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Performance of Cassava (Manihot esculenta Crantz) Clones Across Locations

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Abstract

The crop cassava belongs to the dicotyledonous family Euphorbiaceae and is mainly cultivated for its starchy roots. In the tropics, it is the most important food staple where it's known for its source of energy and in the world, it's ranked sixth most important source of calories in human diet. In Ethiopia, its produced for its starchy root and found to be very valuable crop especially in Southern region of the country. But its productivity is highly lower than most of cassava producing countries and even lower than the yield obtained in research centers. Thus This experiment was conducted to evaluate different cassava clones for their storage root performance and yield stability across locations. The experiment was conducted for two seasons (one cassava season constitutes 18 months from planting to maturity) at three locations, Amaro, Hawassa and Jima. A randomized complete block design (RCBD) with three replications was used for the study. Storage root yield and yield related data were collected and analyzed by using SAS and Genstat statistical software. The performance result indicated that the clone TMC 191/0427 (C1), MM96/930 (C3) and MM96/936 (C2) gave the highest storage root yield in their respective order with mean storage yield of 35.27, 30.38 and 28.36t/ha per a growing season . Besides higher storage root yield, TMC 191/0427 (C1) was the most stability clone across different locations and seasons. Hence, the clone was recommended for verification (18 months after planting). But the clones MM96/930 (C3), MM96/528 (C4), Naliende (C6) and MM96/936 (C2) were the best performer at Jima compared to other locations. Therefore, these genotypes might be recommended for adaptation to specifically to Jima and similar environments

Keywords: Cassava, Candidate, stability, Wider production

Introduction

Cassava (*Manihot esculenta* Crantz) is a perennial shrub reaching 1-4m height and is commonly known as tapioca, manioc, mandioca and yuca in different parts of the world. It belongs to the dicotyledon family Euphorbiaceae and is mainly cultivated for its starchy roots. In the tropics, cassava is the most important food staple where it's known for its source of energy and in the world, it's ranked sixth most important source of calories in human diet (FAO and IFAD, 2000). Although cassava is a perennial crop, its storage roots can be harvested from 6 to 24 months after planting depending on the cultivar and growing conditions (El-Sharkawy, 1993). Cassava can be propagated from either stem cuttings or sexual seed though the former is the commonest.

Cassava is cultivated mainly in the tropic and sub-tropic regions of the world, over a wide range of environmental and soil conditions. It is very tolerant of drought and heat stress and produces well on marginal soils. It is an important dietary staple in many countries within the tropical regions of the world (Perez and Villamayor, 1984), where it provides food for more than 800 million people (FAO, 2007). As a subsistence crop, cassava is the third most important carbohydrate food source in the tropics after rice and maize, providing more than 60% of the daily calorific needs of the populations in tropical Africa and Central America (Nartey, 1978).

Even if the introduction of cassava to Ethiopia is not known, some evidences indicated that it trace back to more than 100 years. It was believed to be introduced by some NGOs to drought prone areas of southern part of the country such as Amaro, Gamogoffa, Sidama, Wolayta, Gedeo primarily to fill the gap for subsistence farmers due to failure of other crops as a result of drought. In these areas, farmers usually grow cassava in small irregular scattered plots either sole or intercropped mainly with taro, enset, maize, haricot bean and sweet potato.

The roots of cassava are very rich in carbohydrates, which makes them an important source of dietary energy. They can be consumed fresh after cooking, processed into food products, or fed to livestock. Cassava root starch can be used in a wide array of industries, from food manufacturing and pharmaceuticals to production of plywood, paper and bio-ethanol. In some countries, cassava is also grown for its leaves, which contain up to 25 percent protein. Cassava is one of the most important food security root and tuber crops grown in the southern region of Ethiopia. It is mostly grown by subsistence farmers in low land areas of Amaro, Gemu Gofa, Wolayta, and South Omo and serves as famine reserve food.

According to Alexandratos (1995), cassava plays an important role in alleviating food problems, because it thrives and produces stable yields under conditions in which other crops fail. In addition to maintaining food security cassava has great potential in re-silencing the ever changing climatic condition and used as a source of industrial row materials. In brief: Policymakers in tropical countries are recognizing the huge potential of cassava to spur rural industrial development and raise rural incomes. Cassava also substitutes imports in such a way that *d*omestically produced cassava flour can replace some of the wheat flour for bread making. It is also used as a source of raw material for bio-ethanol manufacturing and starch factories (Tesfaye et al, 2013).

Despite its important only two varieties of cassava were officially released for a larger production in Ethiopia. Due this variety trials were conducted at a number of locations and two additional out performing varieties in comparison with the local and the standard checks were released for official production and utilization. Thus this paper was prepared with the aim to disseminate the information about the performance and qualitative characteristics of the newly released varieties to farmers, producers, scientific communities and policymakers.

Material and Methods

Description of test genotypes and environments: A total of 8 cassava clones were evaluated at three locations for two years constituting six environments. Among the genotypes two were checks (local and standard checks). The genotypes and the six environments were listed in Table 1.

Table 1. description of Environments and cassava clones investigated

Environment	Code	Genotypes	Code
Hawassa 2010/11	H11	TMC 191/0427	C1
Hawassa 2011/12	H12	MM96/936	C2
Amaro 2011/12	A11	MM96/930	C3
Amaro 2012/13	A12	MM96/528	C4
Jima 2011/12	J11	Kigoma red	C5
Jima 2012/13	J12	Naliende	C6
		Qulle	C7
		Local Check	C8

Methodology and statistical analysis: A randomized complete block design (RCBD) with three replications was used for the study. Each clone (genotype) was planted by using 1meter and 1 meter raw and plant spacing respectively at 6 meter by 4 meter (24m^2) plot size from which 8m^2 size of the plot was considered as harvestable plot. Hand weeding was conducted as per the recommendation and no fertilizer was applied in the course of the experiment. Data on storage root length (cm), storage root diameter/girth (cm), marketable yield per hectar (t), unmarketable storage root yield per hectar (t) and total storage root yield per hectar (t) were recorded.

Analysis of variance: Analysis of variance (ANOVA) of the multi-environment trial was conducted using Annicchiarico (2002) model and a SAS procedure PROC GLM (SAS Institute Inc., 2002) version 9 was employed to detect the presence of GxE interaction so as to proceed for stability analysis. Annicchiarico (2002) model:

$$Y_{ijkl}=\mu+G_i+L_j+Y_k+B_l(LY_{jk})+GL_{ij}+GY_{ik}+LY_{ji}+GLY_{ijk}+\varepsilon_{ijkl}$$

Where, Y_{ijkl} = observed value of genotype *i* in block *k* nested in (location *j* and year k), μ = grand mean, G_i = genotype effect, G_i = location effect, Y_K= year effect,GL_{ij}, $GY_{ik,}$ LY_{ji}, and GLY_{ijk} are the interaction effect of genotype *i* with location *j*, genotype *i* with year *k* and genotype *i* with locations and years *jk*, respectively; $B_l(LY_{jk})$= the effect of block *l* in location *j* and year *k*, ε_{ijkl} = error (residual) effect. Mean separation was conducted using the Least Significant Difference (LSD) to discriminate the genotypes and identify high yielding ones. Association of traits and their impact on total storage root yield was computed by using person correlation coefficient.

GGE-Biplot Analysis: The GGE-Biplot of Yan (1999) and Yan et al. (2001) was used for investigating G x E interaction and stability of the genotypes across environments. GGE biplot best identifies GxE interaction pattern of data and clearly shows which variety performs best in which environments, and thus facilitates mega-environment identification. The GGE-Biplot model based on singular value decomposition (SVD) of *t* principal components is given as follows: μ_i

$$Y_{ijkl}-\mu_i-B_l=\sum_{(k=1)}^{t}\lambda_k\alpha_{ik}\gamma_{jk}+\varepsilon_{ijl}$$

Where: Y_{ij} is the performance of genotype i in environment j, μ_i is the grand mean, B_l is the main effect of environment j, *k* is the number of principal components (PC); λ_k is singular value of the kth PC; and α_{ik} and γ_{jk} are the scores of ith genotype and jth environment, respectively for PCk; ε_{ijl} is the residual associated with genotype i in environment j. Usually only the first two PCs are used especially if they account for the major portion of the G x E interaction.

Results and discussion

Analysis Varience (ANOVA):

The result of the combined ANOVA also showed that there was a highly significant difference ($P < 0.001$) among the cassava clones for their storage root yield averaged over location, years, locations and their interactions with very few exception ($P < 0.001$). The overall interaction of genotype, location and year was statistically significant at $p<0.05$). Among the interaction effects, only clone by year was found to be no significant (Table 2). This may indicate that the genotypes performance had not been affected by the difference in year. Location main effect contributed a much larger variation (63.14%) followed by year (18.69) and genotype main effect (5.31%) and location by year interaction (6.93%). As the large yield variation due to location is not relevant to cultivar evaluation and mega-environment investigation (Fox and Rosielle, 1982; Gauch and Zobel, 1996; Yan et al., 2000). Hence, G and GE interaction are the only important components for yield variation.

Table 2. Analysis of variance of storage root ($t\ ha^{-1}$) of cassava clones (genotypes) evaluated at three locations in the period 2011 to 2013

Source	**DF**	**Type I SS**	**Mean Square**	**F Value**	**Pr > F**	**Proportion of variance (% SS)**
LOC	2	15236.24734	7618.12367	87.94	<.0001	63.14
REP(LOC)	6	1065.37449	177.56241	2.05	0.0671	1.47
YEAR	1	2254.90437	2254.90437	26.03	<.0001	18.69
TRT	7	4485.82252	640.83179	7.40	<.0001	5.31
LOC*YEAR	2	1671.66076	835.83038	9.65	0.0002	6.93
LOC*TRT	14	3662.98829	261.64202	3.02	0.0008	2.17
YEAR*TRT	7	188.58114	26.94016	0.31	0.9473	0.22
LOC*YEAR*TRT	14	2269.19825	162.08559	1.87	0.0402	1.34
Error	90	7796.96085	86.63290			0.72
Total	143	38631.73800				
CV	35.85					
R^2	79.8					
Mean yield (t/ha)	25.97					

Performance of clones:

The mean yield of clones at each environment and across environments is presented in Table 3.The clone TMC 191/0427 (C1), C3 and C2 gave the highest root yield more than 28t/ha in their order of placemen with mean storage yield of 35.27, 30.38 and 28.36t/ha per a growing season (18 months after planting). With some exceptions the clones were leading at almost all locations. They had shown greater yield advantage over both the standard check and local checks. The yield advantage of cassava clones over the standard check, Qulle, which was officially released and currently under production in the country by 38.1, 18.95 and 11.04%. In the same way they showed smart storage root yield performance over the farmer variety (local check). Accordingly the clone C1 (191/0427) out yielded the local check by 30.97%. Similarly clones C3 and C2 showed yield advantage of 12.81 and 5.31% over the local check respectively. The value is by far higher than FAO world estimate which stated that the average yield in 2009 for cassava growing regions of the world was 12.6 t/ha (FAOSTAT, 2009)These results demonstrate that under improved agronomic practices, increases in tuber yields can be obtained from cassava.

Table 3: Total storage root performance of cassava clones tested over locations (set I)

Treatment/Cassava accessions	Each Location by year performance (cassava root yield t/ha									Year x location/environment	Yield advantage over standard check (%)	Yield advantage over local check (%)
	Hawassa			Amaro			Jima					
	2011/1	2012/13	Mean	2011/12	2012/1	Mean	2011/12	2012/1	Mean			
TMC 191/0427	32.63	32.13	32.38	21.10	31.53	26.32	39.00	55.20	47.10	35.27	38.10	30.97
MM96/936	19.10	17.77	18.43	8.67	20.83	14.75	38.63	65.13	51.88	28.36	11.04	5.31
MM96/930	17.90	24.20	21.05	19.23	21.20	20.22	45.87	53.90	49.89	30.38	18.95	12.81
MM96/528	14.17	16.30	15.23	8.30	27.03	17.67	39.61	41.20	40.41	24.43	-4.35	-9.28
Kigoma red	10.50	11.63	11.00	10.70	20.37	17.34	37.59	39.53	38.56	21.72	-14.96	-19.35
Naliende	7.90	5.37	8.00	8.00	26.27	15.76	17.38	26.20	21.79	15.19	-40.52	-43.59
Qulle	13.17	8.77	11.00	13.57	50.73	32.15	37.68	29.33	33.51	25.54	0.00	-5.16
Local Check	20.57	14.63	17.60	14.00	33.83	23.92	33.12	45.40	39.26	26.93	5.44	0.00
CV	53.71	34.18	43.69	55.84	31.97	39.13	28.66	26.55	27.56	35.82		
LSD	20.69	9.79	9.12	12.66	16.22	10.10	18.12	20.69	13.13	6.16		

The best dry matter content of 44.5% was recorded from clone C4 (TM96/528) followed by C5 (Kigoma red), C6 (Nalinde) and C1 (TMC 191/0427) with the respective value of 40.6, 39.73 and 39.26%. But the dry matter content of all clones were by far higher than both the standard and local checks as shown in table 4 except the value of the clone C2 (MM96/936) which yielded 4.09% lower than the standard check C7 (Qulle). The dry matter content of the clones under the test is within the range of the dry matter content reported by Kenneth (2011), who evaluated three cassava varieties and found the dry matter content ranging from 41.1% to 46.3% depending on the varieties.

Table 4: Root dry matter content (%) of cassava clones tested over locations (set I)

Treatment/Cassava accessions	Each Location by year performa (cassava root DM (%)			Mean dry m content of the cl across locations	DM advan over stan check %)	DM advan over l check %)
	Hawassa	Amaro	Jima			
TMC 191/0427	39.07	41.03	37.67	39.26	1.66	8.54
MM96/936	34.63	39.47	37.03	37.04	-4.09	2.41
MM96/930	37.83	42.90	38.80	39.84	3.16	10.15
MM96/528	46.40	47.17	39.93	44.50	15.23	23.03
Kigoma red	39.43	46.57	35.80	40.60	5.13	12.25
Naliende	36.07	42.73	40.40	39.73	2.87	9.84
Qulle	32.30	45.40	38.80	38.62	0.00	6.77
Local Check	23.00	45.00	40.50	36.17	-6.34	0.00
CV	13.62	10.22	12.23	11.92		
LSD	8.61	7.84	8.26	4.48		

Table 5. Pearson Correlation Coefficients, N = 144

	MRYT	**UNRYT**	**TRYT**	**RL**	**RG**
MRYT	1.00000	-0.39729 <.0001	0.96815 <.0001	0.59521 <.0001	0.40329 <.0001
UNRYT		1.00000	-0.15486 0.0638	-0.18753 0.0244	0.06248 0.4569
TRYT			1.00000	0.58961 <.0001	0.45121 <.0001
RL				1.00000	0.33976 <.0001
RG					1.00000

MRYT=marketable storage yied (t/ha), UNRYT= unmarketable storage root yield (t/ha), TRYT= total storage root yield (t/ha), RL=average storage root length (cm) and RG=Average storage root girth (cm)

The correlation coefficient of most of the traits indicated positive and significant association among each other with some exceptions. Cassava storage root diameter is significantly correlated with root length (r=0.34), marketable root yield (r=0.40) and total storage root yield (r=45). But it is statistically not significantly correlated with unmarketable storage root yield. Root length was also significantly positively correlated with marketable and total storage root yields with r value of 0.60 and 0.59, respectively. In the contrary, it was negatively but significantly (P<0.05) correlated with unmarketable storage root yield (r=-0.19). Even though total storage root yield and unmarketable storage root yields were not statistically correlated with each other, it was positively and statistically correlated with marketable root yield (r=0.97). Unlike marketable and total storage root yields, marketable and unmarketable root yields were significantly but negatively correlated with r=-40 (Table 5). Marketable storage root yield, root length and root girth can be considered as the best indicator for the total storage root yield of cassava clones. Root length was also significantly positively correlated with marketable and total storage root yields with r value of 0.40 and 0.25 respectively. The result is also in line with the result reported by Tesfaye et al., 2017. It was indicated that Cassava storage root diameter is significantly correlated with root length (r=0.24), marketable root yield (r=0.50) and total storage root yield (r=53). Ntawuruhunga and Dixon (2010) also indicated that storage root number, storage root size and storage root diameter were the main yield components contributing to yield enhancement in cassava. But its not significantly correlated with unmarketable storage root yield and number of roots per plant.

Stability of characters

Table 6. ANOVA for AMMI model

Source	Df	SS	MS	F	F_prob
Total	143	38632	270.2	*	*
Treatments	47	29770	633.4	7.61	0.00000
Genotypes	7	4486	640.9	7.70	0.00000
Environments	5	19164	3832.8	24.59	0.00000
Block	12	1870	155.8	1.87	0.04957
Interactions	35	6120	174.9	2.10	0.00302
IPCA	11	4539	412.6	4.96	0.00001
IPCA	9	856	95.1	1.14	0.34299
IPCA	7	561	80.1	0.96	0.46371
IPCA	5	144	28.9	0.35	0.88276
Residuals	3	20	6.8	0.08	0.96970
Error	84	6992	83.2	*	*

GGE-Biplot analysis: GGE-Biplot analysis of storage root yield of cassava clones using PC1 and PC2 is presented in Fig. 1. Large positive PC1 scores for genotypes indicate that those clones had higher average yield and PC2 scores near zero indicate that those genotypes were more stable (Yan et al., 2000; Yan, 2001). Accordingly, clones C1 and C2 were high yielding clones (Fig. 1). On the other hand, clones C5, C6, C8 and C4 were with large negative PC1 scores and they were low yielding genotypes (Fig. 1). Clones with relatively low PC2 scores near zero such as C5, C7, C1 and C4 can be considered relatively as stable clones. However, among these clone, only C1 was high yielding and could be considered for recommendation.

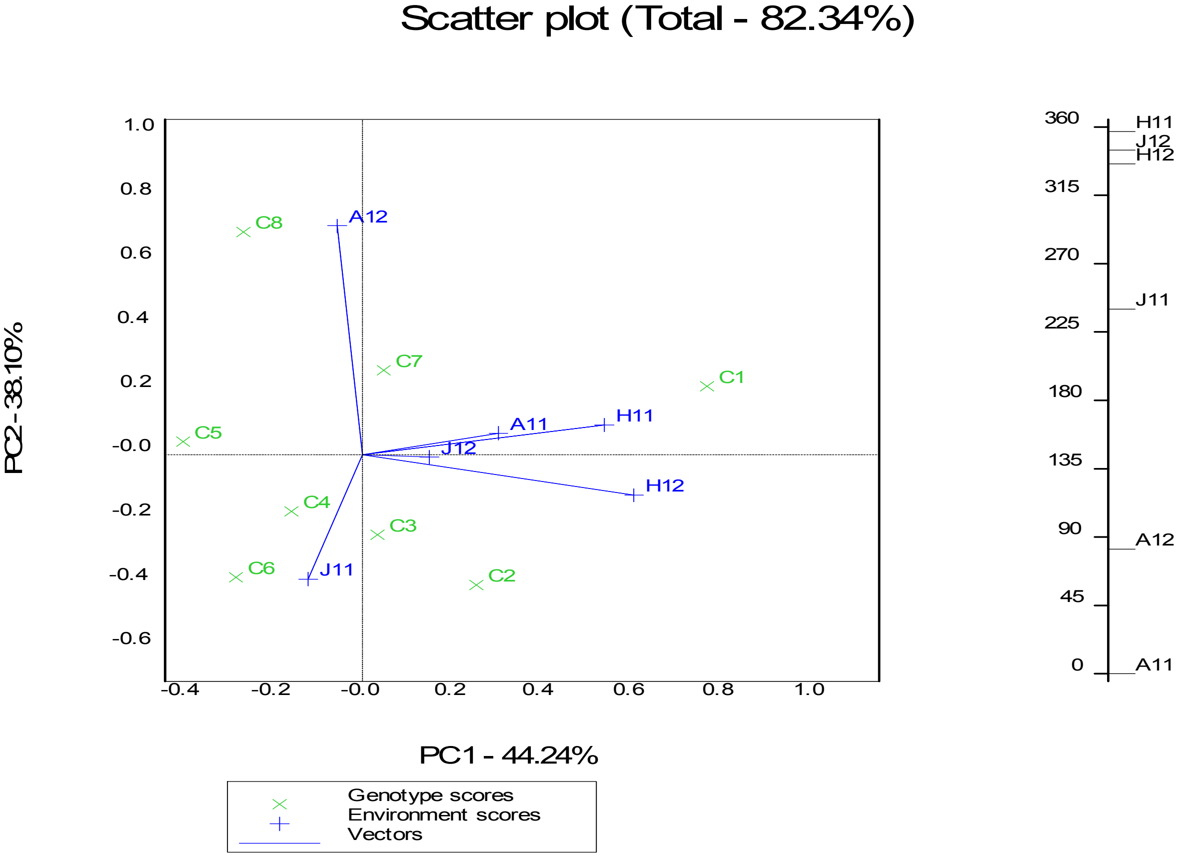

Fig. 1 Scatter plot showing performance and stability of clones across environments

Environments with large PC1 scores are better discriminate among genotypes and those with PC2 scores near zero are more representative of an average environment (Yan et al., 2000; Yan, 2001). In the current study, three of the environments (Hawassa 2010/11, Hawassa 2011/12 and Amaro 2010/11) had larger PC1 scores and well discriminated among the clones and the other three (Amaro 2010/11, Jima 2010/11 and Jima 2011/12) were considered to more representative of an average environment. Genotypes at the apex of each sector are the best performing at environments included in that sector if the GGE is sufficiently approximated by PC1 and PC2 (Yan et al., 2000 and Yan, 2001.)

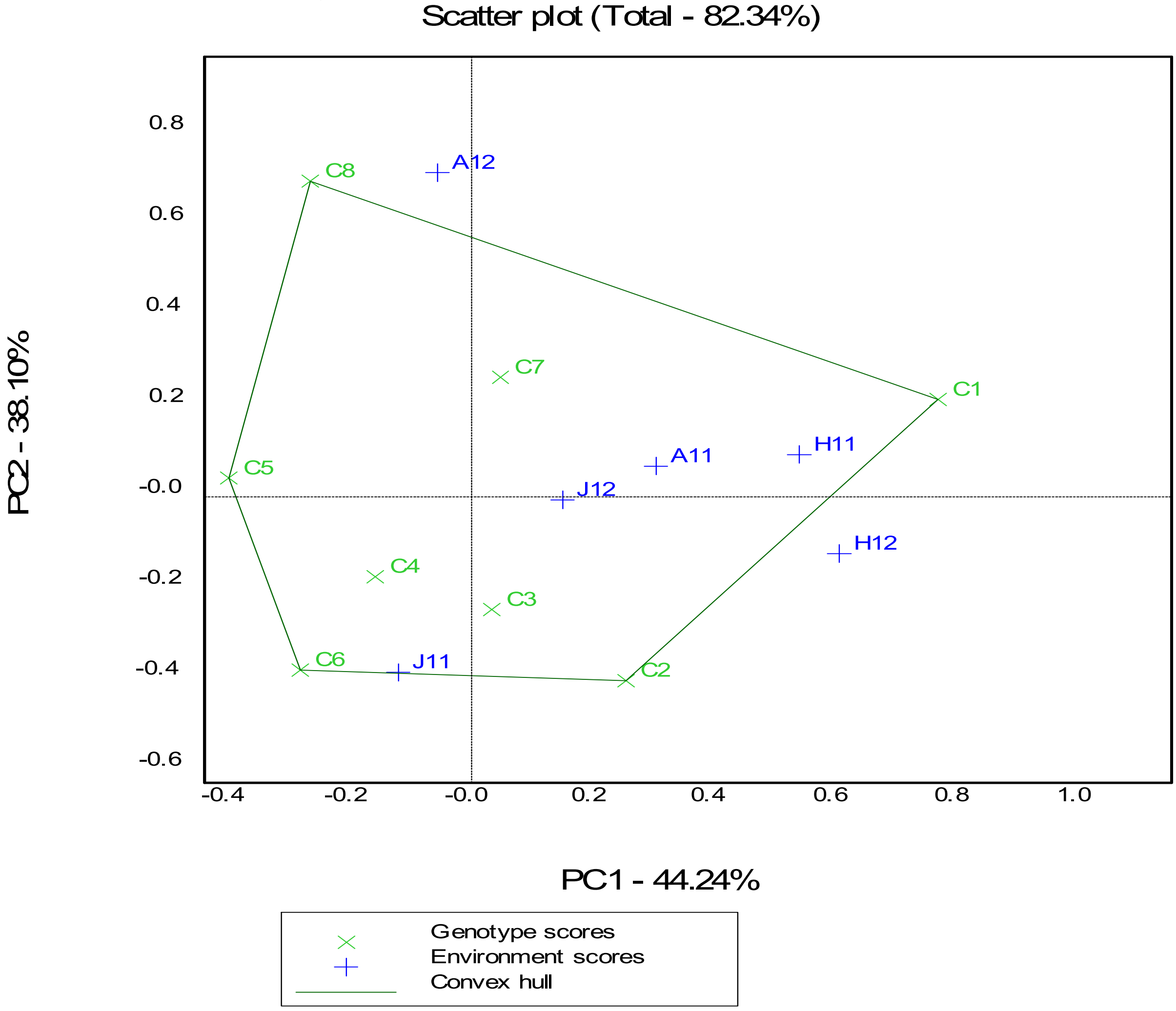

Fig 2. GGE-Biplot showing environments and their respective cassava clones

As shown in Fig. 2, PC1 and PC2 accounted for 82.34% of the total PCs indicating that they had sufficiently explained the GGE. Accordingly, the clones C1 was the best performers at all locations (Hawassa, Amaro and Jima) which can be recommended for wider adaptability while the clones C3, C4, C6 and C2 were the best performer at Jima compared to other locations. Therefore, these genotypes might be recommended for adaptation specifically to Jima and similar environments. However, stability of the genotypes across environments should first be considered. The stability of the genotypes is displayed in Fig. 2.

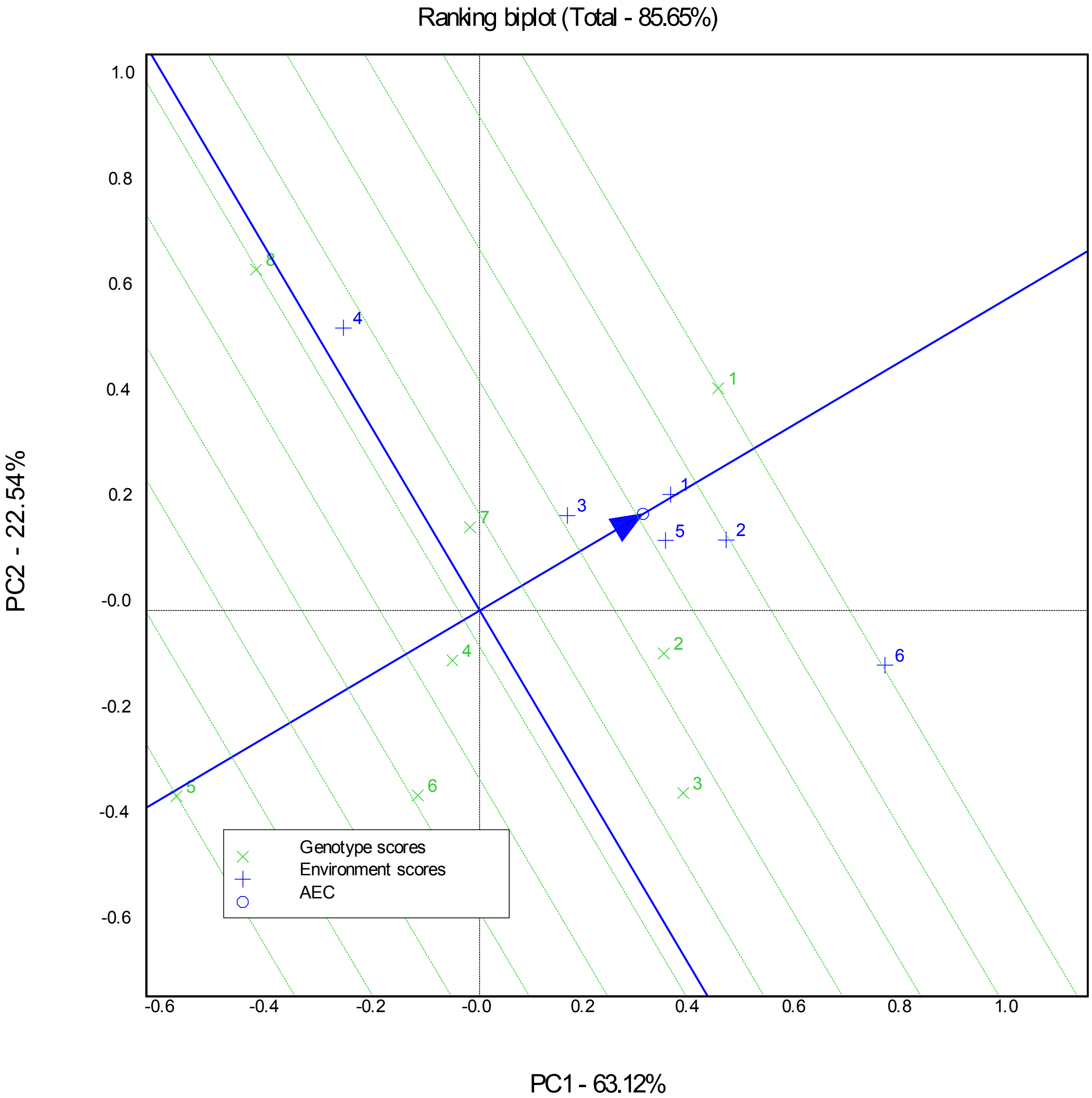

Fig. 3 Ranking plot shows best performing genotypes (or environments) in specific environment (or genotype).

The line that passes through the biplot origin is called the average environment coordinate (AEC), and it shows the stability of the genotypes (Yan, 2001). The stability of the genotypes is measured by their projection to the AEC *y*-axis (A line). That means, the greater the absolute length of the projection of a genotype, the less stable it is or the shorter the absolute length, the more stable it is (Yan, 2001). The A line (Fig. 3) separates genotypes with yield below the mean and above the mean. Those genotypes/clones to the right of this line are high yielders while those to the left are low yielders. Therefore, the clones ranking, according to this interpretation, was C5, C4, C3,C1,and C2 in that order (Fig. 3).

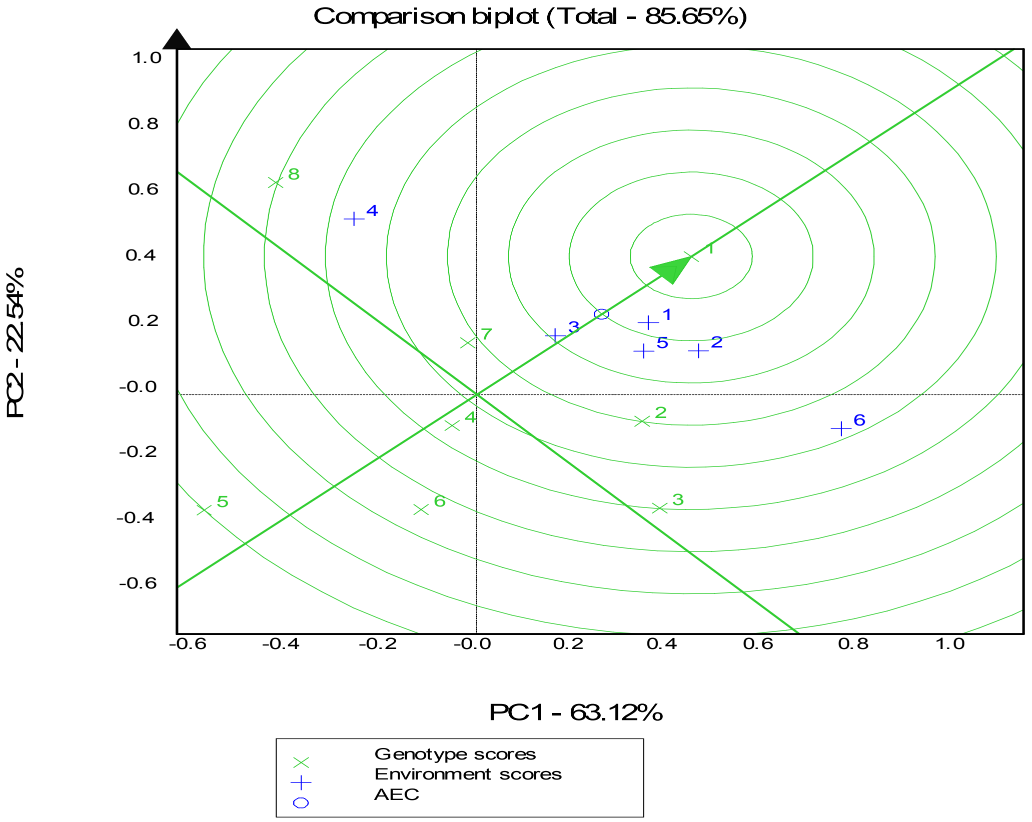

Fig. 4 Comparison of genotypes and environments with ideal genotypes and environments respectively.

The clone C8 was the poorest genotype for storage root yield. Fig. 4 shows the concentric circles around the ideal clone (C1). This clone had a lower value projection on the y-axis and hence can be called the most stable clone with wider adaptation to all the test environments and can be recommended for wider production in similar environments of the country, Ethiopia. Those clones that are closer to C3 can be considered ideal genotypes. Accordingly C2 and C4 are also ideal clones. The standard check variety (C7) was also among the high yielding and relatively stable clone. Using Hawassa 2010/11(H11) as an ideal environment, environments in closer concentric circles such as , A11, H12 and J12 (Fig. 4) were ideal environments while J11 and A12 were poor environments.

Conclusion and Recommendation

Cassava is the most important food staple where it's known for its source of energy and in the world. The crop is tolerant to harsh climatic conditions and poor soils so that it is considered as the most important food security crop in the world. In addition to maintaining food security cassava has great potential in re-silencing the ever changing climatic condition and used as a source of industrial row materials. But its productivity is still low compared to other cassava producing countries. Thus extensive performance evaluations were conducted across location and came up with the best clones that are going to be verified, multiplied, popularized and disseminated to farmers for wider production. Accordingly the best performing cassava clone, TMC 191/0427 (C1), was recommended and verified for wider environments as it is the higher yielder and the most stable clone among the clones under investigation. Similarly the clones MM96/930 (C3), MM96/528 (C4), Naliende (C6) and MM96/936 (C2) were recommended for specific location as they showed higher performance at Jima compared to other locations.

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