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Original Article

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

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## 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

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## 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. Among these factors, disease, specifically 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 yield. 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 mega-environment. 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 on-station 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 di-ammonium 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.

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

| Month | TACRI Lyamungo | | | TARI Selian | | | Karatu | | | Siha | | | Lushoto | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainfall (mm) | Temperature (°C) | | Rainfall (mm) | Temperature (°C) | | Rainfall (mm) | Temperature (°C) | | Rainfall (mm) | Temperature (°C) | | Rainfall (mm) | Temperature (°C) | |
| | | Max | Min | | Max | Min | | Max | Min | | Max | Min | | 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** |

### 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):

$$ASV = \sqrt{\left[\frac{SSIPC1}{SSIPC2}\,(IPC1)\right]^2 + (IPC2)^2} \quad \text{……...(Equation 1)}$$

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)

## 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 ($P \leq 0.05$) 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 on-farm 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 ($P \leq 0.05$) 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 (1.38) and TARI Selian (1.24) Table 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 ($P \leq 0.05$) among G, E & GEI (Table 4) for all other bean yield components. Yields and yield components were higher in on-station 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 for TARI Selian and TACRI Lyamungo, 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≤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 (mean 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≤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), number of grains per pod (NGP), 100-grain weight (100GW) and grain yield (GY)**

| Source of variation | DF | NPP | NGP | 100GW(gm) | GY (kg/ha) |
|---|---|---|---|---|---|
| | | 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

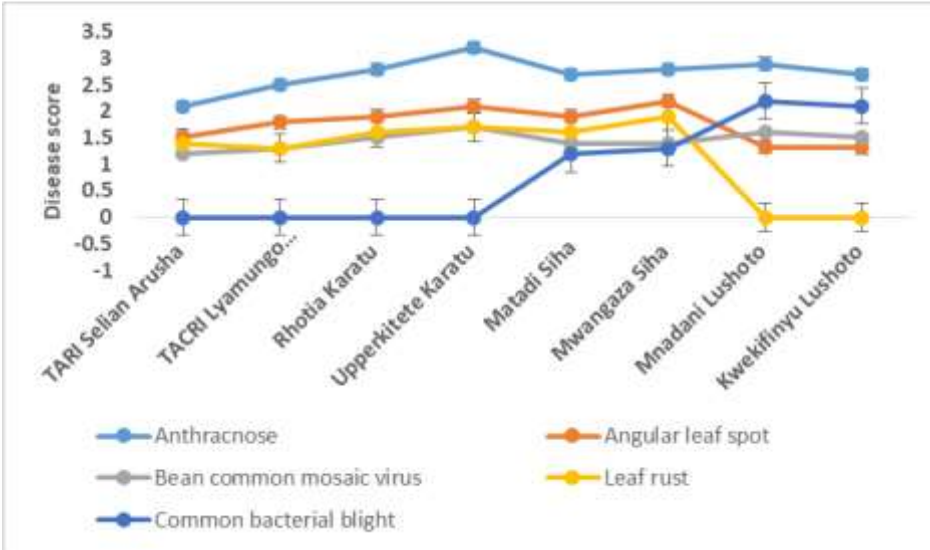


**Figure-1. Common bean disease infection mean scores by trial location.**

**Table-5. Genotype grain yield means by environment**

| Location | TARI Selian | TACRI Lyamungo | Rhotia Karatu | Upperkitete Karatu | Matadi Siha | Mwangaza Siha | Mdadani Lushoto | Kwekifinyu Lushoto | Genotype 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 | 1223.5 | 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 | 34.3 | 9.5 | 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 |

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.

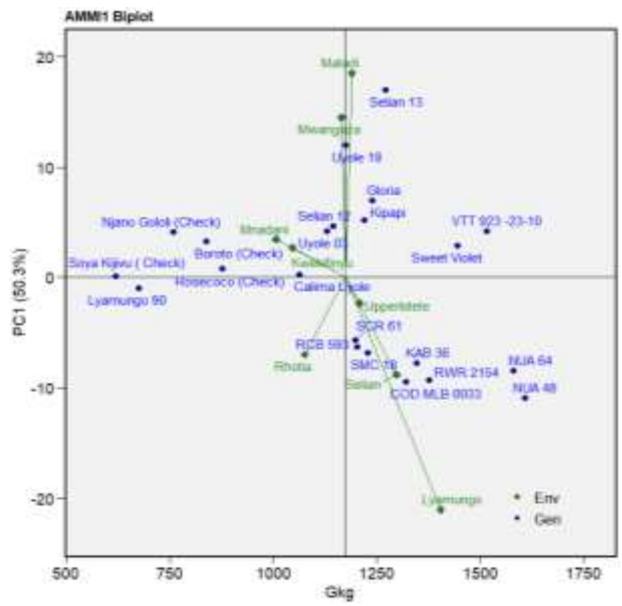


**Figure-2. AMMI biplot model for grain yield (kg/ha) presenting means of genotype and environment**

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

| 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-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 |

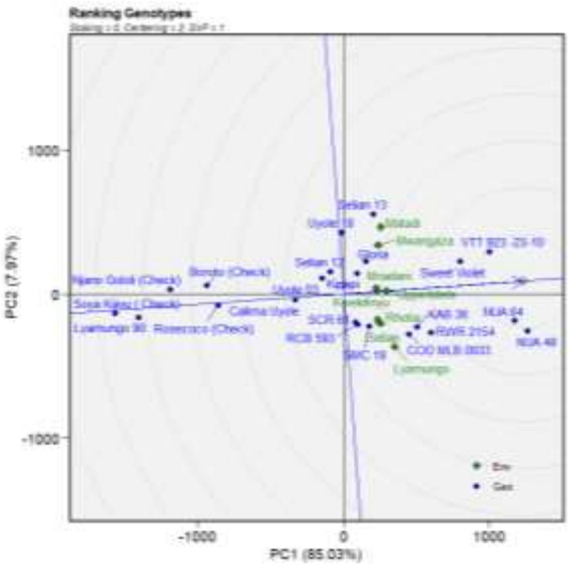


**Figure-3. GGE biplot showing superior genotypes for mean grain yield across environments.**

## 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 Uyole 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 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), nutrient-rich 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 on-farm 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 100-grain 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 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 recommended for potential release and commercialization.

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## 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.

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**Supplementary Information**

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

**8a**

| | TARI Selian Arusha - On-station | | | | | TACRI Lyamungo Moshi – On-station | | | | | Rhotia Karatu – On-farm | | | | | Upperkitete Karatu – On-farm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Breeding Material** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **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 | | | | | Mwangaza Siha – On-farm | | | | | Mnadani Lushoto – On-farm | | | | | Kwekifinyu Lushoto – On-farm | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Breeding Material** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **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** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **CW** | **PV** | **PSH** | **PSE** | **CH** | **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 Lyamungo Moshi – On-station** | | | | **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 |

**9b:**

| Location | Matadi Siha - On-farm | | | | Mwangaza Siha – On-farm | | | | Mnadani Lushoto – 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**

| 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** | | |
| 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 | | |