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Effects of plant densities on the performance of common bean varieties in multiple environments of northwestern Tanzania

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A study was carried out at two sites in Tanzania to assess the effect of different planting densities on growth and yield of five recently released bush bean varieties. The experiment was laid out in a split-plot design in a factorial arrangement with three replications during long and short rainy seasons of 2019/20 and 2020/21. The treatments comprised five bean varieties; TARIBEAN 1, 2, 3, 4 and 5 and five plant population densities; 200000, 222222, 250000, 266666 and 333333 plants/ha. Variables evaluated were plant height, angular leaf spot and common bacterial blight disease scores in leaves, number of pods per plant, number of seeds per pod, hundred seed weight and grain yield. The variables were subjected to ANOVA and means of statistically significant variables to plant density, variety, and environment were analyzed by Tukey HSD test and "which-won-where" view of the GGE biplot. The interaction of factors only affected significantly plant height and yield. Highest grain yield of 1,353 and 1,607 kg/ha were recorded by plant density of 200,000 plants/ha and TARIBEAN 1 variety at Maruku site during short rainy seasons (E2). Therefore, a plant density of 200,000 plants/ha and TARIBEAN 1 variety are recommended in all four environments.

Key words: Plant density, bean varieties, grain yield, environment, GGE biplot, "which-won-where".

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is a major food grain legume for human consumption that plays a principal role in the livelihoods and income of smallholder farmers in Sub-Saharan Africa (Letaa et al., 2020). The leading common bean producing countries in East Africa are Tanzania, Uganda and Kenya with average annual production of 1,114,500, 876,576 and 615,992 tons respectively (Mukankusi et al., 2019). Kagera, Kigoma

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and Manyara regions are the largest bean growing areas in Tanzania (NBS, 2016).

In Tanzania, common bean is grown mostly by smallholder farmers often intercropped with maize, sorghum, bananas, or other crops with minimal use of improved varieties at a recommended plant density/ spacing (Kiriba et al., 2020). The average yield of common beans in Tanzania is 0.6 t/ha lower than the potential yield of 1.5 to 3 t/ha. Regional bean yield differences are seen with Kigoma region reporting highest yield of 0.8 t/ha, followed by Kagera and Manyara regions with yield of 0.6 t/ ha (NBS, 2016). The generally low bean productivity in the Tanzania is due to inadequate use of improved bean varieties, low soil fertility, poor crop managements and susceptibility to insect pests and diseases (Kiriba et al., 2020). Various studies have assessed the strategies that improve bean growth and yields, among them are use of appropriate organic and inorganic fertilizers, nitrogen fixing rhizobia, irrigation, spacing and crop configuration, pest and disease management (Naser et al., 2013; Ibrahim, 2012; Vanlauwe et al., 2019; Campos et al., 2021). Several studies have reported on growth and yield responses of different common bean varieties to various fertilizers or inoculation (Ndakidemi and Dakora, 2007; Shumi, 2018), water stress/drought tolerant (Asemanrafat and Honar, 2017; Karantin et al., 2019; Mbiu et al., 2020a), irrigation methods (Ibrahim et al., 2017; Campos et al., 2021), maize-legumes intercropping (Yoseph and Shanko, 2017) or combination of plant density/spacing with fertilizers (Kiriba et al., 2020). However, few studies have assessed the yield responses of various common bean varieties to a range of high planting densities. Plant density is an important factor in the cultivation of common bean varieties, affecting significantly growth and yield attributes. Uneven plant spacing in the sowing row increases the plants intraspecific competition for environmental resources, potentially lowering grain yields (Bisognin et al., 2019). However, use of high yielding bean variety at a right plant density has been reported as one of the ways of building sustainable and resilient food systems even during pandemic period (Nchanji and Lutomia, 2021) when majority of smallholder farmers may not afford buying fertilizers. Moreover, the blanket plant density practiced currently in Tanzania is 200,000 plants/ha allowing planting beans at a spacing of 50 cm between rows and 20 cm between planting hills with two seeds per hill (Kanyeka et al., 2007) with or without fertilizers. Studies have assessed only one common bean variety with different plant densities/spacing fertilizers (Endres et al., 2019; Musana et al., 2020); variety by environment interaction (Mbiu et al., 2020b; Philipo et al., 2021). However, few studies have assessed the yield responses of various common bean varieties to a range of high plant densities/spacing (variety by plant density interaction). This study compared the recommended blanket plant density of 200,000 plants/ha (50 × 20 cm) with different high plant densities while other factors such as fertilizers or inoculation, water stress, irrigation are kept constant. The objectives of the study are to: (i) determine the effect of high plant densities on growth and yield responses of common bean varieties in four environments represented by on-station and on-farm during long and short rainy seasons; (ii) assess the best performing common bean variety and the respective plant density; and (iii) evaluate effects of interaction of plant density and bean varieties in four environments. It was hypothesized that high plant densities will lead to highest grain yield and plant height to all five tested common bean varieties.

MATERIALS AND METHODS

Study area

The field experiment was conducted in 2020/2021, in two different agro-ecological sites, namely the station TARI Maruku in Bukoba district, and Kitengule in Karagwe districts, for two rainy seasons of 2019/20 and 2020/21. TARI Maruku-Bokoba is located at latitude 01°25ˈ1"S and longitude 031°46ˈ 41"E and rest at altitude of 1,178 m. The site receives 1,648 mm of rainfall and records an average temperature of 20°C (Figure 1). The soils are sandy clay loam with pH (H_2O) of 5.26. The Kitengule-Karagwe site is located at latitude 0°18.027"S and longitude 031°21.494"E at an altitude of 1,160 m. This site experiences low rainfall of about 846 mm and average temperature of 22°C (Figure 1). The soil is loamy sand and pH (H_2O) of 5.87. Both sites are moderately fertile and suitable for bean production (Table 1).

Experimental design and layout

The experimental design used was split-plot arranged in randomized complete block design replicated three times in a factorial format at four different environments (Figure 2). There were two factors, the main factor (main plot) was improved bean varieties with five treatments/levels and the sub-factor (sub-plot) was plant density with a combination of 25 treatments. The five plant population densities were selected to compare the blanket recommendation plant density of 200,000 plants/ha to other four plant densities of 222,222, 250,000, 266,666 and 333,333 plants/ha. The five improved bush bean varieties were TARIBEAN 1- Medium red and drought tolerant, TARIBEAN 2- Medium white and rich in high iron and zinc, TARIBEAN 3- Medium red and drought tolerant, TARIBEAN 4- Red mottled and rich in high iron and zinc and TARIBEAN 5- Red mottled and rich in high iron and zinc. Choice of these varieties was influenced by their dwarf growth type and non-trailing plant traits. Four different experimental environments composed of two locations and two planting seasons, namely the Maruku long rainy season (E1), Maruku short rainy season (E2), Kitengule long rainy season (E3) and Kitengule short rainy season (E4). Similar experimental designs with different randomizations were used at each location and in each rainy season. The experimental fields were ploughed and harrowed using tractor during March 2020 and September 2020. Both sites were laid out and planted on 01 April, 2020 and 09 October 2020 for 2019/20 and 2020/21 planting seasons, respectively. Two seeds per hole were planted in rows on 3 × 1 m plot separated by 1 m from the other, with application of NPK 20:10:10 fertilizer as basal dressing. The crops were managed using recommended agronomic techniques including manual weeding, two and four weeks after planting,

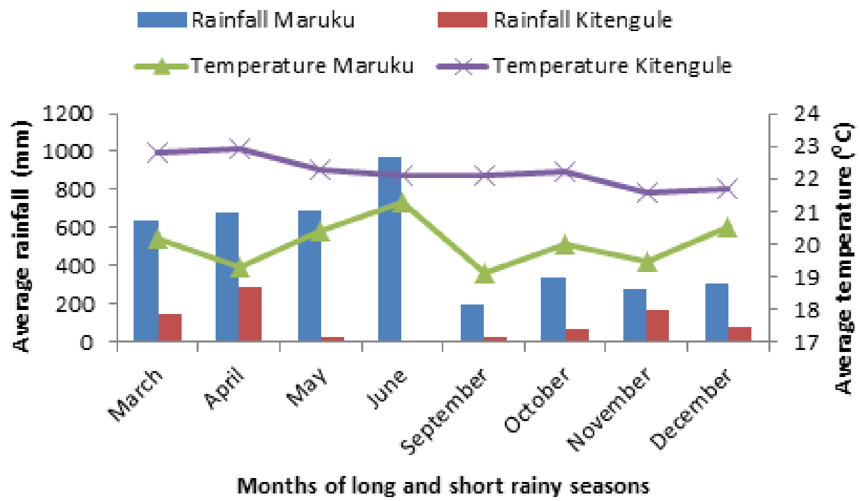

Figure 1. Rainfall and temperature trend for long and short rainy seasons 2019/20 and 2020/2021.
Source: Author

Table 1. Characteristics of the sites.

Soil	Location	
	Maruku-Bukoba	Kitengule-Karagwe
pH (H_2O)	5.26	5.87
Total Nitrogen (%)	0.24	0.17
Phosphorus (mg/kg)	17.90	23.40
Organic Carbon (%)	2.39	2.41
Magnesium (meq/100 g soil)	0.12	0.36
Calcium (meq/100 g soil)	0.66	2.04
Electrical conductivity (Ms/cm)	0.33	0.30
Cation exchange capacity (CEC)	3.10	5.20

Source: Mbiu et al. (2020b).

routine insecticide and herbicides application.

Data collection

Data was collected during three stages of crop development, namely the flowering, physiological maturity and harvesting stages for the plants in the middle row to avoid border effects. Plant height (PH) was measured in cm, using 2 m ruler during physiological maturity at reproductive stage of R9. Number of pods per plant (NPP) were counted and recorded prior to harvesting for randomly selected 10 plants in the middle row. Number of seeds per pod (NSPP) was counted from the same 10 randomly selected plants in the middle row. Ten pods were collected from the bottom mid and upper part of the plants during harvesting time and these pods were threshed individually and numbers of seed per pod were counted carefully from each plot and the weighed to determine the Hundred Seed weight (HSW). Finally bean grains were threshed from each plot to determine the final grain yields (GY) in kg/plot which was then converted to kg/ha. Data for Angular Leaf Spot (ALSF) and Common Bacteria Blight (CBBF) diseases in the leaf were collected during reproductive stage (R8) of crop development when the disease symptoms are easily observed. The diseases symptoms in leaves were scored using a 1-9 disease scoring scale, where 1-3 is resistant, 4-6 is intermediate, and 7-9 is susceptible (van Schoonhoven and Pastor-Corrales, 1987).

Statistical analysis

Analysis of variance (ANOVA) and GGE biplots were computed using R statistical software version 4.1.3. The packages used were “tidyverse” (Wickham et al., 2019) and “metan” (Olivoto and Lúcio, 2020). All measured variables were subjected to ANOVA and the statistically significance undergone means comparison and GGE biplots analysis.

RESULTS AND DISCUSSION

Analysis of Variance (ANOVA)

To express the main effect and interactions among and

Replication I	Replication II	Replication III
V1D4	V2D1	V5D3
V1D2	V2D3	V5D1
V1D1	V2D5	V5D4
V1D5	V2D2	V5D5
V1D3	V2D4	V5D2
V5D1	V4D5	V3D2
V5D5	V4D2	V3D5
V5D3	V4D4	V3D1
V5D2	V4D3	V3D3
V5D4	V4D1	V3D4
V3D3	V1D2	V4D4
V3D4	V1D4	V4D2
V3D2	V1D1	V4D3
V3D1	V1D5	V4D5
V3D5	V1D3	V4D1
V2D5	V5D3	VID1
V2D1	V5D1	V1D3
V2D3	V5D4	V1D5
V2D4	V5D2	V1D4
V2D2	V5D5	V1D2
V4D2	V3D4	V2D1
V4D3	V3D5	V2D4
V4D5	V3D3	V2D2
V4D1	V3D1	V2D3
V4D4	V3D2	V2D5

Figure 2. A split-plot design involving five common bean varieties (V1- TARIBEAN 1, V2- TARIBEAN 2, V3- TARIBEAN 3, V4- TARIBEAN 4 and V-5- TARIBEAN 5) and five plant density levels (D1- 200000 plants/ha, D2- 222222 plants/ha, D3- 250000 plants/ha, D4- 266666 plants/ha and D5- 333333 plants/ha).
Source Author

within the source of variations, analysis of variance (ANOVA) was performed. ANOVA for plant density (D), variety (V) and environment (E) showed significant differences among plant density ($p \leq 0.01$) and grain yield (GY) and plant height (PH). Other remaining measured traits, such as the angular leaf spot (ALSF), common bacteria blight (CBBF), number of pods/plant (NPP), number of seeds/pod/plant (NSPP) and hundred seed weight (HSW) were not statistically significant. However, these non-significant traits were affected by environment as the only source of variation (Table 2). On the other hand, there was a significant difference among varieties for all traits with exception to ALSF and CBBF which seemed to be especially affected by the environment (Table 2). Highly significant differences ($p < 0.01$) were observed among environments for all measured traits except NSPP with ($p \leq 0.05$) showing a certain variation among experimental sites and rainy seasons (Table 2). The interaction between variety and density was not statistically significant for all traits, with exception for plant height ($p \leq 0.05$) (Table 2). The effect of plant density to grain yield unlike number of pods per plant, number of seeds per pod and 100 seed weight could be due to the stability of number of seeds per pod and 100 seed weight. The stability of number of seeds per pod and 100 seed weight were also reported by Kazemi et al. (2012) who revealed non-significant effect of plant density for number of seeds per pod and 1000 seed weight. It is possible that the variation in the number of pods per plant is due to the genetic factor and not the plant density. This result is contrary to Merga (2020) who reported a significant difference in the interaction between bean varieties and row spacing. Present findings also agree with the results of Kiriba et al. (2020) who reported no significant effect of plant density on number of seeds per pod and 100 seed weight of bush bean varieties. Moreover, other studies that evaluated the bean varieties for different row spacings also reported non-significant effects of the interaction between bean varieties and row spacing (Asemanrafat and Honar, 2017; Merga, 2020) which are in agreement with this study. Conversely, these results are contrary with the results of Musana et al.

Table 2. Estimated mean squares of traits measured in five bean varieties evaluated with five plant densities regimes in four environments at Maruku and Kitengule sites during long and short rainy seasons.

Sources of variation	Degree of freedom	Mean squares						
		PH	ALSF	CBBF	NPP	NSPP	HSW	GY
V	4	339.7***	4.047[ns]	2.105[ns]	25.18*	16.1*	100.8**	4589958***
E	3	987.7***	26.09***	24.787***	298.40***	116.24*	98.75**	2510754**
Error	12	41.9	0.90	1.889	24.39	4.49	14.14	414560
D	4	186.13**	0.5883[ns]	0.0967[ns]	3.272[ns]	0.6383[ns]	6.987[ns]	772297***
V X D	16	85.17*	0.4113[ns]	0.2779[ns]	6.961[ns]	0.8071[ns]	5.449[ns]	93750[ns]
Error (within)	260	43.21	1.2574	0.8512	7.152	0.9923	6.517	145828

*, **, *** and ns represents ≤ 0.05, ≤ 0.01, < 0.001, and non-significant respectively
Source. Author

Table 3. Comparison of grain yield means per each plant density and common bean variety in four environments E1-E4, representing Maruku and Kitengule locations during long and short rainy seasons.

Variable	E1	E2	E3	E4
Plant densities				
200000 plants/ha	1,228.8[a]	1,353.8[a]	806.73[a]	1,015.93[a]
222222 plants/ha	826.8[a]	955.6[a]	635.6[a]	838.73[a]
250000 plants/ha	1,073.33[a]	1,202.3[a]	802.2[a]	1,050.2[a]
266666 plants/ha	1,040[a]	1,145.9[a]	760.07[a]	984.33[a]
333333 plants/ha	1,000[a]	1,135[a]	620[a]	812.13[a]
SEM (+/-)	207760.8	228441.6	55162.1	96975.8
LSD	466.79	489.476	240.527	318.915
Variety				
TARIBEAN 1	1,411.07[a]	1,607.4[a]	1,166.73[a]	1,506.47[a]
TARIBEAN 2	1,033.4[ab]	1,138.5[ab]	535.67[c]	711.8[b]
TARIBEAN 3	915.6[b]	1,016.2[b]	924.4[b]	1,197.27[a]
TARIBEAN 4	755.53[b]	869.9[b]	568.87[c]	736.73[b]
TARIBEAN 5	1,053.33[ab]	1,160.5[ab]	428.93[c]	549.07[b]
SEM (+/-)	207760.8	228441.6	55162.1	96975.8
LSD	466.79	489.476	240.527	318.915

Means with the same letter shows no significant difference (p ≤ 0.05) between treatments at Critical Value of Studentized Range of 3.966 using Tukey's Honestly-Significant-Difference (Tukey HSD) test.
Source: Author

(2020) who indicated significant effect of planting density on the number of pods per plant for common bean variety.

Grain yields of varieties per plant density in four environments

Highest grain yield of 1,353 kg/ha was recorded by plant density of 200,000 plants/ha at E2 and the least grain yield of 620 kg/ha by 333,333 plants/ha at E3. In terms of varieties, TARIBEAN 1 showed the highest grain yield of 1,607 kg/ha at E2 while TARIBEAN 5 had the lowest grain yield of 428kg/ha at E3 (Table 3). When comparing environments, generally all plant densities and varieties revealed high grain yield at E2 and E4 (short rainy season in both locations) than E1 and E3 (long rainy season in both locations). Highest grain yield experienced by all plant densities and varieties at E2 and E4 could be due to moderate and good rainfall distribution during short rainy season. This situation, confirms that common beans require more rain during flowering and pod filling stages than early and late stages since high rainfall during late stage may lead to grain rotting (Table 3 and Figure 1). The results of this study agree with the results of Bulyaba et al. (2020) and Philipo et al. (2021) who

Table 4. Comparison of plant height means per each plant density and common bean variety in four environments E1-E4, representing Maruku and Kitengule locations during long and short rainy seasons.

Variable	E1	E2	E3	E4
Plant density				
200000 plants/ha	39.27[a]	45.53[a]	45.53[a]	45.53[a]
222222 plants/ha	36.87[a]	44.07[a]	43.73[a]	45.07[a]
250000 plants/ha	38.33[a]	47[a]	47[a]	47.27[a]
266666 plants/ha	36.67[a]	41.47[a]	40.53[a]	42.80[a]
333333 plants/ha	36.87[a]	45.07[a]	44.87[a]	44.46[a]
SEM (+/-)	17.23	68	64.03	39.68
LSD	4.25	8.445	8.19	6.451
Variety				
TARIBEAN 1	41.93[a]	45.13[a]	45.13[a]	45.73a
TARIBEAN 2	37.33[b]	47.13[a]	47.33[a]	47.40a
TARIBEAN 3	35.73[b]	39.60[a]	39.60[a]	41.67a
TARIBEAN 4	35.33[b]	43.87[a]	42.40[a]	42.87a
TARIBEAN 5	36.80[b]	47.40[a]	47.40[a]	47.47a
SEM (+/-)	17.229	68.00	64.026	39.68
LSD	4.251	8.445	8.195	6.451

Means with the same letter shows no significant difference ($p \leq 0.05$) between treatments at Critical Value of Studentized Range of 3.966 using Tukey's Honestly-Significant-Difference (Tukey HSD) test.
Source: Author

reported variation of seed yield in different environments.

Plant height of varieties per plant density in four environments

The highest plant height of 47.27 cm was recorded at a plant density of 250,000 plants/ha by TARIBEAN 5variety at E4. The lowest height was recorded at a plant density of 266,666 plants/ha by TARIBEAN 3 variety and 333,333 plants/ha at E1 (Table 4). The result implies that intermediate spaced plants between rows (40 cm) are taller than thinly spaced between plants/holes (20 cm), a phenomenon that agree with the results reported by Bisognin et al. (2019). There was no clear changes in plant height with increase of plant density contrary to Musana et al. (2020) who reported an increase of plant height to higher plant density due to intraspecific competition. None difference in growth parameters at different plant densities in this current study reveals that plant densities do not affect much the growth performance of common beans.

GGE biplot analysis for grain yields in multi-environment

GGE biplot is a new and more realistic and effective method to analyze crop growth and yield components in multi-environment for complex genotype and environment interactions (GEI). It supplements the results of significant mean squares for GEI from ANOVA by graphically analyzing the nature of the interactions (Akinwale et al., 2014). Which-won-where view of the GGE biplot is the best visual tool because it is a summary of the genotype by environment, the genotype ranking based on mean and stability of the genotypes, and the interrelationships among the environments (Yan, 2002). It comprises an irregular polygon and a set of lines drawn from the biplot origin which intersect each of the sides at right angles (Yan et al., 2007). The vertices of the polygon are the genotype markers located farthest away from the biplot origin in various directions, in a way from the biplot origin in various directions, in a way that all genotype markers are contained within the resulting polygon (Tarekegn and Serawit, 2017). A line that starts from the biplot origin and perpendicularly intersects the polygon side represents the set of supposed environments in which the two genotypes defining that side perform equally. Therefore, the perpendicular lines to the polygon sides divide the biplot into sectors, each having its own winning genotype. The winning genotype for a sector is the vertex genotype at the intersection of the two polygon sides whose perpendicular lines form the boundary of that sector. Besides, genotypes at the vertices of the polygon are either the best or poorest in

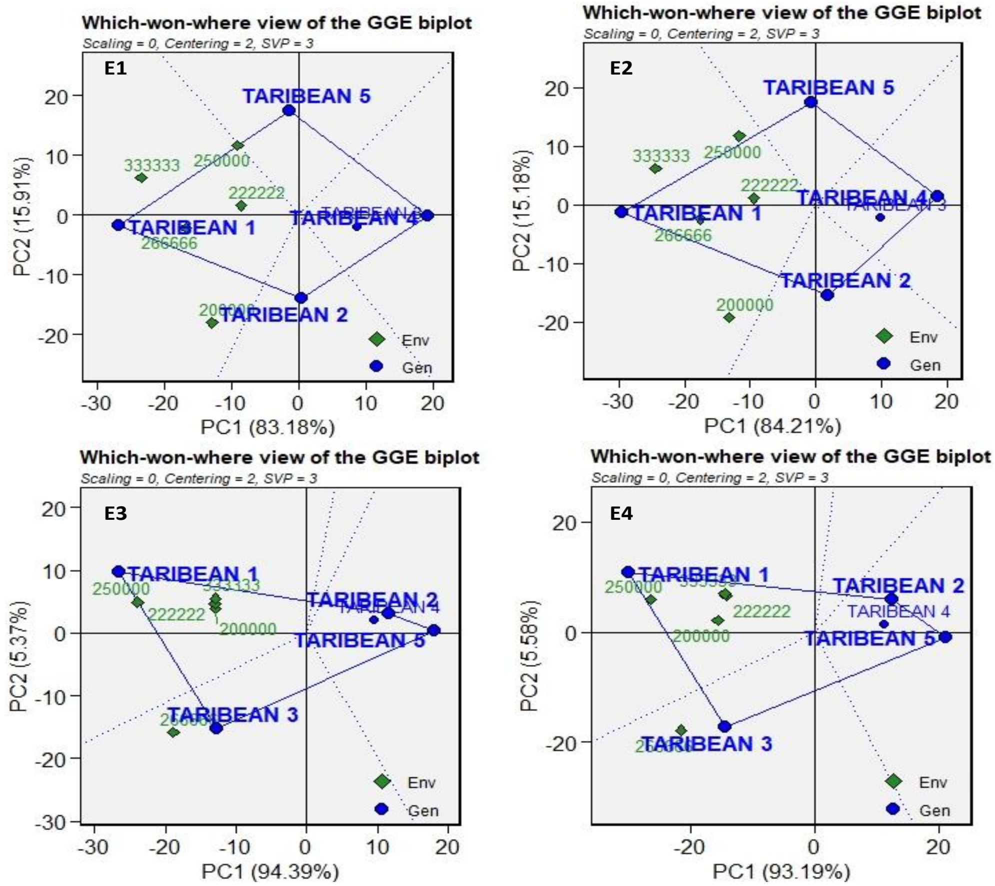

Figure 3. Which-won-where view of GGE biplot for grain yield comparing plant densities at four environments E1-E4, representing Maruku and Kitengule locations during long and short rainy seasons.
Source: Author

one or more environments. The genotype at the vertex of the polygon performs best in the environment falling within the sectors (Yan et al., 2007). For GGE biplot analysis, five different plant densities of 200000, 222222, 250000, 266666 and 333333 plants/ha equivalent to plant spacing of 50 × 20 cm, 30 × 30 cm, 40 × 20 cm, 50 × 15 cm and 30 × 20 cm respectively represented multi-environments.

Grain yield on plant densities

Which-won-where biplots for grain yield (GY) were made from five bean varieties as genotypes and five plant densities as environment at Maruku and Kitengule sites during long and short rainy seasons (E1, E2, E3 and E4). The polygons were informative, discriminative and well distributed, however the shapes of the polygons differed per location/site (Figure 3). In the biplot of Maruku site during both seasons (E1 and E2), a polygon was formed by connecting vertex varieties with straight lines and only one variety (TARIBEAN 3) was placed within the polygon (Figure 3). Varieties TARIBEAN 1, TARIBEAN 2, TARIBEAN 4 and TARIBEAN 5 were the vertex varieties which are the best or the poorest varieties in some or all of the environments because they were farthest from the origin of the biplot. From the polygon view, the genotypes and locations fell in four and one sections, respectively. All five plant densities 200000, 222222, 250000, 266666 and 333333 plants/ha, representing one location had TARIBEAN 1 variety as the winner. No plant density fell into the sector of vertex of TARIBEAN 2, TARIBEAN 3, TARIBEAN 4, and TARIBEAN 5 varieties (Figure 3). Therefore, the vertex of TARIBEAN 2, TARIBEAN 3, TARIBEAN 4, and TARIBEAN 5 were not the winners in any of the tested plant densities, hence they were likely to be the poorest genotypes in some or all plant densities. As reported by Yan et al. (2007), if all environmental markers fall into a single sector, it indicates that a single cultivar had the highest yield in all

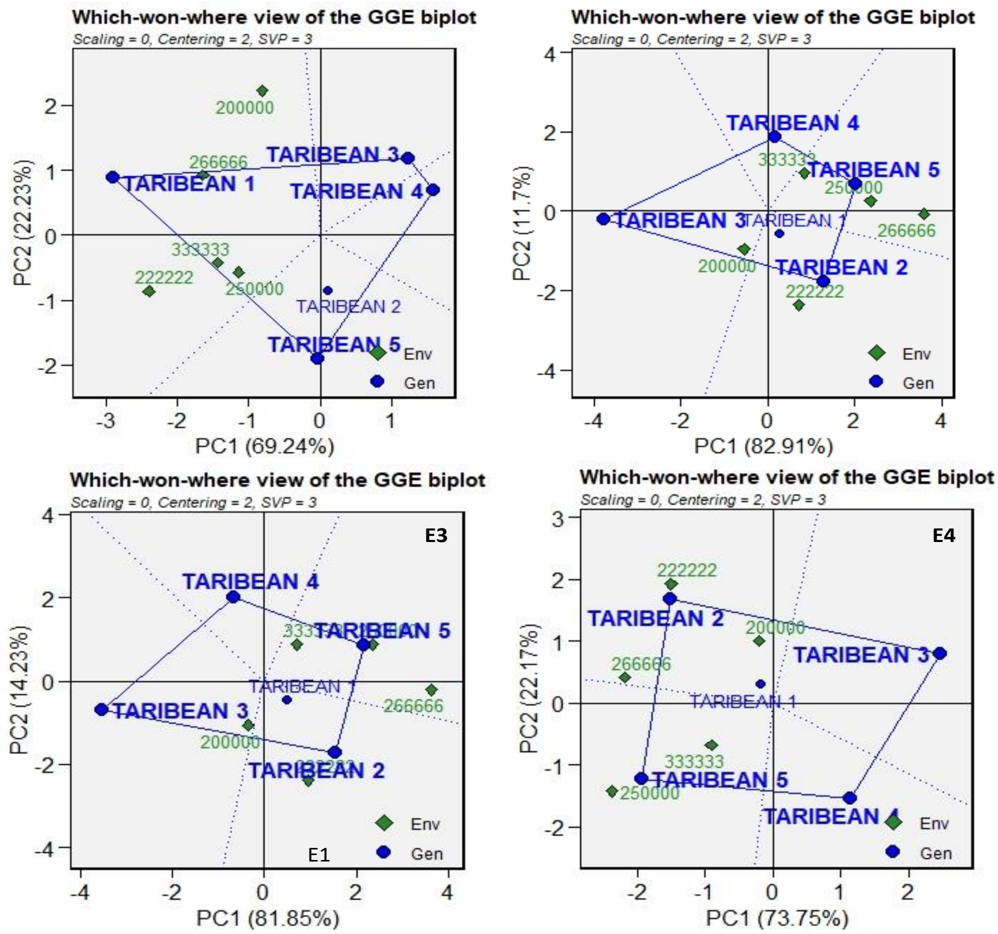

Figure 4. Which-won-where view of GGE biplot for plant height comparing plant densities at four environments E1-E4, representing Maruku and Kitengule locations during long and short rainy seasons.
Source: Author

environments. In current study, TARIBEAN 1 variety was the highest yielding variety with all five tested plant densities pointing to its vertex. In the biplot of Kitengule site during both seasons (E3 and E4), "which-won where" GGE biplot for GY, the first section had TARIBEAN 1 as the winning variety under four plant densities of 200000, 222222, 250000 and 333333 plants/ha and the second section covered plant density of 266666 plants/ha with TARIBEAN 3 as the best yielder. No plant density felt into the sector of TARIBEAN 2 and TARIBEAN 5 varieties vertex (Figure 3). This shows that TARIBEAN 2 and TARIBEAN 5 varieties were not the winner in any of the plant densities, and were hence the poorest varieties in some or all of the tested plant densities. In terms of PC scores, TARIBEAN 1 reveals to be the ideal variety in all four environments (E1-E4) due to largest PC1 scores indicating highest average yield and near zero PC2 scores indicating it was the most stable variety. When comparing the planting density, 250000 plants/ha had the highest PC2 scores. Besides, GGE partitioning via GGE biplot analysis revealed that PC1 and PC2 for GY at E1 and E2 were 83.18 and 15.19% as well as 84.21 and 15.18% of GGE sum of squares, respectively; resulting in total variations of 98.37% and 99.39%, respectively. E3 had 94.39% in PC1 and 5.3% in PC2, resulting in a total variation of 99.69%, while E4 had 93.19 and 5.58%, respectively for PC1 and PC2, giving a total variation of 98.77% (Figure 3).

Plant height (PH) for plant densities in multi-environment

The "which-won-where" view of GGE biplot had four sectors with different winning varieties in terms of plant height (PH) (Figure 4). At E1, TARIBEAN 1 had the highest PH for all plant densities. In E2, there were four sectors with each winning variety per plant density (Figure 4). TARIBEAN 1 had the highest height at plant density of 200000 plants/ha, TARIBEAN 4 at 333333 plants/ha, TARIBEAN 5 at 250000 and 266666 plants/ha and TARIBEAN 2 at 222222 plants/ha. E3 also had four sectors with TARIBEAN 3 having high height at 200000 plants/ha, TARIBEAN 2 at 222222 plants/ha and TARIBEAN 5 at three plant densities of 333333, 250000 and 266666 plants/ha (Figure 4). E4 had four sectors with only two genotypes having winning plant heights with TARIBEAN 2 leading in height at 200000, 222222 and 266666 plants/ha while TARIBEAN 5 had highest heights at both 250000 and 333333 plants/ha (Figure 4). Complex GE and crossover interactions were shown in E2, E3 and E4 which makes it difficult to identify the variety with highest height per each plant density. However, TARIBEAN 3 seems to be affected more by 200000 plants/ha in both E2 and E3 while TARIBEAN 2 seemed to be affected by 200000, 222222, and 266666 plants/ha in E4. Also, in E4, height of TARIBEAN 5 seemed to be affected by 250000 and 333333 plants/ha.

Conclusion

The study reaffirmed the planting density of 200,000 plants/ha as the optimal recommended for all five varieties in all four environments (Maruku, Bukoba district and Kitengule, Karagwe district during long and short rainy seasons respectively). Higher planting densities did not yield any better yields meaning that farmers can save on cost otherwise spent on seed purchase by adopting the planting density of 200,000 plants/ha. TARIBEAN 1 variety showed better performance compared to the other 4 varieties hence is recommended under all five plant densities in all four growing environments. The results are critical as they help to target the best suited bean variety for the lake region of Tanzania. Using the GGE, the study was able to better identify the variety-environment interactions which is key for selecting the best suited variety for a given agroecology. Future research should therefore integrate this method in targeting and identifying best niches of other varieties across the vast bean growing areas of Tanzania and Africa as whole. The GGE approach can be used to assess for other bean growth traits such as leaf area index (LAI), dry matter distribution (DMD), growth rate (GR), radiation use efficiency (RUE), biomass and harvest index (HI). In addition, effects of plant densities on crop pathology and insect pests also deserve research attention in Tanzania.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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