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Performance of cassava (*Manihot esculanta.* Cratz) clones in potential and low moisture stressed areas of Ethiopia

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Cassava (*Manihot esculanta.* Cratz) is one of the most important food crops that constitute a considerable portion of the daily diet of the people and also serves as one of the major source of carbohydrate. Despite its importance, production of cassava in Ethiopia has different constraints and opportunities. Among which, shortage of improved varieties is the first and the most important one. It is mainly cultivated by small resource poor farmers on smallholding plots of land. Average storage root yield obtained per a given plot of cassava is as low as 100 tons per hectare despite the potential yield of 600 tons per hectare per year. This low yield might be due to the cultivation of local, low yielding, late maturing cultivars. To contribute to alleviating the problem and provide farmers other alternative varieties, Hawassa Agricultural Research Center, in collaboration with Jimma and Sekota Agricultural Research Centers, conducted evaluation of cassava clones in potential and moisture stressed agroclimatic conditions of the country. Jima and Hawassa sites represent potential agroclimatic condition, while Amaro and Sekota represent moisture stressed areas. A total of seven cassava clones namely AWC-1 (MM 96/5280), AWC-2 (MM 90/5280), AWC-3 (MM 96/7151), AWC-4 (MM96/1871), AWC-5 (MM96/3868) and Kello (standard check) were evaluated by using randomized complete block design replicated three times. The evaluation was carried out for two consecutive years, from 2012 to 2014. The combined analysis result indicated that there was statistically significant difference among the clones tested and the locations where the experiment was conducted. The clone AWC-1 (37.17 t/ha) followed by AWC-2(35.52 t/ha) and AWC-5 (35.51 t/ha) gave the highest storage root yield but there was no statistically significant difference in the total storage yield among the clones AWC-2, AWC-3 and AWC-5. In the same way, the highest dry matter content was recorded from the clones AWC-2 (51.8%), AWC-3 (48.5%) and Kello (49.1%). Among the locations tested, the best result was obtained from Amaro (35.14 t/ha) which is characterized by its low moisture stress, indicating that cassava can resist/tolerate low moisture stress and give comparative yield provided that other factors are not limited. Thus, those clones with the highest storage root yield and dry matter content were promoted for variety verification and will be released for wider production.

Key words: Cassava, moisture stress, potential, storage root, dry matter.

INTRODUCTION

Cassava is a monoecious perennial shrub having variable height ranging between 1 and 5 m, although maximum height usually does not exceed 3 m (Bernardo and Hernan, 2012). But it is extensively cultivated as an annual crop in tropical and subtropical regions for its edible starchy tuberous roots (MoC, 2014). Cassava is a very important food crop in the tropics, that is, at latitudes of 30° and from sea level to 1800 m above sea level. Also, the principal economic products are its roots, cassava leaves also have excellent potential and are extensively used in Africa and Asia, as either human food or animal feed. Cassava is the fourth most important commodity after rice, wheat and maize, and is a basic diet of many millions of people (FAO and IFAD, 2000).

In addition to the economic value of the products and byproducts obtained from cassava, it offers other recognized advantages: tolerance of drought, capacity to produce considerable yield in degraded soil, resistant to insect pests and diseases, tolerance of acid soils (which are predominant in most of the world's tropical plains), and flexibility in planting and harvesting time (Bernardo and Hernan, 2012).

Despite its enormous production potential, adaptation to a great diversity of environments, its recognized tolerance of biotic and abiotic constraints to production, and its diversity of uses, cassava has not yet been managed to fully develop its potential in tropical agriculture due to numerous factors. Among the factors that constrained the production of cassava is lack of early maturing, high yielding and low hydrogen cyanide containing varieties.

According to FAO estimates, 276,721,584 tons of cassava were produced worldwide in 2013. Africa accounted for 57%, Asia for 32%, and others 11% of the total world production. In 2013, Nigeria produced 54 million tones making it the world’s largest producer followed by Thailand, Indonesia and Brazil with 30.2, 23. 94 and 21.23 million tons, respectively. In terms of area harvested, a total of 20732192 hectares was planted with cassava throughout the world in 2013; about 64% of this was in sub-Saharan Africa. The average yield in this year was 11.3 tons per hectare, but this varied from 1.3 tons per hectare in Burkina Faso to 35 tons per hectare in India. In the largest producer, Nigeria, the average yield was 14 tons per hectare (FAOStat, 2013).

In Ethiopia, It is mainly cultivated by small resource poor farmers on smallholding plots of land. It is both a food security crop and a source of household income. It is increasingly becoming a source of industrial raw material for production of starch, ethanol, waxy starch, bio-plastics, glucose, bakery and confectionery products, glue, among others (Tesfaye et al., 2013). In Ethiopia, cassava generally is being grown in almost all parts of the country. But bulk of its production is situated in south, south western and western parts of the country.

The average total coverage and production of cassava per annum in Southern region of Ethiopia is 195055 hectares with the yield of 501278.5 tones indicating the average productivity of cassava in the country is not more than 25 ton per hectare (SNNPR, BoA, 2014). Which is by far lower than the yield obtained by other tropical countries such as Nigeria that recorded 35.00 tons per hectare per year (FAOStat, 2013)

In Ethiopia, most of the varieties produced were local farmers' varieties which are low yielding, late maturing, bitter type and containing high hydrogen cyanide (Anshebo et al., 2004). To alleviate these problems, a number of research activities focusing on crop variety improvement were conducted in different agroecological locations and two out performing varieties were released in 2005 (MoA, 2005). But the varieties were late maturing and the numbers were low to provide additional alternative to the farmers and increase genetic diversity. Hence evaluation of seven cassava clones including standard and one local check were conducted at different agroclimatic condition of the country. As a result, promising varieties with regard to storage root yield per a given period from a given area of land were obtained. Therefore, this paper aimed to show the performance of cassava clones under different agro ecological conditions of the country.

MATERIALS AND METHODS

Evaluation of cassava clones for their storage root yield and other agronomic traits was conducted in four location of the country namely Hawassa, Amaro, Jima and Sekota. Two of the locations (Hawassa and Jima) are classified as potential areas for the production of cassava, whereas the other two arbitrary are classified as low moisture stressed dry land areas. The overall description of the locations is given in the Table 1.

A total of seven cassava clones (five introduced, one standard check, and one local farmers variety) were tested in the experiment. The experiment was arranged in randomized complete block design with three replications and conducted for two consecutive years, 2012-2014, except Jimma where only one season data was availed. Gross and net plot size where the experimental units were planted were 4 x 6 and 2 x 4 m, respectively. Storage root yield and other yield related data such as root length, root girth, number of roots per plants and growth rate were taken from the net plot at harvesting except the growth rate which was taken in three months interval from planting. Data on the root length, root girth, number of

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Table 1. Mean annual temperature, rainfall, altitude, longitude and latitude of Hawassa, Amaro, Sekota and Jima.

Locations	Mean annual Temptarure (°C)			Mean annual rainfall (mm)	Altitude (masl)	Longitude	Latitude
	Minimum	Maximum	Mean				
Hawassa	7.2	33.5	20.35	1024.2	1708	38° 28' 34"E	7° 3' 43" N
Amaro	12	25	19.5	800	1477	37°32"10': 38°E	5° 3" 55': 60N
Jima*	11.3	26	18.65	1597	1753	36^0 E	$7^0$46'
Sekota	28	40	34	474.5	1300	38^o 58' 50" E	13^o 14' 06" N

*Nebyu (2006).

Table 2. Analysis of variance.

Variable	df	SS	MS	MSe	F value	Pr > F
RD	6	26.3908779	4.3984796	0.7283698	6.04**	<.0001
RL	6	982.246564	163.707761	52.22382	3.13**	0.0079
MRYT	6	1721.069671	286.844945	62.95768	4.56**	0.0005
UNRYT	6	98.268046	16.378008	9.875142	1.66^{NS}	0.1411
TRYT	6	1994.189061	332.364844	92.76680	3.58**	0.0032
RNPP	6	73.1054296	12.1842383	4.048105	3.01*	0.0102

*= Significant at α value less than 0.05, **= highly significant at α value less than 0.01; RD= average root girth (cm), RL=root length (cm), MRYT= marketable root yield per hectare (tones), UNRYT = unmarketable root yield per hectare (tone), TRYT= marketable root yield per hectare (tone), RNPP=average number of roots per plant.

roots per plants and growth rate were taken from randomly selected five plants. Whereas, the storage root yield data was taken from each plot in kilogram and converted into yield per hectare in ton by using the following formula:

$$\text{Yield per hectare} = \frac{\text{Yield per plot (kg) x 10000 m}^2}{8 \text{ m}^2 \text{ x 1000 (kg/t)}}$$

Note that 1 ton(t) is equals to 1000 kg.

Storage root yield was clustered into marketable, unmarketable and total yield. Marketable storage roots yield was referred to the yield of those roots weighting 100-500 g, storage roots not infected by disease and infested by insect pests, whereas unmarketable storage root yield was referred to those roots weighting more than 500 g and less than 100 g, storage roots infected by disease and infested by insect pests and miss shaped rots. Total storage root yield was the sum total of marketable and unmarketable root yields.

The dry matter content of the clones were taken after oven drying for 24 h at 110°C for consecutive dates until the weight was constant. The clones were planted by using 1 x 1 m plant and row spacing. The spacing between plots were 2 m, whereas, the space between reps were 3 m. Before carrying out the combined analysis, homogeneity of variances test for total storage root yield across locations and years was conducted by using Levene's, Welch's and Bartlet's tests. The collected data were analyzed by using SAS statistical software, 2002 version 9 and IRRISTAT statistical software, 2007.

RESULTS

Analysis of variances

Cassava clones performed differently at different environmental conditions. But the combined analysis of variance table indicated that there was highly statistically significant difference among clones (P<0.01) for their root girth (RD), root length (RL), marketable and total storage root yield. There was also statistically significant difference among clones for their number of storage roots per plant (RNPP). But there was no statistically significant difference among the clones for their unmarketable yield (Table 2). The test for equality of variances showed no significant difference for all Levene's, Weltch's and bartlett's test at p value ≤0.05 (Table 3).

Storage root yield and yield related components

As far as storage root performance is concerned, the highest marketable and total storage yield was obtained from the clone AWC-1 followed by AWC-2 and AWC-5. The least score was recorded from local cassava farmers' variety followed by kello (the standard check) and AWC-4 in the increasing order. The local varieties showed the largest storage root diameter but there was no statistically significant difference among the clones for this particular trait. The cassava variety Kello followed by the clone AWC-5 and AWC-2 gave the highest storage length, 40.67, 38.25 and 37.77 cm respectively. The highest number of roots per plant was recorded from the clone AWC-2 next to AWC-5 (Table 4).

All cassava clones have higher yield advantage over both the local and standard checks. The clone AWC-1

Table 3. Test for homogeneity of variances.

Source	DF	Sum of squares	Mean square	F value	Pr > F
Levene's test for TRYT					
trt	6	3.82E+09	6.37E+08	1.48	0.189
Error	134	5.77E+10	4.30E+08		
Welch's ANOVA for TRYT					
Source	DF	F Value	Pr > F		
trt	6	1.91	0.0941		
Error	57.64				
Bartlett test for equality of variances TRYT					
CHISQ				Pvalue	
8.6778491				0.1925226	

Table 4. Storage root yield of cassava clones combined over location.

Cassava clones	Marketable storage root yield (t/ha)	Unmarketable storage root yield (t/ha)	Total root storage yield (t/ha)	RD (cm)	RL (cm)	RNPP
AWC-1	31.85	5.322	37.17	4.831	32.69	6.879
AWC-2	30.89	5.047	35.52	4.524	37.77	8.115
AWC-3	28.63	4.04	32.67	4.826	33.81	7.873
AWC-4	26.31	2.996	29.31	4.751	35.55	6.517
AWC-5	30.94	4.591	35.51	4.557	38.25	8.515
Kello	23.86	4.674	28.53	4.756	40.67	7.45
Local	20.3	4.416	24.72	6.059	38.26	6.59
CV(%)	29.69	65.75	32.29	17.59	19.71	26.99
LSD	5.35	1.72	6.09	0.5383	4.55	1.27

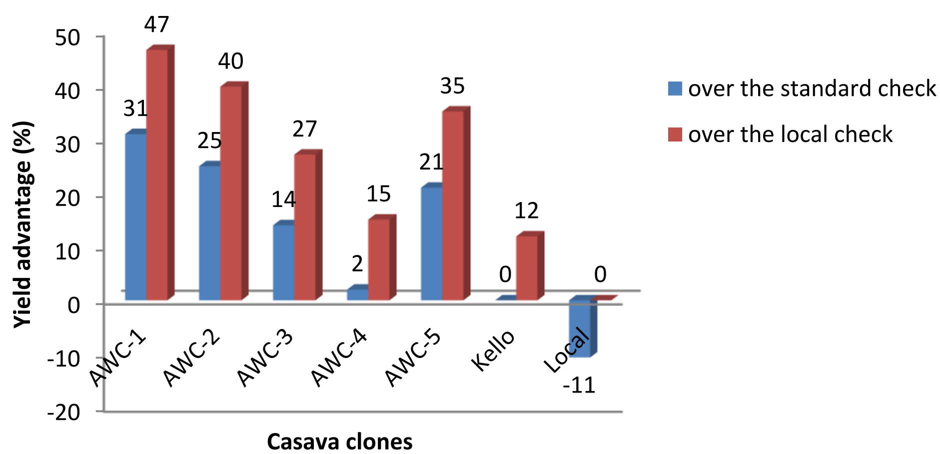

Figure 1. Yield advantage of cassava clones over the standard and local checks.

has 47 and 31% yield advantage over the local and the standard check followed by the clone AWC-2 which recorded 40 and 25% yield advantage over the local and standard checks, respectively. However, the yield advantage of the clone AWC-4 over the local and the standard checks was very minimal. Similarly, the yield of standard check was better than the average performance of the local farmer varieties (Local Checks). The yield advantage of the local check over the standard check was -11 as opposed the standard check over the local checks which recorded 12% yield increment (Figure 1).

The combined analysis result of the dry matter content

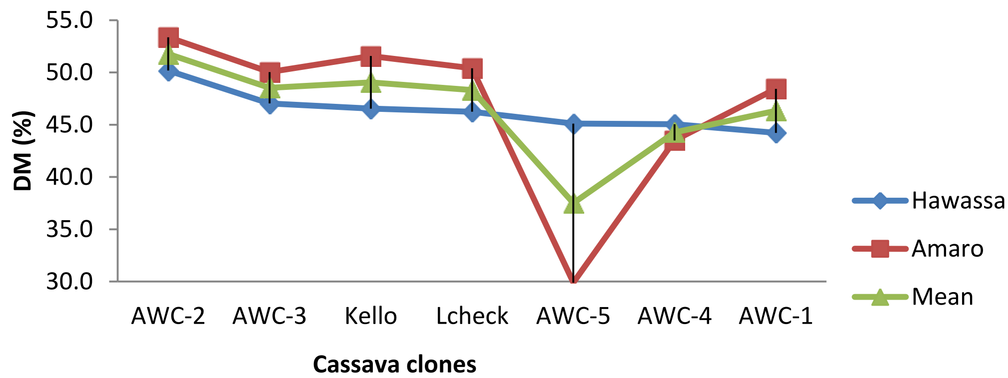

Figure 2. Percent dry matter content of storage root over location.

Table 5. Percent dry matter content of cassava clones tested across locations.

Cassava clones	Hawassa	Amaro	Mean
AWC-2	50.2	53.4	**51.8**
AWC-3	47.0	50.0	48.5
Kello	46.5	51.6	49.1
Lcheck	46.2	50.4	48.3
AWC-5	45.1	29.9	37.5
AWC-4	45.0	43.5	44.3
AWC-1	44.2	48.4	46.3
LSD	NS*	20.3	10.5
CV	10.58	24.45	18.9

*NS= Non-significant.

of storage root of cassava clones under investigation showed the presence of statistically significant differences. The clone AWC-2 gave highest dry matter content followed by the clones AWC-3 and the standard check (Kello) (Table 5). The dry matter content also varies with the locations where the experiment was conducted as it there was no statistically significant difference among cassava clones tested at Hawassa as opposed the values obtained from Amaro (Figure 2).

Characters' association

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=0.24), marketable root yield (r=0.50) and total storage root yield (r=53). But it is statistically not significantly correlated with unmarketable storage root yield and number of roots per plant. Root length was also significantly positively correlated with marketable and total storage root yields with r value of 0.40 and 0.25, respectively. In the contrary, it was negatively but significantly correlated with unmarketable storage root yield (r=-0.34) and not statistically significantly correlated with number of roots per plant. Even though marketable and unmarketable storage root yields were not statistically correlated with each other, both of them were significantly and positively correlated with total storage root yield with correlation coefficient of 0.92 and 0.41, respectively. The total storage root yield was also positively significantly correlated with root numbers per plant with r=0.41.6. It was also positively and significantly correlated with leaf yield per plant. Root weight per plant was positively and significantly correlated with dry matter content and leaf yield per plant (Table 6).

Yield stability of cassava clones across locations

As indicated in Table 7, the performance of cassava clones tested across locations varied with agroclimatic conditions. The clone AWC-1 gave the top total storage yield (tons)/hectare at Hawassa and Amaro locations. At Sekota, the other clone, AWC-2 gave the highest storage root yield and at Jimma, the clone AWC-5 followed by the clone AWC-2 gave the highest yield (Table 7). As far as the location performance is concerned, the best mean yield of the two seasons average indicated that the location Amaro is the best area for cassava production followed by Hawassa. The value of Jimma is higher but it was the average of only one season so was not included in the comparison. The additive main effects and multiplicative interaction (AMMI) stability analysis of seven genotypes on seven environments also indicated the variability of performance of cassava clones under different environmental condition (Table 8). The clones AWC-1 and AWC-5 possessed wider adaptability as they were found close to the origin. In the contrary, farmer varieties (local checks) were able to adapt to specific environmental conditions which is far from the origin of the plot.

The interaction principal component axis (IPCA) score

Table 6. Pearson correlation coefficients of storage root yield and yield component of cassava clones.

Variables	RD	RL	MRYT	UNRYT	TRYT	RNPP	RWPP	DM	LYPP
RD	1	0.34337	0.5053	0.08437	0.492	0.089	0.557	0.08	0.377
		0.0036	<0.0001	0.4874	<0.0001	0.465	<0.0001	0.508	0.001
RL		1	0.4251	-0.40108	0.235	-0.113	0.072	-0.481	0.547
			0.0002	0.0006	0.05	0.35	0.551	<.0001	<0.0001
MRYT			1	0.03987	0.926	0.267	0.486	-0.288	0.503
				0.7431	<0.0001	0.025	<.0001	0.016	<0.0001
UNRYT				1	0.415	0.457	0.337	0.652	-0.41
					4E-04	<0.0001	0.004	<0.0001	4E-04
TRYT					1	0.416	0.57	-0.016	0.303
						3E-04	<0.0001	0.899	0.011
RNPP						1	0.508	0.046	-0.145
							<0.0001	0.704	0.231
RWPP							1	0.312	0.037
								0.009	0.76
DM								1	-0.514
									<0.0001
LYPP									1

also indicated the stability of a clone across environments. The more the IPCA approximate zero, the more stable the clone is over all the environments tested. According to IPCA1 (Table 7), clone AWC-1 and AWC-5 had approximately zero score (0.1 and 0.27, respectively) and hence could be considered as most stable clones.

DISCUSSION

Storage root yield and yield related components

The highest total storage root yield obtained from the clone AWC-1 (37.17 t/ha), AWC-2 (35.52 t/ha) and AWC-5 (35.51 t/ha) was by far higher than the yield obtained from most of cassava growing countries in the world in general and East Africa in particular. FAOstat 2013 indicated that the average yield obtained from India, China, Brazil and Nigeria was 34.96, 24.55, 13.92 and 14.03 tons per hectare per year. Average storage yield obtained from East African countries such as Kenya, Uganda and Tanzania in 2013 was 15.89, 12.02, 7.50 tons per hectare, respectively. Differences in cassava tuber yield are determined by several factors, such as number of tubers, tuber length and tuber weight per plant. Ntawuruhunga and Dixon (2010) concluded that storage root number, storage root size and storage root diameter were the main yield components contributing to yield enhancement in cassava.

As far as yield related traits are concerned, the value obtained directly concedes with the report of Kenneth (2011). In his study, the highest storage root length obtained from the variety, Cuban White Stick was 40.46 cm. In the same way, the highest storage root number per plant was obtained from the variety John LaMotte (7.78) which is similar to the value recorded from the current study (8.52).

Characters' association

The total storage root yield was positively significantly correlated with root numbers per plant, storage root length, storage root weight/plant, leaf yield per plant but negatively correlated with dry matter content. This show those traits which are positively and significantly correlated with storage root yield were important components of yield across locations. The current study finding is also in line with the report made by Ntawuruhunga et al. (2001). They indicated that storage root weight (r=0.53) and storage root number (r=0.45) are the main component of total yield per a given area per a given time. Dry matter content was negatively correlated with storage root weight, suggesting that when the storage root weight is high, the dry matter content tends to be low which is in line with the study conducted by Kenneth (2011).

Yield stability of cassava clones across locations

The AMMI and the IPCA scores indicated the clones AWC-1 and AWC-5 seams possessed wider adaptability as they are found near the origin. In the contrary, farmer varieties (local checks) were able to adapt specific environmental conditions which is far from the origin of

Table 7. Mean total storage yield (ton/ha) clone ranks in seven environments.

Clone name	Environments														TRT means	Rank	IPCA1 SCORE	IPCA2 SCORE
	Hawassa1	Rank	Hawassa2	Rank	Amaro1	Rank	Amaro2	Rank	Jima1	Rank	Sekota1	Rank	Sekota2	Rank				
AWC-1	460.4	1	456.2	1	416.7	1	444.6	3	351.2	5	238	3	210.8	3	368.3	1	-0.10	0.10
AWC-2	299.2	5	367.5	3	289.2	3	507.9	1	478.9	2	241	2	274.3	1	351.1	2	0.49	-0.75
AWC-3	320.8	3	327.9	5	257.9	5	474.6	2	453.1	3	190.4	5	210.7	4	319.3	4	0.37	0.81
AWC-4	281.2	6	250.4	6	269.2	4	410.8	4	352.1	4	232.3	4	225.9	2	288.9	5	0.92	-0.55
AWC-5	352.1	2	416.7	2	236.7	6	396.2	6	531.3	1	247	1	196.2	6	339.4	3	0.27	0.11
Kello	318.8	4	347.9	4	326.2	2	302.9	7	285.9	7	182.6	6	202.3	6	281	6	0.69	-0.46
Lcheck	156.2	7	161.7	7	179.2	7	407.5	5	351	6					251.1	7	-0.88	-0.98
Environment mean	312.67		332.61		282.16		420.64		400.5 0		221.88		220.03		314.16			
IPCA1	-0.67		-0.55		-0.70		0.71		0.10		0.95		0.12					
IPCA2	0.25		0.70		-0.53		-0.56		0.64		-0.83		-0.41					

Table 8. Analysis of variance for the AMMI model.

Source	D.F.	S.S.	M.S.	F	FPROB
Treatments	6	98987.1	16497.8		
Locations	6	277624.	46270.6		
Treatment x sites	34	123804.	3641.29		
AMMI component 1	11	78078.0	7098.00	3.570	0.005
AMMI component 2	9	30019.5	3335.50	2.973	0.033
AMMI component 3	7	10469.3	1495.61	1.999	0.190
AMMI component 4	5	3374.80	674.960	0.725	0.666
GXE residual	2	1862.41			
Total	46	467901.			

the plot and larger absolute value scores of IPCA (Figure 3). This indicates that the clones, AWC-1 and AWC-5 are not affected by environmental conditions. In the same way, a variety performance trial was conducted in Indonesia by using 15 genotypes at different range of altitudes, some of the clones' storage root yield was stable across locations. The clone Malang 4 (G3) and CMM 03038-7 (G8) are adaptive clones to environment at medium altitude of up to 800 masl (Noerwijati and Budionob, 2015). Noerwijati et al. (2014) indicated that environment gives the most effect (64.69%), followed by genotype-by-environment interaction effect (6.53%), and genotype effect (4.94%) on performance of a given genotype of cassava. He also indicated the most stable cassava genotype by using that GGE biplot with high yield which is in line with this study, showing the possibility of obtaining the most stable varieties across locations.

CONCLUSION AND RECOMMENDATIONS

The clone Awc-1 gave the highest yield, followed by AWC-2 when compared with standard and local checks. As far as the yield advantage over

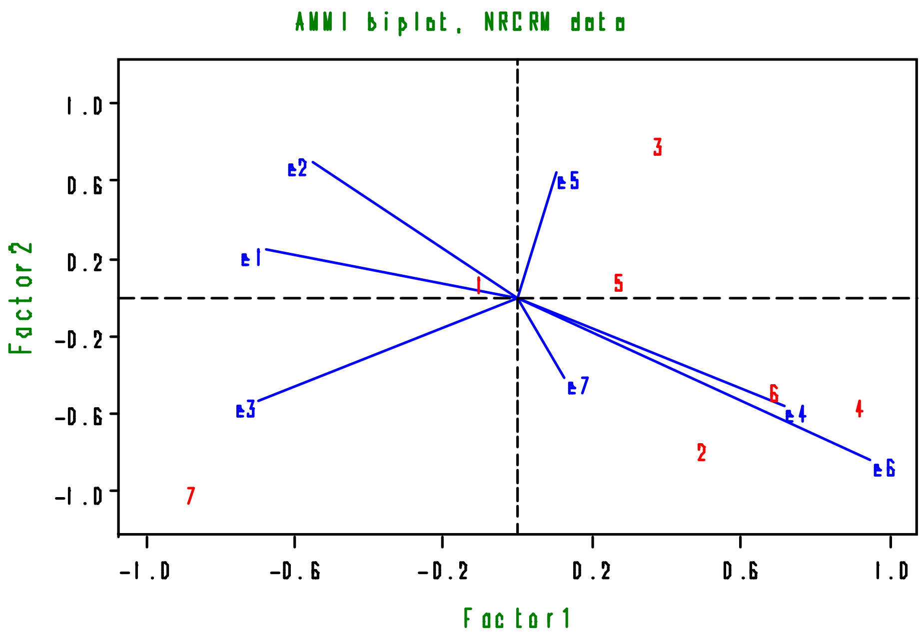

Figure 3. AMII biplot of seven environments and seven varieties.

the standard and local checks is concerned, the clone AWC-1 have 47 and 31% yield advantage over the local and the standard check followed by the clone AWC-2. Three clones (AWC-1, AWC-2 and AWC-3) have statistically no significant difference for their dry matter content (more than 50%). Those clones having stable and higher root yield combined with higher dry matter content were proposed for variety verification trial for a wider dissemination as well as production. One of the most important problems of cassava production is the lack of early maturing varieties. In Ethiopia, cassava generally grows in almost all parts of the country. But bulk of its production is in south, south western and western parts of the country. Most of the varieties produced were local farmers' varieties which are low yielding, late maturing, bitter type and containing high hydrogen cyanide. The existing improved and farmers' varieties take more than 18 months for full maturity. Therefore, continuous breeding and selection program is required to fill the gap due to the production of late maturing varieties.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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