to the vertical axis. The most stable genotypes are those less affected by GEI. VTT 923-23-10 and Sweet Violet exhibited the highest positive GEI, while NUA 48 and NUA 64 exhibited the highest negative GEI. Mwangaza and Matadi sites respectively had the highest GEI, while Rhotia kati, Kwekifinyu and Mnadani sites respectively had the lowest genotype by environmental interaction. The two on-station trials at TACRI Lyamungo and TARI Selian, as well as the Upperkitete on-farm trial showed significant variation on grain yield performance when compared with the other trials.

Basing on AMMI stability values (ASV) for bean grain yield among 22 genotypes and environment, genotypes were ranked according to their scores, where lower scores indicate greater stability. Calima Uyole was identified as the most stable genotype due to its lowest ASV, followed by Soya Kijivu, Lyamungo 90, Rosecoco and Boroto (Table 7). Contraly Selian 13 was deemed the most unstable genotype due to its highest ASV. When considering the Genotype Stability Index (GSI_i), which combines grain yield (RY_i) and AMMI stability rankings (RASV_i). Soya Kijivu emerged as the top-performing and most stable common bean genotype across sites. This was followed by Lyamungo 90, Njano gololi, Boroto and Rosecoco (Table 7). Conversely, NUA 48 was designated as the most unstable common bean genotype based on GSI_i.

GGE Biplot

Genotype main effect -G and genotype by environment interaction - GE (GGE) biplot was used

to compare how different environments and genotypes perform in term of grain yield. The length of environmental vector helps to understand how each environment discriminates between genotypes based on their yield. Genotypes with a shorter route from the center of the concentric cycles had low power of discrimination (Figure 3). NUA 64 ranked first, because it is closest to the innermost circle on the plot, indicating it had a higher discriminating capacity for superior grain yield. Following closet were VTT 923-23-10, NUA 48 and Sweet Violet. On the other hand, genotypes like Soya Kijivu, Lyamungo 90, Njano Gololi, Boroto and Rosecoco ranked lowest, being furthest from the innermost core, indicating they had a lower ability to discriminate. NUA 64 and NUA 48 showed the best performance in TACRI Lyamungo, TARI Selian, Upper Kitete, Rhotia and Kwekifinyu, respectively. While VTT 923-23-10 and Sweet Violet performed well in Upperkitete, Mnadani, Kwekifinyu, Mwangaza and Matadi.



Figure-2. AMMI biplot model for grain yield (kg/ha) presenting means of genotype and environment



Asian J Agric & Biol. 2024(4).

Source of variation	DF	SS	MS	F	P value	%GEISS
Total	674	227426.5	92680.2			
Genotypes	21	38424730	1829749	2703.3	0.000***	
Environments	7	8152880.4	1164697.2	2448.5	0.000***	
Genotype * Environment Interaction	147	7826902.5	53244	78.7	3.309***	
PC1	27	3933109.6	145670.7	215.2	0.000***	50.3
PC2	25	2015304.8	80612.2	119.1	0.000***	25.7
PC3	23	1041291.5	45273.5	66.9	0.000***	13.3
PC4	21	504915	24043.6	35.5	0.000***	6.5
PC5	19	183369.2	9651	14.3	0.000***	2.3
PC6	17	88961.8	5233	7.7	0.000***	1.1
PC7	15	59950.6	3996.7	5.9	0.000***	0.8
Error	336	62466452	676.9			

Table-6. ANOVA AMMI biplot model for genotype, grain yield, environment, and genotype by environment interaction

Table-7. Common bean genotype ranking - AMMI stability value (ASV) and Genotype stability index (GSI)

Bean genotypes	IPCA1	PCA2	ASV	RASV _j	RY _i	GSI i	RGSI i
Gloria	7.00	1.90	13.79	13	1240	1253	14
Kipapi	5.16	6.20	11.82	10	1220	1230	12
NUA 48	-10.88	-1.68	21.29	20	1607	1627	22
NUA 64	-8.46	-2.02	16.63	15	1579	1594	21
Sweet Violate	2.85	-15.77	16.72	16	1445	1461	19
VTT 923 -23-10	4.17	-16.48	18.38	18	1514	1532	20
COD MLB 0033	-9.43	-0.83	18.42	19	1321	1340	16
KAB 36	-7.74	1.48	15.18	14	1346	1360	17
RCB 593	-6.28	1.73	12.38	11	1203	1214	11
RWR 2154	-9.28	0.32	18.1	17	1376	1393	18
SCR 61	-5.70	2.26	11.36	9	1198	1207	10
SMC 18	-6.80	1.78	13.39	12	1229	1241	13
Selian 12	4.69	-3.51	9.8	8	1145	1153	8
Selian 13	16.98	8.09	34.12	22	1270	1292	15
Uyole 18	11.97	-5.73	24.06	21	1175	1196	9
Calima Uyole	0.23	1.88	1.93	1	1062	1063	6
Uyole 03	4.20	4.32	9.27	7	1129	1136	7
Lyamungo 90	-0.96	4.84	5.19	3	675	678	2
Boroto (Check)	3.27	-2.75	6.95	5	837	842	4
Njano Gololi (Check)	4.15	3.04	8.65	6	758	764	3
Rosecoco (Check)	0.77	6.75	6.91	4	876	880	5
Soya Kijivu (Check)	0.09	4.18	4.19	2	619	621	1





Figure-3. GGE biplot showing superior genotypes for mean grain yield across environments.

Discussion

Fluctuations in weather, disease occurrence and grain yield

The highest rainfall across all study locations was recorded at TACRI Lyamungo on-station site (Table 1). This could be because the site is close to mount Kilimanjaro with good environmental conservation, especially trees. The site has consistent rainfall throughout the cropping season (December to July) hence contributing to the greatest amount of rainfall among all the locations studied. Comparative analysis indicated that high rainfall led to a significant increase in the number of emerging plants, number of plant stands at the time of harvest and the overall grain yield. Similar findings were reported by Binagwa et al. (2020); Mashamba et al. (2021), who concluded that weather conditions significantly influenced bean growth and grain yield.

High rainfall provides plants with an abundant water supply, which is essential for germination and early growth. Adequate moisture in the soil helps seeds to swell and break dormancy, facilitating the emergence of seedlings (William et al., 2006). With favorable moisture conditions, plants experience vigorous growth and development. Adequate rainfall supports robust root development, which aids in nutrient uptake and overall plant health. As a result, plants can easily handle environmental stresses and disease pressures. Rainfall is a critical factor influencing crop yield (Lizumi and Ramankutty, 2015). Sufficient moisture availability during the growing season allows plants to photosynthesize efficiently, leading to increased biomass production. Adequate rainfall also ensures that plants have the necessary water supply for nutrient transport and metabolic processes (Lizumi and Ramankutty, 2015). Additionally, high rainfall can mitigate the negative effects of drought and heat stress, reducing yield losses.

Common bean growth variation by genotype and environment

The analysis of variance reveals highly-significant variations among and between G, E and GEI on the number of emerging plants, plant vigor, canopy height, canopy width and number of plant stands at harvest (Table 2). Comparable results were documented by Musharaf et al. (2015) and Tadesse et al. (2018) on the performance of common bean varieties across mega-environments. The differences observed among genotypes indicate genetic variability of bean plant growth under varying environment conditions. The significant effects of environment highlight the importance of external factors such as soil, weather variabilities and management practices in shaping bean growth and development. Understanding these environmental influences can help to optimize bean production in different locations. The interactions between genotype and environment emphasize the complexity of plant responses, indicating that different genotypes may perform differently across various environment. This suggests the need to develop breeding and management strategies that consider different genotypes or environments to maximize bean productivity and resilience. The number of emerging plants and plant stands at harvest was higher on advanced breeding lines (Gloria, Kipapi, Nua 48, Nua 64, Sweet Violet and sVTT 923 -23-10) and improved varieties (Calima Uyole, Lyamungo 90, Selian 12, Selian 13, RCB 593, SMC 18, SCR 61, COD MLB 0033, RWR 2154, KAB 36, Uyole 03 and Uvole 18) compared to local varieties (Boroto, Njano Gololi, Rosecoco and Soya Kijivu). Similar findings were reported by Kadege and Lyimo (2015) and Reis et al. (2022). This implies that the newly developed genotypes and improved variety possess traits or characteristics that contribute to higher bean plant emergence and survival under prevailing conditions. This success suggest that breeding efforts in Tanzania have been effective in developing bean varieties with desirable traits such as disease resistance, and



Asian J Agric & Biol. 2024(4).

drought tolerance that enhance emergence and survival rate.

Additionally, the numbers of emerging plants and plant stands at harvest are influenced by suboptimal seed storage temperatures, whereby different seed storage regimes for seeds collected on station and from farmers' saved seed significantly contributed to differences in plant germination and development. Poor plant emergence and plant stands from farmers' saved seed resulted from poor pre-harvest seed management techniques and post-harvest handling, especially poor storage conditions, where 75% of farmers' saved seeds were stored in tins and plastic bags. Moreover, larger seeds resulted in significantly better emergence and number of plant stands at harvest due to their large endosperms, which facilitate their germination, emergence, and early plant development (Yan et al., 2014). Canopy height and width showed best performance on-station compared to on-farm trials. Satisfactory canopy height and width under on-station conditions were observed where they were supported by efficient soil management practices prior to the cropping season (fallowing, crop rotation, deep ploughing), nutrientrich soil, and soil moisture during bean growth. This result confirms findings by Mahesh (2007) for groundnut who found that shoot length and shoot width indices differed significantly among varieties, seed sources and tested locations.

Bean plant vigor was measured by increases in the number of plants emerging, canopy height, canopy width and plant stands at harvest. Several factors affect plant vigor, including soil fertility, seed maturity at harvest, seed processing, seed storage conditions and treatment, which can influence the number of plant stands emerging, canopy height, canopy width and plant stands at harvest in the field. Plant stand emergence significantly affects canopy height and canopy width, which eventually affects plant stands at harvest and plant vigor. Plant vigor affects plant growth, subsequently affecting the plant's developmental stages and can eventually shorten the crop cycle (Mondo et al., 2016). The advanced breeding lines and improved varieties demonstrated excellent plant vigor compared to local varieties, which is likely due to better seed management, processing and storage compared to the farmers' varieties. Seed quality is extremely important for the bean business, because it can affect plant stand emergence, plant development and competitive ability, which can affect plant vigor

(Reis et al., 2022). The use of high-quality seed under good environmental conditions favors plant stand emergence, initial plant development, and canopy height and width, with a positive influence on the plant stands at harvest.

Common bean disease infection by genotype and environment

Highly-significant differences were revealed for anthracnose, angular leaf spot, BCMV, common bacterial blight and leaf rust among G, E and GEI. This provide insights to better understand disease dynamics, and disease resistance and susceptibility, hence informing the research effort and management authorities aimed at enhancing healthy bean plant and productivity. Genotype traits and environmental factors are recognized to be influential in inducing variations in plant disease progression, impacting either the host, the pathogen, or their interplay (Girma et al., 2022). Common bean disease infection levels were highest among on-farm trials compared with the on-station trials. The higher infection levels observed in on-farm trials were influenced by factors such as natural environment, variability in farming practices, disease pressure, lack of disease management and crop diversity.

On-farm trials expose crops to a broader range of disease-causing pathogens and insects, increasing the likelihood of disease infection. The majority of onfarm trials practiced continuous cropping, which resulted in higher disease pressure due to an accumulation of pathogen inoculum over time as the result of pathogen carryover from previous crops and nearby fields. Girma et al. (2022) reported similar findings on evaluation of common bean genotypes for resistance to common bacterial blight and angular leaf spot, and concluded high disease pressure is exerted by high inoculum levels in the soil and crop residues in the study locations. Furthermore, farmers' management practices (fallow, crop rotations, tillage techniques, fertilizer, and pesticide applications) differed across farms. These variations have an impact on the development and spread of common bean diseases, while on-station trials implement standardized management practices that reduce the potential for common bean disease infection and spread.

Across all the trial locations and types, anthracnose disease developed the highest infection levels compared to angular leaf spot, BCMV, common bacterial blight and leaf rust (Figure 1). Masunga et



al. (2020) on characterization of anthracnose in common bean reported the existence of new races and variability of C. lindemuthianum in major growing areas of Tanzania. This means the highest anthracnose infection level revealed in this study was due to a wide distribution and variability of this pathogen in the study locations. Advanced breeding lines showed lower infection levels among genotypes and across study locations compared to the commercial checks, indicating the potential for disease resistance in those lines. The advanced breeding lines tested in this study were developed through a selection process that prioritized disease resistance, particularly for economically important disease in Tanzania, hence those leading to lower infection levels compared to the commercial checks.

Grain yield variation by genotype and environment

Highly-significant differences (P< 0.01%) were observed for grain yields and yield components among G, E and GEI, indicating differential performance of genotypes under different environments. Similar findings were reported by Mashamba et al. (2021) on evolution of common bean genotypes in different agroecosystems of Tanzania. This finding suggests the need for further common bean agroecosystem evaluations for the selection of potential genotypes based on their performance in major environments and according to farmers' preferences. On-station trials scored high on number of pods per plant, number of grains per pod, 100-grain weight and grain yield among G, E and GEI. Significant differences among G, E and GEI indicate the effect of testing location in GEI, genetic variability among genotypes and stability among genotypes. Similar findings were reported by Mashamba et al. (2021).

AMMI analysis indicated that the primary factor influencing common bean grain yields was the genotype, accounting for 50.3% of the variation, while environmental factors played a smaller role at 25.7%. This observation suggests that the selected genotypes and experimental locations exhibited diversity, making them suitable for both specific and overall genotype adaptability assessments. Similarly, when Moreno and Ladino (2021) evaluated common bean for grain yield performance they reported highest contribution by genotype (53.14%) on grain yield compared to environment effects (15.87%). A Balakrishnan et al. (2016) study revealed that genotype main effects accounted for 41.3% of rice grain yield, whereas environmental main effects contributed 31.9%. Conversely, Tadesse et al. (2018) common bean research exhibited a notable shift, with environmental effects playing a more prominent role at 78.2%, while genotype main effects lagged behind at 6.5%. This divergence in genotype main effect findings in our study might be from discrepancies in the selection of common bean genotypes and experimental locations. Our study used twenty-two bean genotypes (12 improved varieties, 6 advanced breeding lines and 4 local varieties) in eight study locations, whereas Tadesse et al. (2018) research focused on fourteen white bean genotypes (12 breeding lines and 2 improved varieties) in three study locations.

Common bean genotypes with ASV values closer to zero are considered more stable, while those with higher values are highly influenced by environmental factors (Horn et al., 2018). Some bean genotypes like Soya Kijivu, Lyamungo 90, Rosecoco and Boroto (Table 7) were ranked as stable by ASV, despite having low yields. This is because stability is not linked to yield levels (Rono et al., 2016). Therefore, the Genotype Stability Index (GSI_i) was utilized to pinpoint common bean genotypes that exhibit both high grain yield and stability, consolidating these characteristics into a single index for genotype selection (Adjebeng-Danquah et al., 2017; Milioli et al., 2018). Genotypes with lower GSI_i values are deemed more advantageous as they possess high mean yield and stability characteristics (Bose et al., 2014). In this study, four bean genotypes (NUA 48, NUA 64, VTT 923-23-10 and Sweet Violet were identified as exhibiting high grain yield and stability based on GSI_i.

Grain yield increased with the increase in number of pods per plant, number of grains per pod and 100grain weight. The number of pods per plant and grain yield significantly determine productive potential of the crop in response to plant population (Kazemi et al., 2012; Barili et al., 2015). Furthermore, higher grain yields at on-station trials are attributed to efficient soil management through deep ploughing, crop rotation with cereals and different legumes, timely weed management and insecticide application, which allow efficient utilization of soil nutrients, soil moisture and partitioning of photosynthesis on grain production. This confirms findings by Bakry et al. (2011) and Alemu et al. (2018), which indicate that grain yield intensity is proportional to nutrient



💓 Asian J Agric & Biol. 2024(4).

availability, and photosynthetic activity, which stimulate the plant to produce more pods and a higher grain yield. Advanced breeding lines showed a higher grain yield advantage over commercial checks across the mega-environment. These results align with findings by Musharaf et al. (2015); Mashamba et al. (2021) and Reis et al. (2022) that reported significant yield increases on candidate lines compared to commercial checks. NUA 48 and NUA 64 outperformed commercial checks in terms of anthracnose resistance and grain yield, while VTT 923-23-10 and Sweet Violet were stable genotypes across the mega-environment.

Conclusion

Based on the trial results, common bean disease infection levels and yields were significantly influenced by G, E and GEI. On-farm trial performance of advanced breeding lines was comparable to their performance in on-station trials for disease infection levels and yield components. Advanced breeding lines exhibited 56% higher grain yield than the commercial checks. NUA 48 and NUA 64 were superior genotypes for grain yield, while VTT 923-23-10 and Sweet Violet were stable genotypes across study locations. We recommend conducting both on-station and on-farm testing to select the best-performing genotypes in varied environments. Further on-farm evaluation is release recommended potential for and commercialization.

Acknowledgment

The Alliance of Bioversity International and the International Centre for Tropical Agriculture (CIAT) is gratefully acknowledged for financial support. Authors extend their appreciation to Tanzania Agricultural Research Institute (TARI) for providing common bean genotypes. The authors also thank Vincent Johnson of the Alliance of Bioversity International and CIAT Science Writing Service, for copy editing of this manuscript.

Disclaimer: None.

Conflict of Interest: None.

Source of Funding: Accelerated Varietal Improvement, Seed delivery of Legumes and Cereals in Africa (AVISA) and 1000FARMS initiative.

Contribution of Authors

Edith L. Kadege conceptualized the research, conducted the experiment, collected data, performed data analysis, and prepared first draft of the manuscript.

Pavithravani B. Venkataramana, Teshale Assefa, and Joseph C. Ndunguru provided technical advice and edited the manuscript.

Jean Claude Rubyogo secured funding and edited the manuscript.

Ernest R. Mbega contributed to conceptualization of the research and edited the manuscript.

References

- Adjebeng-Danquah J, Manu-Aduening J, Gracen VE, Asante IK and Offei SK, 2017. AMMI stability analysis and estimation of genetic parameters for growth and yield components in cassava in the forest and Guinea savannah ecologies of Ghana. Int. J. Agron. 1-10.
- Alemu A, Nebiyu A and Getachew M, 2018. Growth and yield of common bean (*Phaseolus vulgaris L.*) cultivars as influenced by rates of phosphorus at Jimma, Southwest Ethiopia. J. Agric. Biotechnol. Sustain. Develop. 10(6): 104–115.
- Bakry BA, Elewa TA, El-Karamany MF, Zeidan MS and Tawfik MM, 2011. Effect of row spacing on yield and its components of some faba bean varieties under newly reclaimed sand soil condition. World J. Agric. Sci. 7(1): 68–72.
- Balakrishnan D, Subrahmanyam D, Badri J and Raju AK, 2016. Genotype × environment interactions of yield traits in backcross introgression lines derived from *Oryza sativa cv. Swarna/Oryza nivara*. Front. Plant Sci. 7: 1-19.
- Barili LD, Martins N, Lelis A, Eustáquio J and Carneiro DS, 2015. Genotype-environment interaction in common bean cultivars with carioca grain cultivated in Brazil in the last 40 years. Crop Breed. App. Biotechnol. 15(4): 244–250.
- Binagwa PH, He G, Egnin M, Bernard GC, Mortley D and Bonsi CK, 2020. Evaluating natural infection of fungal, bacterial, and viral pathogens to dry bean genotypes under field conditions. J. Plant Breed. Crop Sci. 12(1): 70-90.
- Bose LK, Jambhulkar NN, Pande K and Singh ON, 2014. Use of AMMI and other stability statistics

in the simultaneous selection of rice genotypes for yield and stability under direct-seeded conditions. Chil. J. Agric. Res. 74(1): 3-9.

- Bucheyeki TL and Mmbaga TE, 2013. On-Farm Evaluation of Beans Varieties for Adaptation and Adoption in Kigoma Region in Tanzania. ISRN Agronomy. 2013. DOI: http://dx.doi.org/10.1155/2013/436064
- FAOSTAT Food and Agricultural Organization, 2021. Crop production data. Available at: http://www.fao.org/faostat/en/
- Girma F, Fininsa C, Tefere H and Amsalu B, 2022. Evaluation of common bean (*Phaseolus vulgaris*) genotypes for resistance to common bacterial blight and angular leaf spot diseases, and agronomic performances. Heliyon. 8(8): e10425. DOI: 10.1016/j.heliyon.2022.e10425.
- Horn L, Shimelis H, Sarsu F, Mwadzingeni L and Laing MD, 2018. Genotype-by-environment interaction for grain yield among novel cowpea (*Vigna unguiculata L.*) selections derived by gamma irradiation. The Crop J. 6(3): 306-313.
- Kadege E and Lyimo HJF, 2015. Prevalence and control of wheat (*Triticum aestivum* L.) seed borne fungi in farmer-saved seeds, Phytopath. Plant Protect. 48(7): 601-610.
- Katungi E, Letaa E, Kabungo C, Ndunguru A, Mukankusi CM, Raatz B and Rubyogo JC, 2019. Assessing the impact of the tropical legumes II & III project on common bean productivity, profitability, and marketed surplus in southern highlands of Tanzania. Technical Report Tanzania. pp. 1-48.
- Kazemi E, Naseri R, Karimi Z and Emami T, 2012. Variability of grain vield and vield components of white bean (Phaseolus vulgaris cultivars as affected by different L.) plant density in Western Iran. J. Agric. Environ. Sci. 12(1): 17-22.
- Letaa E, Kabungo C, Katungi E, Ojara M and Ndunguru A, 2015. Farm level adoption and spatial diffusion of improved common bean varieties in southern highlands of Tanzania. Afr. Crop Sci. J. 23(3): 261-277.
- Lizumi T and Ramankutty N, 2015. How do weather and climate influence cropping area and intensity. Glob. Food Secur. 4: 46-50.
- Mahesh CG, 2007. Effect of seed source, growing season and genotypes on seed yield and quality in Groundnut (*Arachis hypogaea* L.) in Dharwad. MSc. Thesis, University of Agricultural Sciences,

Dharwad.

- Mashamba P, Ndakidemi PA and Mbega ER, 2021. Environmentally stable common bean genotypes for production in different agro-ecological zones of Tanzania. Heliyon 7(1): e05973. DOI: https://doi.org/10.1016/j.heliyon.2021.e05973
- Masunga M, Nchimbi MS, Robert M and Luseko AC, 2020. Races of *Colletotrichum lindemuthianum* (Sacc. Magnus) Briosi Cavara in major bean growing regions in Tanzania. Afr. J. Plant Sci. 14(8): 308–314
- Milioli AS, Zdziarski AD, Woyann LG, Dos Santos R, Rosa AC, Madureira A and Benin G, 2018. Yield stability and relationships among stability parameters in soybean genotypes across years. Chil. J. Agric. Res. 78(2): 299-309.
- Mondo VH, Nascente AS and Neto MOC, 2016. Common bean seed vigor affecting crop grain yield. J. Seed Sci. 38(4): 365-370.
- Moreno GL and Ladino CP, 2021. Grain yield and genotype x environment interaction in bean cultivars with different growth habits, Plant. Prod. Sci. 25(2): 232-241.
- Mushagalusa NG, Kashemwa A, Sinza CB, Bigirimwami LC, Karume K and Lubobo AK, 2016. Responses of biofortified common bean varieties to di-ammonium phosphate fertilizer under climate variability conditions in South-Kivu, DR Congo. Afr. J. Agric. Res. 11(38): 3569-3577.
- Musharaf K, Muhammad A, Ahamad N, Khan K, Khan SU and Chaudhry Z, 2015. Variability of Vigor and Viability of Various Varieties of Common Bean (*Phaseolus vulgaris* L.) Land Races. J. Agric. Environ. Sci. 15(5): 957-996.
- Purchase JL, Hatting H and Van Deventer CS, 2000. Genotype × environment interaction of winter wheat (*Triticum aestivum L*) in South Africa: II. Stability analysis of yield performance. S. Afr. J. Plant Soil. 17(3): 101–107.
- Reis VUV, Penido AC, Calvalho ER, Rocha DK, Reis LV and Semolin PHZ, 2022. Vigor of maize seeds and its effects on plant stand establishment, crop development and grain yield. J. Seed Sci. 44(3):1–12.
- Rono JK, Cheruiyot EK, Othira JO, Njuguna VW, Joseph K, Macharia JK, Owuoche J, Oyier M and Kange AM, 2016. Adaptability and Stability Study of Selected Sweet Sorghum Genotypes for Ethanol Production under Different Environments Using AMMI Analysis and GGE

Biplots. Sci. World J. 1-14.

- Schoonhoven AV and Pastor-Corrales MA, 1987. Standard System for the Evaluation of Bean Germplasm. Centro Internacional de Agricultura Tropical, Cali, Colombia. p. 53.
- Shida N, Mdachi M, William M, Kadege E, Kessy G, Mugunda D, Msaky J and Rubyogo JC, 2019.
 Grain Yield Performance of Biofortified Climbing Common Bean Genotypes (*Phaseolus Vulgaris* L.). J. Biol. Agric. Health. 9(4): 36-40.
- Tadesse T, Sefera G, Asmare B and Teklaign A, 2018. Application of AMMI for Grain Yield Stability Analysis in Large Speckled Bean Genotypes Grown in Midlands of Bale Zone Ethiopia. Chem. Biomol. Engin. 3(3): 17-21.

Tadesse T, Tekalign A, Mulugeta B and Sefera G

2018. Evaluation of the effect of genotype, environment and genotype X environment interaction on white common bean varieties using additive main effect and multiplicative interaction (AMMI) analysis in the mid- altitude of Bale zone Southeastern Ethiopia, Afr. J. Agric. Res. 13(7): 338-344.

- William E, Savage F and Metzger GL, 2006. Seed dormancy and the control of germination. New Phytologist 171(3): 501-523.
- Yan D, Duermeyer L, Leoveanu C and Nambara E, 2014. The functions of the endosperm during seed germination. Plant Cell Physiol. 55(9): 1521-1533.



Supplementary Information

Tables 8a & b: Growth habit genotype means by environment

8a

	TARI Selian Arusha - On-station				TACRI Lyamungo Moshi – On-station				n Rhotia Karatu – On-farm					Upperkitete Karatu – On-farm						
Breeding Material	PSE	СН	CW	PV	PSH	PSE	CH	CW	PV	PSH	PSE	СН	CW	PV	PSH	PSE	CH	CW	PV	PSH
Boroto	71.0	38.7	13.0	4.7	55.0	73.0	40.7	13.7	4.7	69.0	72.3	40.7	12.3	3.3	51.3	71.0	40.3	12.0	4.3	68.0
Calima Uyole	76.0	45.0	20.0	5.0	61.0	78.0	45.0	17.7	5.0	74.0	76.0	43.3	16.0	4.0	66.7	77.0	43.3	16.0	4.0	73.0
COD MLB 0033	75.7	53.0	18.3	5.0	61.7	77.7	55.0	17.7	5.0	75.3	76.0	50.0	16.3	4.0	67.3	76.0	51.3	16.0	4.0	73.7
Gloria	77.0	43.0	12.0	4.0	62.0	79.0	44.0	12.7	4.7	76.0	76.3	43.0	12.3	4.0	67.3	77.7	43.3	11.7	4.0	74.0
KAB 36	75.0	48.0	15.0	5.0	63.0	77.0	47.0	15.3	5.0	75.0	76.3	46.0	14.3	4.0	67.3	76.3	45.7	14.3	4.0	74.0
Kipapi	75.0	43.0	16.0	4.0	61.0	77.0	42.3	16.0	4.7	74.0	75.0	42.0	14.3	4.0	67.7	76.0	41.3	14.3	4.0	73.0
Lyamungo 90	79.0	44.7	16.3	3.3	61.0	78.0	45.0	16.0	3.3	74.0	77.0	44.3	14.3	3.3	63.3	78.0	44.0	14.0	4.0	71.7
Njano Gololi	68.0	36.3	16.0	3.7	54.0	72.0	38.0	16.0	3.7	68.0	69.3	37.3	14.3	3.0	49.7	72.0	36.7	14.7	4.0	67.7
NUA 48	78.0	44.0	16.3	5.0	63.0	79.7	44.3	15.3	5.0	78.0	77.7	43.3	14.0	4.0	68.0	78.0	43.7	14.3	4.0	74.3
NUA 64	77.7	44.7	16.3	5.0	62.3	79.0	44.3	16.0	5.0	77.3	77.7	43.7	15.0	4.0	68.0	78.0	43.3	14.3	4.0	75.0
RCB 593	75.3	42.0	16.0	5.0	60.0	78.0	44.0	17.0	5.0	75.0	75.0	43.0	15.3	4.0	67.0	75.0	43.0	15.7	4.0	72.0
Rosecoco	68.0	45.0	15.0	3.0	53.0	74.0	46.7	15.0	3.3	71.0	70.7	45.0	14.0	3.0	49.0	70.3	45.7	14.0	3.3	67.3
RWR 2154	77.0	43.3	16.0	5.0	61.0	79.0	42.7	15.7	5.0	77.0	77.0	42.7	14.3	4.0	67.0	75.3	42.7	14.3	4.0	73.3
SCR 61	76.0	36.7	15.0	5.0	62.0	78.0	38.3	14.3	5.0	76.0	76.0	35.7	13.7	4.0	67.7	75.3	35.7	12.7	4.0	73.3
Selian 12	77.0	35.3	18.0	5.0	60.0	78.0	38.0	17.3	5.0	75.0	76.3	37.0	14.7	4.0	66.0	76.7	36.0	15.3	4.7	72.0
Selian 13	76.0	35.0	15.0	5.0	63.0	76.0	38.3	15.7	4.3	74.0	76.3	37.3	13.7	4.0	65.7	77.7	37.0	14.3	5.0	72.7
SMC 18	77.0	41.0	16.0	5.0	62.0	78.0	40.7	16.0	5.0	76.0	76.7	40.0	14.0	4.0	67.7	77.3	40.3	15.3	4.0	74.3
Soya Kijivu	68.0	47.7	17.3	3.3	54.0	73.0	47.7	16.3	3.3	70.0	66.3	47.3	15.7	3.0	48.7	70.3	45.7	14.7	4.0	67.0
Sweet Violet	77.7	45.0	13.0	5.0	63.0	79.0	44.0	13.3	5.0	77.0	77.0	43.3	12.0	4.0	67.7	75.7	43.3	12.0	4.0	73.7
Uyole 03	77.0	42.3	16.3	5.0	61.0	79.0	43.0	16.7	5.0	78.0	76.0	42.3	15.0	3.3	67.0	76.3	42.0	15.7	3.7	73.3
Uyole 18	76.3	62.7	16.0	5.0	61.0	77.7	63.7	17.0	5.0	77.3	77.3	53.3	13.7	4.0	66.7	75.3	55.3	15.3	4.7	73.3
VTT 923 -23-10	78.0	56.0	16.0	5.0	61.0	79.0	56.3	17.3	5.0	77.3	78.0	52.0	15.0	4.0	67.7	75.7	53.7	15.3	4.0	74.3
Mean	75.3	44.2	15.9	4.6	60.2	77.2	45.0	15.8	4.6	74.7	75.3	43.3	14.3	3.8	63.8	75.5	43.3	14.4	4.1	72.3
SD	0.3	0.4	0.3	0.1	0.1	0.1	0.4	0.5	0.2	0.2	0.7	0.5	0.6	0.1	0.4	0.7	0.5	0.8	0.1	0.7
CV%	0.4	0.9	1.9	2.3	0.1	0.2	0.8	2.9	4.5	0.2	0.9	1.1	4.2	2.1	0.6	0.9	1.2	5.6	3.2	1.0

8b

	Matadi	Siha- On	-farm			Mwang	aza Siha	– On-far	m		Mnada	ni Lusho	to – On-f	arm		Kwekifinyu Lushoto – On-farm				
Breeding Material	PSE	СН	CW	PV	PSH	PSE	СН	CW	PV	PSH	PSE	СН	CW	PV	PSH	PSE	СН	CW	PV	PSH
Boroto	72.3	40.3	12.0	4.0	52.3	71.7	40.7	12.3	3.7	51.3	70.0	40.3	12.7	4.0	53.3	70.3	40.3	12.3	3.7	54.3
Calima Uyole	77.0	43.7	15.3	4.0	66.7	75.7	43.3	16.0	3.7	66.7	77.0	43.7	15.7	3.7	68.7	76.7	43.3	15.7	3.7	69.7
COD MLB 0033	77.3	50.7	15.3	4.0	67.3	76.3	50.7	16.0	4.0	67.3	76.0	50.0	16.0	4.0	69.3	76.7	50.3	16.0	4.0	70.3
Gloria	77.7	43.3	11.7	4.0	68.7	76.7	43.0	12.3	4.0	67.3	76.3	43.0	13.3	4.0	69.3	76.7	43.0	12.7	4.0	70.3
KAB 36	77.7	45.7	14.3	4.0	67.3	77.0	46.0	14.3	4.0	67.0	76.7	46.0	14.3	4.0	69.0	77.3	46.0	14.3	4.0	70.0
Kipapi	77.3	41.3	14.3	4.0	67.0	76.0	42.0	14.0	4.0	67.7	75.3	42.0	14.0	4.3	69.7	76.0	42.0	14.0	4.3	70.7
Lyamungo 90	78.3	44.0	14.0	3.7	65.7	77.7	44.3	14.3	3.7	64.3	77.0	44.3	14.3	3.7	66.3	77.7	44.3	14.3	3.7	67.3
Njano Gololi	68.3	36.7	14.7	3.7	51.3	70.0	37.3	14.3	3.0	49.3	67.3	37.3	14.3	3.0	51.3	68.7	37.0	14.3	3.0	52.3
NUA 48	78.3	43.7	14.3	4.0	68.7	77.3	43.3	13.7	4.3	68.0	77.0	43.3	14.0	4.3	70.0	77.0	43.3	13.7	4.7	71.0
NUA 64	78.3	43.3	14.0	4.0	67.7	77.3	44.0	15.0	4.0	68.0	77.7	44.0	15.0	4.3	70.0	78.0	44.0	15.0	4.3	71.0
RCB 593	76.3	43.0	15.0	4.0	68.0	75.7	43.0	14.7	4.0	67.0	75.3	43.0	14.7	4.0	69.0	76.3	43.0	14.7	4.0	70.0
Rosecoco	71.3	45.7	14.0	3.0	50.0	70.3	45.0	14.0	3.3	49.0	69.7	45.0	14.0	3.3	51.0	70.7	45.0	14.0	3.3	52.0
RWR 2154	77.7	42.7	14.3	4.0	68.0	76.7	42.7	14.3	4.3	67.0	78.0	43.0	14.3	4.3	69.0	78.0	43.0	14.3	4.7	70.0
SCR 61	76.7	35.7	12.7	4.0	67.3	75.3	36.0	13.7	4.0	67.0	76.3	36.0	13.7	4.0	69.0	76.7	36.0	13.7	4.0	70.0



	Matadi Siha- On-farm				Mwangaza Siha – On-farm				Mnadani Lushoto – On-farm					Kwekifinyu Lushoto – On-farm						
Breeding Material	PSE	СН	CW	PV	PSH	PSE	СН	CW	PV	PSH	PSE	СН	CW	PV	PSH	PSE	СН	CW	PV	PSH
Selian 12	78.0	36.0	14.7	4.7	66.3	77.3	37.0	14.7	4.7	65.0	77.3	36.7	15.0	4.0	67.0	77.7	36.7	14.7	4.7	68.0
Selian 13	77.3	37.0	14.0	5.0	63.0	76.0	37.3	13.7	4.3	66.0	77.0	37.3	13.7	4.7	68.0	77.3	37.3	13.7	4.3	69.0
SMC 18	78.0	40.3	14.0	4.0	67.0	77.3	40.0	14.0	4.0	67.0	77.3	40.0	14.0	4.0	69.0	77.7	40.0	14.0	4.0	70.0
Soya Kijivu	68.0	46.0	14.3	3.3	51.0	67.7	46.3	15.3	3.0	48.7	66.3	45.3	15.3	3.0	50.7	68.0	46.0	15.3	3.0	51.7
Sweet Violet	78.0	43.3	12.0	4.0	68.0	77.0	43.3	12.0	4.0	67.7	76.7	43.3	12.3	4.7	69.7	77.3	43.3	12.3	4.3	70.7
Uyole 03	77.3	42.0	15.0	4.0	68.3	76.3	42.3	14.7	3.7	67.0	76.3	42.3	14.7	3.3	69.0	77.0	42.3	14.7	3.3	70.0
Uyole 18	77.0	53.3	15.0	4.7	67.0	76.3	53.7	13.7	4.0	66.7	77.0	52.3	14.0	4.0	68.7	77.7	52.7	14.0	4.0	69.7
VTT 923 -23-10	78.7	52.7	14.7	4.0	68.3	78.3	53.0	14.7	4.3	67.0	77.3	52.7	14.7	4.3	69.0	78.0	52.0	14.7	4.3	70.0
Mean	76.2	43.2	14.1	4.0	64.3	75.5	43.4	14.2	3.9	63.7	75.2	43.2	14.3	4.0	65.7	75.8	43.2	14.2	4.0	66.7
SD	0.6	0.5	0.8	0.2	0.8	0.8	0.5	0.6	0.3	0.4	0.7	0.5	0.6	0.3	0.4	0.7	0.5	0.6	0.3	0.4
CV%	0.8	1.1	5.6	4.4	1.3	1.1	1.2	4.2	6.7	0.6	1.0	1.2	3.9	7.3	0.6	0.9	1.1	4.0	8.6	0.6

Table 9a, b and c: Common bean disease infection scores by genotype and environment 9a

Location	TARI Selian Arusha – On-station				TACRI	Rhotia Karatu – On-farm				Upperkitete Karatu – On-farm						
Common bean genotypes	ALS	ATHS	LR	BCMV	ALS	ATHS	LR	BCMV	ALS	ATHS	LR	BCMV	ALS	ATHS	LR	BCMV
Boroto (Check)	1.667	2.667	1.000	1.333	3.000	3.000	1.333	1.333	3.000	3.333	1.000	2.000	2.333	3.667	1.333	2.333
Calima Uyole	1.000	1.667	2.667	1.000	1.000	2.667	2.333	1.000	1.667	4.333	2.333	1.000	1.333	4.000	2.000	1.000
COD MLB 0033	1.000	1.667	1.333	1.333	1.333	1.333	1.000	1.000	1.000	1.667	1.000	1.000	1.000	2.333	1.333	1.000
Gloria	1.333	1.667	1.000	1.000	1.000	2.333	1.000	1.333	1.000	2.000	2.333	1.000	1.000	3.000	2.000	1.333
KAB 36	1.000	1.667	1.333	1.000	1.000	1.667	1.000	1.333	1.000	1.667	1.667	1.000	1.000	2.667	1.333	1.000
Kipapi	1.000	1.000	1.333	1.333	1.667	2.000	1.000	1.333	1.667	2.000	1.000	1.667	1.333	2.333	1.667	1.000
Lyamungo 90	3.333	3.667	2.000	1.333	4.333	4.667	2.667	1.000	5.000	4.333	3.000	1.333	6.000	5.000	2.667	1.333
Njano Gololi (Check)	2.333	2.667	1.000	1.333	3.667	4.000	1.000	2.667	4.000	3.667	2.333	2.333	4.667	4.333	1.333	3.000
NUA 48	1.000	1.000	1.000	1.000	1.000	1.333	1.667	1.000	1.000	1.333	1.000	1.000	1.000	1.667	1.000	1.000
NUA 64	1.000	1.333	1.000	1.000	1.000	1.333	1.333	1.000	1.000	1.667	2.333	1.333	1.000	2.667	1.333	1.333
RCB 593	1.000	1.333	1.667	1.000	1.333	1.667	1.000	1.333	1.000	2.333	1.000	1.333	1.000	2.333	1.000	1.000
Rosecoco (Check)	2.667	4.000	2.667	1.333	3.000	4.000	2.333	2.000	5.000	5.000	3.000	2.667	5.667	4.333	2.667	2.333
RWR 2154	1.000	1.667	1.333	1.333	1.333	2.667	1.000	1.333	1.000	2.000	1.667	1.000	1.000	2.000	1.667	1.000
SCR 61	1.000	1.333	1.667	1.333	1.000	1.667	1.000	1.000	1.000	1.333	1.333	1.000	1.000	2.000	1.333	1.000
Selian 12	1.333	2.000	1.333	1.333	1.667	2.667	1.000	1.333	3.000	3.667	1.000	2.667	3.000	4.333	2.000	2.000
Selian 13	2.667	3.000	1.000	1.333	3.000	3.667	1.000	2.000	3.333	4.000	1.000	2.667	4.333	4.667	2.667	1.667
SMC 18	1.000	1.667	1.333	1.333	1.000	2.000	1.000	1.000	1.000	2.333	1.333	1.000	1.000	2.000	1.333	1.000
Soya Kijivu (Check)	3.000	3.333	1.000	1.667	3.000	2.667	1.000	2.667	3.000	5.000	1.667	3.000	3.667	5.000	2.333	3.000
Sweet Violet	1.000	1.333	1.000	1.333	1.000	1.667	1.333	1.000	1.000	3.000	1.000	1.333	1.000	2.667	1.667	1.000
Uyole 03	2.000	3.333	1.333	1.333	1.333	3.667	1.667	1.000	1.000	3.000	1.667	1.000	1.667	4.333	1.667	2.000
Uyole 18	1.333	2.333	1.333	1.333	2.000	2.333	1.000	2.000	2.000	3.000	2.000	1.667	1.667	3.333	2.000	1.333
VTT 923 -23-10	1.000	1.667	1.333	1.333	1.000	1.667	1.333	1.000	1.000	1.667	2.000	1.000	1.000	2.333	1.000	1.000
MEAN	1.530	2.091	1.394	1.258	1.803	2.485	1.318	1.394	1.985	2.833	1.667	1.545	2.121	3.227	1.697	1.485
SD	0.236	0.492	0.387	0.420	0.301	0.499	0.262	0.327	0.215	0.609	0.360	0.289	0.262	0.556	0.485	0.275
CV %	15.43	23.51	27.7	33.39	16.69	20.07	19.91	23.47	10.84	21.48	21.62	18.68	12.37	17.24	28.55	18.49

Location	Matadi Siha - On-farm				Mwangaza Siha – On-farm				Mna	adani Lus	hoto – On-	farm	Kwekifinyu Lushoto – On-farm				
Common bean genotypes	ALS	ATHS	LR	BCMV	ALS	ATHS	LR	BCMV	ALS	ATHS	BCMV	RR	ALS	ATHS	BCMV	RR	
Boroto (Check)	2.000	3.000	2.000	1.667	1.333	2.333	1.333	1.667	1.667	2.667	2.667	3.000	1.333	3.000	2.667	1.333	
Calima Uyole	2.667	3.000	1.667	1.000	1.667	2.667	1.667	1.000	1.000	3.000	1.000	1.000	1.000	3.000	1.000	2.000	
COD MLB 0033	1.000	2.000	2.000	1.000	1.333	2.333	1.000	1.000	1.000	2.000	1.000	1.000	1.000	2.000	1.000	3.000	
Gloria	2.333	2.667	1.667	1.333	2.000	2.333	1.333	1.000	1.000	3.000	1.000	1.667	1.000	3.000	1.000	1.333	
KAB 36	1.667	3.000	1.000	1.000	1.000	2.000	2.000	1.000	1.000	1.667	1.667	1.000	1.000	2.333	1.667	1.000	
Kipapi	1.000	3.000	1.667	1.000	1.333	2.000	1.000	1.000	1.000	1.667	1.000	2.667	1.000	2.333	1.000	1.000	
Lyamungo 90	4.667	4.000	2.667	1.000	4.667	5.000	2.667	1.000	2.000	4.667	2.000	1.333	2.000	5.000	2.000	1.333	
Njano Gololi (Check)	4.000	3.333	2.000	2.000	2.667	4.000	2.000	2.000	2.000	4.333	2.000	3.000	2.333	4.333	2.000	2.333	
NUA 48	1.000	2.667	1.667	1.000	1.000	2.333	1.333	1.000	1.000	1.333	1.000	2.333	1.000	2.333	1.000	1.333	
NUA 64	1.000	2.000	2.000	1.000	1.000	1.000	1.667	1.000	1.000	1.333	1.000	1.000	1.000	1.667	1.000	1.333	
RCB 593	1.000	3.000	2.333	1.000	1.000	1.667	1.000	1.000	1.333	2.333	1.000	1.333	1.000	2.667	1.000	1.000	
Rosecoco (Check)	5.000	4.333	3.000	1.333	4.333	5.000	3.000	1.667	3.000	4.667	2.000	1.333	2.667	5.000	2.000	1.667	
RWR 2154	1.000	2.000	1.000	1.000	1.000	1.667	1.000	1.667	1.000	1.667	1.000	1.000	1.000	1.667	1.333	1.333	
SCR 61	1.000	1.667	1.667	1.000	1.000	1.667	1.333	1.000	1.000	1.667	1.000	1.000	1.000	1.000	1.000	1.000	
Selian 12	3.333	3.333	1.667	2.000	2.000	2.667	1.333	1.000	1.000	2.333	2.000	2.000	1.000	3.667	2.000	1.333	
Selian 13	3.667	3.000	2.000	2.333	2.667	2.333	1.000	2.000	2.000	3.333	3.000	2.000	2.333	4.000	3.000	1.667	
SMC 18	2.000	3.000	1.667	1.000	1.333	2.333	1.000	1.000	1.000	1.333	1.000	1.000	1.000	2.000	1.000	1.000	
Soya Kijivu (Check)	4.000	3.667	2.667	2.667	3.667	4.000	3.000	2.667	1.667	4.333	2.000	3.667	2.000	4.667	2.333	2.333	
Sweet Violet	1.333	2.000	1.667	1.333	1.333	1.667	1.000	1.000	1.000	1.667	1.000	1.000	1.000	2.333	1.000	1.667	
Uyole 03	1.333	3.000	2.000	1.000	1.667	2.000	1.667	1.667	1.000	3.667	1.667	1.000	1.333	3.333	1.667	1.667	
Uyole 18	2.333	3.000	2.333	2.000	2.333	2.667	2.000	1.333	1.333	3.333	2.000	3.667	1.000	3.333	2.667	1.667	
VTT 923 -23-10	1.333	2.333	1.333	1.000	1.000	1.333	1.000	1.000	1.000	1.333	1.000	2.333	1.000	2.000	1.000	1.667	
MEAN	2.212	2.864	1.894	1.348	1.879	2.500	1.561	1.303	1.318	2.606	1.500	1.788	1.318	2.939	1.561	1.545	
SD	0.470	0.470	0.413	0.248	0.341	0.485	0.327	0.210	0.268	0.597	0.287	0.353	0.222	0.497	0.346	0.446	
CV %	21.27	16.43	21.8	18.42	18.16	19.38	20.96	16.11	20.3	22.89	19.12	19.76	16.85	16.9	22.19	28.87	

9c

Logation	Mata	di Siha On farm	Mwangaga	Siho On form	May	dani Luchata Or	form	Kuralifinun Luchata On farm				
Location	Iviata	ui Sina – On-Iarin	wwangaza	Sina – On-tarin	IVIIIa	idalli Lusiloto – Ol	n-rarm	Kwekiniiyu Lushoto – Oli-tarili			-larm	
Common bean genotypes	CBB		CBB		CBB	WM		CBB	WM			
Boroto (Check)	2.000		1.333		1.333	3.000		2.000	3.000			
Calima Uyole	1.000		1.000		2.333	1.000		3.000	1.000			
COD MLB 0033	1.000		1.000		1.667	2.333		1.333	2.000			
Gloria	1.000		1.000		2.333	3.000		3.000	3.000			
KAB 36	1.000		1.000		2.333	1.000		1.333	2.000			
Kipapi	1.000		1.000		2.000	2.000		3.000	3.000			
Lyamungo 90	2.000		2.333		1.667	1.000		2.667	1.000			
Njano Gololi (Check)	1.667		1.000		2.667	3.667		3.000	3.000			
NUA 48	1.000		1.000		2.333	1.000		1.667	1.000			
NUA 64	1.000		1.000		1.667	1.000		1.333	1.000			
RCB 593	1.000		1.000		1.333	1.667		2.000	1.000			
Rosecoco (Check)	2.667		2.333		3.000	1.000		2.667	1.000			
RWR 2154	1.000		1.000		2.333	1.000		2.333	1.000			
SCR 61	1.000		1.000		1.667	2.667		1.333	1.000			
Selian 12	1.000		1.000		2.667	2.000		2.333	2.667			
Selian 13	1.000		1.000		2.667	2.667		1.667	3.000			
SMC 18	1.000		1.000		1.667	1.000		2.000	1.000			



Location	Matadi Siha – On-farm			Mwangaza Siha – On-farm				Mnadani Lushoto – On-farm				Kwekifinyu Lushoto – On-farm			
Common bean genotypes	CBB		CBB				CBB	WM			CBB	WM			
Soya Kijivu (Check)	2.000		2.000				3.000	4.333			2.667	3.333			
Sweet Violet	1.000		1.000				1.667	1.667			2.333	2.667			
Uyole 03	1.000		1.000				1.667	1.000			2.000	2.667			
Uyole 18	2.000		1.333				2.000	3.333			2.667	3.000			
VTT 923 -23-10	1.333		1.667				2.000	1.000			1.333	2.667			
MEAN	1.303		1.227				2.091	1.924			2.167	2.045			
SD	0.196		0.203				0.707	0.282			0.556	0.177			
CV %	15.03		16.53				33.8	14.64			25.67	8.637			