Variability of Sweet Potato (*Ipomea Batata L.*) Varieties for Their Yield and Yield Components in South and South East Areas of Tigray Region, Ethiopia

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Abstract:

Seven sweet potato varieties were tested at three locations of southern and eastern zones of Tigray.in 2012 cropping season. The objective of the study was to evaluate the yield and yield components of the varieties and the *experiment was laid out in RCBD with three replications and in plot size of 4.2m x 2.4m. Net harvestable plot area was 7.2 m^2 with inter and intra-row spacing of 0.60m and 0.30m respectively. Individual analyses of variance for the three locations indicated the existence of significant to highly significant ($P < 0.01$) genotype differences for all traits except vine length, above ground fresh biomass weight and stand count at harvest considered at Rarhe and Kukufto locations. In addition, vine length, unmarketable storage root number per plot and stand count at harvest were also showed non-significance genotype difference at Illala location. Similarly, the combined analysis of variance across locations showed significant variation among genotypes, locations and the interaction for all traits except vine length and above ground fresh biomass weight. Kukufto was the highest total root yielding location followed by Illala for almost all varieties but Rarhe yielded lowest. Varieties tulla, LO and kulfo had highest total root yield at Kukufto and Illala locations. Vitae gave above average root yield only at Rarhe but kabode, temesgen and bellela yielded lower and below average total roots at all locations. Based on the combined mean total root yield of locations and different yield evaluation methods, high yielding varieties were identified. Accordingly, LO and Tulla varieties gave highest root yield per unit area at all locations, followed by Kulfo. Therefore, these varieties can play a vital role in food self sufficiency and food security of Tigray region and they should be widely distributed to farmers of the testing locations and similar areas of the region*.

Key Words: Genotypes (varieties), Location, Sweet potato

1. Introduction

Sweet potato is grown around the world in diverse environments, often by small farmers in marginal soils, using few inputs (Manrique and Hermann, 2000). Likewise, this crop is one of the root and tuber crops grown in Ethiopia, and it is the third important root crop next to Enset and Potato (Engida *et al*., 2009). The area covered and production of sweet potato in Ethiopia increases from time to time. However, not only the sweet potato research but also its production is very limited to specific regions, like that of South Nation Nationalities and Peoples, Oromia, Harerghe and Amhara regions. In Tigray region, sweet potato is grown mainly in the lowlands and medium altitude areas. Currently, the area coverage of the crop in the region is increasing from time to time. Despite the crop potential, lack of improved sweet potato varieties suitable for different agro-ecologies and resistant to insect pests are some of the factors that hider the crop expansion.

Sabaghnia *et al*. (2006) pointed out the importance of studying genotype by location interaction not only from the genetic and environmental point of view but also its relevance to the production problems of agriculture in general. The importance of any variety testing program is to obtain the most accurate estimate of variety performance that is possible within the limitations imposed by the environmental growing conditions (Addis, 2003). Farmers are basically interested in superior and specifically adapted varieties to their condition and with a high degree of stability over time (Scott and Maldonando,1998). Hence, the study of multi-location variety trial is particularly relevant to countries that have diverse agro-ecologies, as is the case in Ethiopia.

The well performing ability of sweet potato over wide range of environments is of major interest to plant breeders (Moussa *et a*l., 2011). Due to the higher productivity and drought tolerance of the crop, it can play vital role in achieving food self sufficiency of the region. Even though Tigray region has wider agro-ecological zones and suitable for sweet potato production, unavailability of improved sweet potato varieties that can give high yield and tolerance for diseases and insect pests is a major problem in most sweet potato growing areas of Tigray. Moreover, despite of the diverse agro-ecologies of the Tigray region, multi-location trials have not been conducted for sweet potato varieties and/or genotypes. Threfore, this study was initiated to evaluate the yield and yield components of the sweet potato genotypes across different locations of the Tigray region

2. Materials and Methods

Description of the Study Area and Planting Materials

The experiment was carried out at three locations of Southern and South Eastern zones of Tigray region. The three locations were Illalla that represented mid - altitude, Kukufto and Rarhe represented the low altitudes. Even though Kukufto and Rarhe represented the low land area, they differ in altitude, rainfall and temperature factors.

Table 1. Area description of Sweet potato varieties testing sites

S. No	Location	Latitude (^{O}N)	Longitude (^{O}E)	Altitude (m asl)	Soil texture	Min and max Temp (^{O}c)	Annual RF (mm)
1	Rarhe	12^{o}23’23”	39^{o}36’12”	1459	Sandy loam	14.6 – 29	747.1
2	Kukufto	12^{o}34’41”	39^{o}40’12”	1535	Sandy loam	16 – 22	594.5
3	Illala	25^{o}51’45”	39^{o}61’28”	1970	Clay loam	11.4 – 27.1	520.2

The materials used in this trial were Bellela, Kabode, Kulfo, LO, Temesgen, Tulla and Vitae. The experiment was arranged in Randomized Complete Block Design (RCBD) with three replications and the materials were planted under rainfed condition in the 2012. Plot size of 2.4 meter by 4.2 meter with a respective inters-and intra row spacing of 0.60 and 0.30m were used. The Net harvestable plot was 2.4m x 3m (7.2 m^2). Total storage root yield data was taken during the study and the central five rows were harvested from each plot leaving border rows to avoid border effects.

The data collected for vine length, storage root length, root girth, root number and root weight were taken from the mean of five randomly selected plants. For other traits, it was taken from the whole plants of each harvestable area. On the other hand, disease severity score was taken from the whole plot visually before harvest. All data were taken at the time of harvest except for the first stand count establishment and disease severity scores.

Statistical Analysis: Combined analysis of variance (ANOVA) for yield and yield component characters of the varieties tested across locations was performed using the GenStat (Payne *et al.*, 2007) statistical package. Before running data analysis, the data were first tested for normality with Shapiro Wilk test method. Accordingly, all data set showed normal distribution.

Principal component analysis (PCA) using a correlation matrix was carried out to define the existing pattern of variation among characters. The values of the first three components were selected and analyzed based on the criteria of eigenvalue > 1, more than 5% proportion of variance for each component and greater than 75 %

cumulative proportion of variance explained (Anglim, 2007). Moreover, to determine the strength of relationship among variables, phenotypic correlations were measured using Correlation Coefficient, r, based on the following formula:

$$r_{xy} = \frac{\Sigma[(X-\bar{X})(Y-\bar{Y})]}{\sqrt{\Sigma(X-\bar{X})^2\,\Sigma(Y-\bar{Y})^2}}$$ Where, r is the Pearson's correlation coefficient;

X and Y are the observation data and $\bar{X}$ and $\bar{Y}$ are the sample means.

Principal component analysis and correlation coefficient were analyzed using Minitab release 14 (Minitab, 1998), PAST (Ryan *et al*., 2001) and GenStat (Payne *et al*., 2007), statistical software, respectively.

3. Results and Discussion

3.1 Estimation of Variances for Sweet Potato Yield Components

The results of the analysis of variance for 13 characters of sweet potato varieties studied at Rarhe, Kukufto and Illala location is presented in Table 2. The analysis of variance for each location showed that there was highly statistical significant differences (*P<0.01*) among the varieties for most of the characters (storage root length, storage root diameter, average storage root number, storage root weight, marketable storage root number, unmarketable storage root number, total storage root number, storage root dry matter content, marketable root yield, unmarketable root yield and total root yield. Engida (2004) and Tesfaye (2006) have reported similar results for the above sweet potato characters. This may be associated with the existence of large variability among varieties. However, statistically non significant differences were also observed among the varieties for vine length and above ground fresh biomass weight at Rarhe and Kukufto locations. Similarly, Vine length and numbers of unmarketable storage roots has showed no significant differences at Illala location.

Table 2. Mean squares of analysis of variances for 13 characters in 7 sweet potato varieties grown at Rarhe, Kukufto and Illala, 2012

Character	Location					
	Rarhe		Kukufto		Illala	
	MSv (6)	MSe (12)	MSv (6)	MSe (12)	MSv (6)	MSe (12)
VL	612.8	530.4	107.4	346.6	281.1	107.9
AGFBW	567.0	378.8	569.8	206.5	83.20**	11.52
SRL	50.52**	3.09	43.78**	1.66	11.83**	1.66
SRG	6.08**	0.78	3.41**	0.26	4.39**	0.33
SRN	3.28**	0.22	13.76**	0.56	0.94**	0.19
SRW	16570**	2114	5528*	1280	7820.2**	875.6
MKSRN	264.41**	18.91	2464.08**	58.25	761.78**	25.99
UMKSRN	1332.52**	39.83	2392.4**	302.7	39.08	14.7
TSRN	1962.44**	55.35	8717.1**	375.2	863.3**	65.97
MKSRY	56.88**	1.86	151.18**	3.94	130.29**	6.43
UMKSRY	26.19**	1.27	323.71**	11.31	19.68**	1.69
TSRY	130.93**	4.99	885.12**	19.78	236.64**	11.9
DMC%	51.60**	3.04	88.98**	0.66	57.62**	2.19

MSv = mean square due to varieties, MSe = error mean square; ns implies non-significance,
** significance at 1% probability levels; ¥ Figures in parenthesis indicate the degree of freedom

*VL = vine length (cm), AGFBW = Aboveground fresh biomass weight tha^{-1}, SRL= storage root length (cm), SRG = storage root girth (diameter) (cm), SRN= storage root number per plant, SRW = storage root weight (g/root), MKSRN = Marketable storage root number per plot, UMKSRN = Unmarketable storage root number/plot, TSRN = Total storage root number per lot, MKSRY = Marketable storage root yield (tha^{-1}), UMKSRY = Unmarketable storage root yield (tha^{-1}), TSRY = Total storage root yield (tha^{-1}), DMC = storage root dry mater content (%),

3.2 Evaluations of Selected Traits at Individual Location

3. 2. 1 Vile length and above ground fresh biomass weight

Analysis of variance revealed that no statistical significance difference ($P > 0.05$) was observed for the character of vine length at Rarhe, Kukufto and Illala locations. However, though no statistical significant difference, highest mean vine length was recorded at Rarhe followed by Kukufto in all the sweet potato varieties. The variety Bellela ranked first in vine length at all locations (156.1 cm/plant at Rarhe, 122.5 at Kukufto and 81.7 cm/plant at Illala). The lowest vine length was obtained from Kabode (118.5 cm/plant) at Rarhe, Vitae (106.3 cm/plant) at Kukufto and Temesgen (56.6 cm/plant) at Illala.

Similarly, the ANOVA for the above ground fresh biomass weight (t/ha) revealed no statistical significant difference ($p > 0.05$) among varieties at Rarhe and Kukufto but it has revealed significance difference ($P < 0.01$) at Illala. However, at Rarhe, the variety Vitae gave the highest mean fresh green top weight (93 t/ha) while the variety Temesgen yielded the lowest (50.2 t/ha). At Kukufto, the highest weight was obtained from Kabode (73.1 t/ha) and the least was recorded by the variety Temesgen (34.5 t/ha). At Illala, the Kulfo variety (22.18 t/ha) gave the highest mean fresh biomass weight, while Temesgen (8.80 t/ha) gave the least result. In all the three locations, the variety Temesgen has shown the lowest above ground fresh biomass weight whereas, variety Kabode (53.2 t/ha) resulted in higher average weight followed by Kulfo (52.48 t/ha) in these locations and could be an important source for animal feed.

3.2.2 Storage Root Weight, Root Dry Matter Content and Total Storage Root Yield

Analysis of variance for all of these characters of the varieties has displayed highly statistical significance difference ($P < 0.001$) in the three locations. The variety mean values for these traits at the individual location are given in Table 3. Since the total storage root yield, average storage root weight and storage root dry-matter content have more important roles in sweet potato varietal selections, the responses of the varieties with respect to these traits is briefly discussed at each location.

The total storage root yield ranges from 4.92 to 22.96 t/ha at Rarhe; 5.69 to 45.55 at Kukufto and 5.3 to 24.72 t/ha at Illala locations**. A**mong the tested varieties, the highest fresh storage root yield was recorded for the varieties Tulla, LO and Kulfo in the tested locations without consistence over the locations. The variety LO (22.96 t/ha) ranked first at Rarhe which statistically significantly differed from all other varieties followed by Tulla (17.87 t/ha). Even though the variety LO did not show statistically significant difference from Kulfo and Tulla varieties, it came first at Illala (24.72 t/ha) and 2nd (45.01 t/ha) at Kukufto next to Tulla (45.55 t/ha). For almost all sweet potato varieties, the maximum storage root yield was recorded at Kukufto testing site, followed by Illala location. Lowest total storage root yield was obtained at Rarhe location. This could be due to the variation of soil and other climatic factors existed in the testing locations. Such yield difference among sweet potato genotypes and locations was also recorded by Yohannes (2007). In addition, Wonda *et al*. (1987) indicated that yield of sweet potato clones was affected significantly by genotype, location and genotype x location interaction.

Table 3. Mean performance of 7 sweet potato varieties for three traits grown at Rarhe, Kukufto and Illala, 2012.

Variety	Storage Root Weight (g/root)			Root Dry Matter Content (%)			Total fresh storage root yield (t/ha)		
	Rarhe	Kukufto	Illala	Rarhe	Kukufto	Illala	Rarhe	Kukufto	Illala
Bellela	96	51	148	25.5	22.5	28.4	4.92	5.69	12.73
Kabode	174	101	91	28.9	29.0	30.9	5.43	18.83	7.00
Kulfo	217	139	193	20.8	17.6	22.9	13.71	43.49	24.44
LO	298	184	190	21.9	18.3	21.9	22.96	45.01	24.72
Temesgen	94	128	96	24.3	27.0	31.8	12.20	13.65	5.30
Tulla	207	108	209	20.6	18.6	22.5	17.87	45.55	24.63
Vitae	125	79	102	31.4	30.5	30.5	17.09	15.53	9.08
Mean	174	114.3	147	24.77	23.36	26.99	13.45	26.82	15.41
LSD (5%)	81.8	63.6	52.6	3.1	1.44	2.6	3.97	7.91	6.14
CV (%)	26.6	31.3	20.1	7.0	3.5	5.5	16.6	16.6	22.4

The average storage root weight (g/root) of the varieties varied from 94 to 298 g/root at Rarhe; from 50.7 to 184.3 at Kukufto; and 91.3 to 209.3 g/root at Illala (Table 3). As indicated in the ANOVA for each location, statistical significance difference was observed among tested varieties for average storage root weight. For that reason, the variety LO had the largest average storage root weight at Rarhe and Kukufto with its values of 298 and 184 gram per root in that order. In these locations, the second and third more weighted varieties with respect to this character were Kulfo (217 and 138.7 g/root) and Tulla (207 and 107.7 gram per root). On the other hand, the three most varieties that had better storage root weight at Illala were Tulla (209.3), Kulfo (193) and LO (190 g/root). Of all the testing locations, Illala had more varieties that showed medium sized storage root weight and fulfills the requirement of marketable roots (100 to 500 gm per root). The smallest average storage root weight was recorded from Bellela (50.7 g/root) and Vitae (78.7 g per root) at Kukufto, According to Feliciano (2004), the average storage root weight of most varieties in all the testing locations fall in the marketable roots classification (individual roots with 100 to 500 gm weight). Nevertheless, for some varieties, this marketable root weight classification was partly due to the more length of the storage roots that caused to the size of this recommended marketable root weight (personal observation at harvesting, 2012). As observed at harvesting time, the acceptable (normal) marketable storage roots had shorter but thicker storage root sizes. Thus, LO, Kulfo and Tulla varieties mostly have showed in such manner

Like the total root yield and average root weight, significant differences were detected between the root dry matter content of the different varieties in all the testing locations. At Rarhe, the highest dry matter content was noticed in the variety of Vitae (31.4%), followed by Kabode (28.9%) and Bellela (25.5%). At Kukufto, the varieties Vitae, Kabode and Temesgen scored higher root dry matter contents in the order of 30.5%, 29 % and 27 %. Similar to that of Kukufto, these varieties indicated higher root dry matter content at Illala location. Nevertheless variety Vitae (30.5%) ranked 3rd next to Temesgen (31.7%) and Kabode (30.9%) at this location.

Lower root dry matter content was found in the varieties of Tulla, Kulfo and LO in all the three testing locations that ranges from 20.6% to 21.9% at Rarhe, 17.6% to 18.6% at Kukufto and 21.9% to 22.9%.at Illala. According to this figure, the varieties that scored more total storage root yield had shown lower root dry matter contents. Moreover, location Illala with its altitude of 1970 meters a s l has shown highest root dry matter contents. On the other hand, lower root dry matter content was obtained in the lower elevated locations with their altitude range ranged 1459 to 1535 meters above sea level.. In general, varieties vitae and Kabode showed highest root dry matter content but Tulla and Kulfo scored least in all the locations. The variation in root dry matter content of varieties over locations could be explained by differences in temperature, rainfall, soil type and other environmental factors (Feliciano, 2004). Root dry matter content of sweet potato genotypes reported by Teow *et al*. (2007) varied between 26.8 and 33.5%. According to Marlize (2010), sweet potato varieties with root dry matter content of 20 % to 26% are acceptable to the taste of both adults and children. From this, most tested varieties achieved the acceptable root dry matter content at all locations.

3. 2. 3 Root Sizes of Sweet Potato Varieties

The combined ANOVA of 7 sweet potato varieties in three locations showed highly significant (*P<0.001*) effects for root sizes. Several undesirable varietal traits for sweet potato production such as, long tails, small sized (< 100 gram), and deformed storage roots were the most observed unmarketable yield classes in the present study (Feliciano, 2004). The other undesirable but less frequently observed and non marketable roots was over sized (> 500g). Mostly, Bellela, Temesgen, Kabode and Vitae varieties had unmarketable root class that result from small sized roots (<100gm) but the traits of unmarketable root class for Kulfo, Tulla and LO was mostly over sized (>500g). Even though the over sized roots are grouped in to unmarketable root class, its value (acceptance by users) is much better than the small sized of unmarketable storage root class.

The average root size was calculated for the different varieties. The tested varieties had average root length ranged from 10.45 (Kulfo) to 17.03 cm (Vitae). Relatively, the first four shortest storage root length was obtained from Kulfo, LO, Tulla and Bellela in the order of 10.45, 10.49, 10.65 and 10.71 cm. However, the longest variety in root length was Vitae followed by Kabode (16.73 cm) and Temesgen (16.36 cm). There was no statistical significance difference among these two groups of varieties for root length (Table 4).

Table 4. . Effect of sweet potato varieties on yield and yield components across all locations

Varieties	VL	AGFBW	SRL	SRG	SRN	SRW	MKSRN	UMSRN	TSRN	MKSRY	UMKSRY	TSRY	DMC
Bellela	120.1**a**	47.6**b**	10.7**a**	3.7**bc**	2.**b**	98.2**a**	17.8**ab**	50.2**b**	68.0b	4.92**a**	2.89**a**	7.8**a**	25.5**b**
Kabode	104.1**a**	53.2**b**	16.7**b**	3.8**c**	1.4**a**	122**a**	19.2**ab**	34.7**a**	53.9a	5.89**a**	4.53**ab**	10.4**abc**	29.6**d**
Kulfo	103.1**a**	52.5**b**	10.4**a**	5.1**d**	3.9**d**	183**b**	46.8**c**	61.0**bc**	107.8d	15.08**b**	12.17**d**	27.2**d**	20.4**a**
LO	116.6**a**	51.5**b**	10.5**a**	6.0**e**	3.5**d**	224**c**	42.8**c**	60.6**bc**	103.cd	16.97**b**	13.92**d**	30.9**e**	20.7**a**
Temesge	107.1**a**	31.2a	16.0**b**	2.8**a**	2.2**bc**	106**a**	14.7**a**	55.4**b**	70.1b	4.57**a**	5.81**bc**	10.4**ab**	27.7c
Tulla	102.8**a**	47.6**b**	10.6**a**	5.1**d**	4.5**e**	175**b**	55.6**d**	69.0**c**	124.6e	15.56**b**	13.79**d**	29.3**de**	20.6**a**
Vitae	106.4**a**	51.1**b**	17.0**b**	3.2**ab**	2.7**c**	102**a**	22.6**b**	70.9**c**	93.5**c**	6.59**a**	7.32**c**	13.9**b**	30.8**d**
Mean	108.5	47.81	13.20	4.24	2.89	144.2	31.34	57.40	88.74	9.93	8.63	18.56	25.05
LSD5%)	20.04	13.67	1.34	0.63	0.53	62.3	5.75	10.49	12.8	2.19	2.00	3.41	2.72
CV (%)	19.4	30.0	10.7	15.6	19.4	26.1	19.3	19.2	15.1	23.1	24.3	19.3	6.6
Location													
Rarhe	144.7**c**	71.88**c**	14.7**b**	4.32**b**	2.12**a**	173	21.43**a**	37.57**a**	59.0**a**	7.62**a**	5.83**a**	13.45**a**	24.79**b**
Kukufto	113.5**b**	55.17**b**	12.7**a**	3.78**a**	4.18**b**	114	42.9**c**	101.2**b**	144.1**b**	12.09**c**	14.73**b**	26.82**b**	33.76**b**
Illala	67.6**a**	16.44**a**	12.2**a**	4.63**b**	2.36**a**	147	29.67**b**	33.43**a**	63.10**a**	10.09**b**	5.34**a**	15.42**a**	31.05**a**

The values in the column having the same letter(s) are not significantly different at P = 0, 05 using LSD test.

* VL: Vine Length (cm); AGFBW: Above Ground Fresh Biomass Weight (t/ha); SRL: Storage Root Length (cm); SRG: Storage Root Girth (cm); SRN: Storage Root Number per plant, SRW: Storage Root Weight (g/root); MKSRN: Marketable Storage Root Number Per Plot; MKSRY: Marketable Storage Root Yield (t/ha); UMKSRN: Unmarketable Storage Root Number Per Plot; UMKSRY: Unmarketable Storage Root Yield (t/ha); TSRN: Total Storage Root Number Per Plot; TSRY: Total Storage Root Yield (t/ha); DMC: Root Dry-Matter Content (%)

Production of large numbers of small roots was an undesirable varietal trait, as the demand was mostly for medium to medium large roots. On the other hand, the mean storage root weight of varieties ranged from 98.2 to 224.1 g/root and varied significantly among the varieties and locations. In this case, LO (224.1 g/root) produced the highest average root weight of all varieties followed by Kulfo (182.9 g). On the contrary, smaller roots were produced by the varieties Bellela (98.2 g) and Vitae (101.8 g/root). The range of marketable storage root numbers of the tested varieties was 14.67 to 55.58 with an average value of 31.34 roots per plot (Table 4). Large numbers of marketable root numbers/plot were harvested from Tulla and Kulfo. But, the lowest marketable storage root numbers were harvested from Temesgen and Bellela. Except Kulfo, LO and Tulla, the remaining varieties gave below average marketable storage root number per plot (31.34). Unmarketable storage root number of varieties was larger than the marketable storage root numbers which ranges from 34.66 to 70.9 roots/ plot. The largest was harvested from vitae (70.9) followed by Tulla (69). The smallest unmarketable storage roots were harvested from Kabode (34.67), Bellela (50.2) and Temesgen (55.44). The contribution of unmarketable roots number per plot for Tulla, LO and Kulfo was mostly due to over sized but under sized for the other varieties. The total storage root numbers/plot, which corresponded (summation of marketable and unmarketable root numbers) also varied significantly among varieties, which ranged from 53.9 to 124.57 roots. Roots of 124.57 per plot were harvested from Tulla which also gave the largest number of marketable and second largest unmarketable storage roots per the harvestable plot area. Not only Tulla, but also LO, Kulfo and Vitae gave above average total storage roots/plot (103.33, 107.8 and 93.47 in that order). However, Kabode (53.9), Bellela (68) and Temesgen (70.1) varieties scored below average.

3. 3 Principal Component Analysis of Sweet Potato Characters

Principal Component Analysis (PCA) uses in identifying hidden patterns in the data and was performed to obtain more reliable information on how to identify groups of genotypes that have desirable yield traits for breeding. Eight components were extracted from the 14 studied traits by PCA analysis. But based on Diana (1999 as cited from Kaiser, 1960), factors to be retained should have more than 1 eigenvalues, at least 5% variance explained for each component, and/or more than 70% cumulative proportion of variance explained. Accordingly, the first three components that explained 92.3 % of total variation were used for displaying characters. In the first principal component, SRW, MKSRY, TSRY, MKSRN and UMKSRY were the most important traits contributing more to the variation and this component was more associated with the high values of the above traits positively. The sign indicates the direction of the relationship between the components and the characters (Yemane and Fasil, 2002). Due to more variation explained by the PC 1 (Table 9), its scores could effectively represent the variety effect (Ali *et al*., 2011). In the second principal component, the observed variation (12.9%) was caused mainly by UMKSRN, SRL, VL SRG and AGFBW of which, the latter three traits had negative relationship with this PC. On the other hand, AGFBW, VL and UMKSRN constituted large part of the total variation (8.7 %) explained by the third principal component (Table 5).

Table 5. Eigenvalues, total variance and cumulative variance for 13 quantitative characters in sweet potato varieties

Characters	PC 1	PC 2	PC 3
VL	-0.1296	-0.7581	-0.5262
AGFBW	0.3639	-0.3608	0.6978
SRL	-0.7584	0.5083	0.2744
SRG	0.8891	-0.3937	0.1636
SRN	0.9508	0.2541	-0.1333
SRW	0.9856	-0.04724	0.06602
MKSRN	0.9772	0.07288	0.1125
UMKSRN	0.5916	0.5344	-0.3955
TSRN	0.9231	0.3068	-0.1183
MKSRY	0.9825	-0.06697	0.1009
UMKSRY	0.959	0.1736	0.03949
TSRY	0.9803	0.04134	0.0735
DMC	-0.9001	-0.7581	-0.5262
Eigenvalues	9.20334	1.67646	1.12547
% of total variance	70.795	12.896	8.657
% Cumulative variance	70.795	83.691	92.348

The first two component scores were plotted to aid visualization of the overall variability among the populations. Hence, Figure 4 showed that there was a positive relationship between total storage root yield (TSRY) and UMKSRY, UMKSRN, TSRN, SRN, MKSRN, MKSRY, SRW SRG and AGFBW whereas SRL and DMC were negatively correlated to the total root yield. Other researchers (Ali *et al*., 2011; Khodadadi et al., 2011; Mooi and Sarstedt *et al.*, 2011) used PCA to explain variation among genotype characters and reported the relationship that existed between yield and yield components of different crops. When analyzed varieties in Figure 1, Tulla, Kulfo and LO varieties had low values with respect to SRL and DMC but high value relatively with other yiled components. This contributed to the variations in the first and second principal components. On the other hand, Temesgen and Vitae (group 3) and Kabode (group 2) had more SRL and DMC. In general, this PCA allowed comparative evaluation of varieties for yield components and total storage root yield and helped to identify varieties that were desirable relative to several traits.

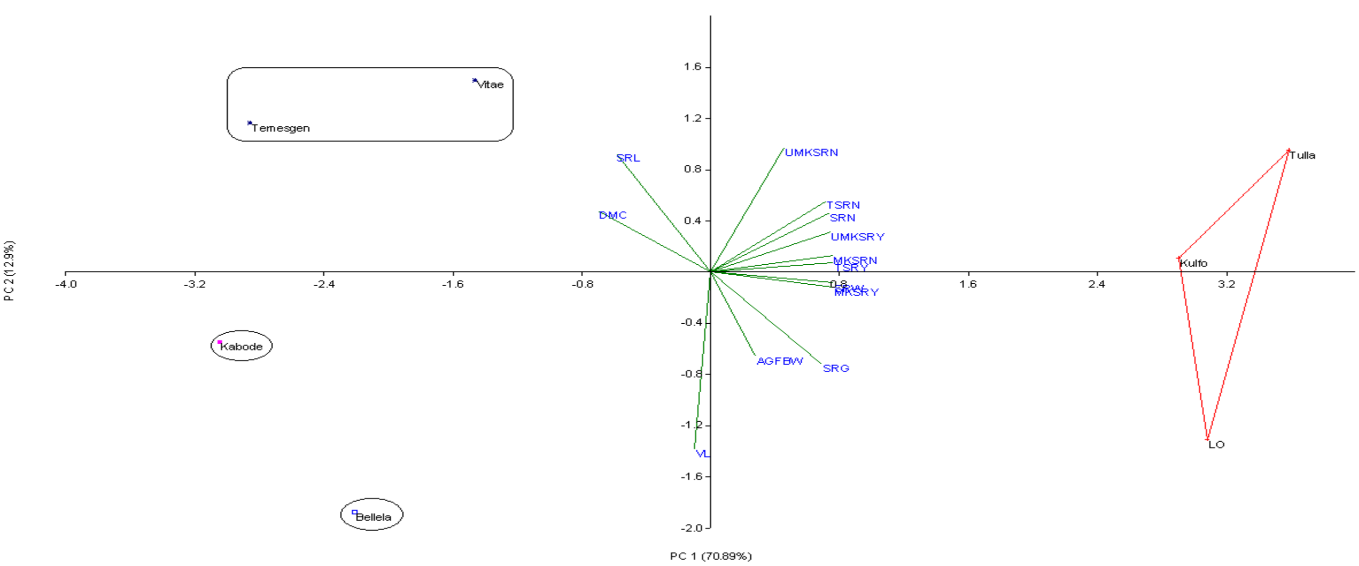

Figure 1. PCA scatter diagram of sweet potato varieties and their yield components

3. 4 Association and Correlation between Sweet Potato Yield Components

In the present investigation, many of the characters were positively and negatively correlated with each other. However, in most cases, the correlations between pairs of characters were non-significant at phenotypic level (Table 6). Among associations exhibited between pairs of characters at phenotypic level, vine length was found to be negative but very non significantly correlated with above ground fresh biomass weight (r = -0.012) but positive with stand count at harvest (table not shown). This indicates that an increase in vine length does not necessarily lead to an increase in biomass weight. But the vine length associated negatively but non-significantly with storage root length, average root weight, unmarketable root number and root yield. Similarly, it correlated negatively and non significantly with the average root number per plant, marketable root number and root yield as well as with root dry matter content. Above ground fresh weight showed highly significant positive relationship only with the stand count at harvest and negatively non significance only with the root length, unmarketable root number and root dry matter. It correlated positively but non-significantly with the remaining characters.

Likewise, the total storage root number correlated in a highly significant and positively approach with unmarketable and marketable storage root numbers and root yields but negatively with the root dry matter. Similar results were obtained by Yohannes (2007) though non- significance for the marketable and unmarketable yield components. Even if the total storage root number was negatively correlated with root length, it was significant. The negative relationship of total root number with root length and dry-matter content of the root is supported by other findings (Islam *et al.*, 2002; Kamalam *et al.*, 1977).

Table 6. Phenotypic Correlation coefficient among sweet potato traits

	VL	AGFBW	SRL	SRG	SRN	SRW	MKSRN	UMKSRN	TSRN	MKSRY	UMKSRY	TSRY
VL	1											
AGFBW	**-0.012**	**1**										
SRL	**-0.359**	**-0.250**	**1**									
SRG	**0.157**	**0.421**	**-0.838****	**1**								
SRN	**-0.260**	**0.188**	**-0.66****	**0.811****	**1**							
SRW	**-0.016**	**0.377**	**-0.661****	**0.943****	**0.741****	**1**						
MKSRN	**-0.278**	**0.388**	**-0.704****	**0.88****	**0.945****	**0.847****	**1**					
UMSRN	**-0.134**	**-0.030**	**-0.270**	**0.426**	**0.765****	**0.299**	**0.541****	**1**				
TSRN	**-0.249**	**0.237**	**-0.588****	**0.776****	**0.986****	**0.693****	**0.913****	**0.837****	**1**			
MKSRY	**-0.123**	**0.412**	**-0.711****	**0.959****	**0.886****	**0.961****	**0.955****	**0.481**	**0 .853****	**1**		
UMKSRY	**-0.249**	**0.269**	**-0.567****	**0.878****	**0.925****	**0.907****	**0.935****	**0.623****	**0.909****	**0.965****	**1**	
TSRY	**-0.180**	**0.35**	**-0.651****	**0.930****	**0.911****	**0.945****	**0.953****	**0.550****	**0.885****	**0.993****	**0.989****	**1**
DMC	**-0.082**	**-0.182**	**0.922****	**-0.919****	**-0.815****	**-0.847****	**-0.863****	**-0.350**	**-0.73****	**-0.882****	**-0.796****	**-0.851****

** significance at 1% probability levels; ¥ Figures in parenthesis indicate the degree of freedom

*VL = vine length (cm), AGFBW = Aboveground fresh biomass weight tha^{-1}, SRL= storage root length (cm), SRG = storage root girth (diameter) (cm), SRN= storage root number per plant, SRW = storage root weight (g/root), MKSRN = Marketable storage root number per plot, UMKSRN = Unmarketable storage root number/plot, TSRN = Total storage root number per lot, MKSRY = Marketable storage root yield (tha^{-1}), UMKSRY = Unmarketable storage root yield (tha^{-1}), TSRY = Total storage root yield (tha^{-1}), DMC = storage root dry mater content (%), Root length and root diameter had shown highly significance negative correlation (r = -0.838). Though, this finding contradicted with the result of Afuape *et al.* (2011), it concurred with the result done by Engida (2004) at Awassa. However, highly Significant positive correlations was attained within root girth and average storage root weight (r = 0.943). This suggested that improvement aimed at any of the character would automatically lead to improvement in the other. The work of Lowe and Wilson (1975b) also linked an increase in storage root diameter within an increase in individual storage root weight. Plants that have smaller root size could have light weight as supported by the result obtained from different authors (Chandra and Tiwari, 1987; Islam *et al.*, 2002). They identified highly significant positive association between these traits. On the other hand, most of the association of average storage root weight and other characters was positive and highly significant, such as with root yields and marketable root number but negative and relatively higher relation observed with root length and root dry matter content. Smaller and positive magnitude of relationship was found between average root weight with unmarketable root number, stand count at harvest, root length and green top fresh biomass weight.

As indicated in Table 6, the marketable storage root yield correlated negatively with the root length and the root dry matter in significant manner. This implies, more and more length in the root resulted in more thinly and fibrous roots that may not end with desired marketable storage roots, i. e, round healthy, neither over sized nor under sized, weighing 100g - 500g as suggested by Bhagsari and Ashley (1990). On the other hand, more marketable root yield leads to lower dry matter content as fresh root yield holds more water content and relatively lower dry matter (Thakur and Saini, 1995). As explained earlier, marketable root yield positively correlated with all the characters except the vine length, root length and root dry matter. However, it had shown very highly relationship with marketable root number (r = 0.955), and average root weight (r = 0.961)and very small with the above ground fresh biomass weight (r = 0.412).

In similar manner with the marketable root yield, the unmarketable storage root yield also showed positive correlation with all the traits but negatively with the root length, vine length and root dry matter. It had highly significant positive association with marketable and unmarketable root numbers (total root numbers), average storage root weights but non- significant positive with the fresh shoot weight and stand count at harvest. As described by Chipungo *et al*. (2000), the positive association of unmarketable storage root yield with the traits suggested that selection of one of the traits would lead to the improvement of unmarketable storage root yield in a similar direction. On the contrary, unmarketable storage root yield was significantly but negatively correlated with root length and dry-matter content of the root. These would lead to the selection of one trait in undesirable direction if we perform selection for higher values of the other traits.

Except storage root length, none of the traits was positively correlated with root dry matter content (Table 6). Similarly, none of the traits was negatively associated with stand count at harvest except unmarketable storage root number and root dry matter. The root dry matter content correlated negatively and non-significantly only with three traits (plant height, above ground fresh biomass weight and unmarketable root number). But it associated highly and significantly with the other characters negatively except root length (positive). Most of the characters examined by Bhagsari and Ashley (1990) were in agreement with this correlation result of root dry matter content correlation. On the contrary, the character of stand count at harvest had non-significant relationship with all the traits except vine length and biomass weight. Additionally, unlike with the unmarketable storage root number and root dry matter (negative), the stand count at harvest was correlated with all the other characters positively. From this statistics, one can understand that, as the number of plant population increased in the harvestable plot, above ground fresh biomass weight also increased.

Conclusion and Recommendation

Root and tuber crop in general and sweet potatoes in particular are the crops that need to be cultivated for food security for countries like Ethiopia in general and Tigray region in particular where population is growing at alarming rate. Therefore, it is paramount important to increase production and productivity of the crop by adopting different agronomic practices out of which working for variety development is the major.

Individual analysis of variance showed significance variation among varieties except vine length at all locations and above ground fresh biomass weight at Rarhe and Kukufto locations. The results of ANOVA for the year data gave an overall view of the relative magnitude of the location, genotype, and genotype x location interaction (GLI) variance terms. Due to the significance and positive correlation among the total root yield and other traits (with an exception of root length and root dry matter), the total root yield was used to evaluate the variety performance. Thus, with respect to mean total root yield obtained, variety LO scored the highest yield, followed by Tulla and Kulfo. On the other hand, bellela gave the lowest total root yield. In view of locations, Kukufto showed highest yield potential and Rarhe the lowest. In addition, Rarhe produced more fresh shoot biomass weight and it uses to reduce the shortage of animal feed. From the present study, it can be concluded that genotype x location interaction study is very important in multi-location sweet potato yield trials. Accordingly, different analysis methods were employed to determine variety adaptability.

Based on the combined mean total root yield of locations and different yield evaluation methods, high yielding varieties were identified. Accordingly, LO and Tulla varieties gave highest root yield per unit area at all locations, followed by Kulfo. Therefore, these varieties can play a vital role in food self sufficiency and food security of Tigray. Moreover, LO, Tulla and Kulfo are early maturing, drought and disease tolerant varieties and thus, they can be appropriate varieties for the dry land areas of the region. Not only higher productivity and drought tolerance, but also they are orange fleshed varieties which contribute in the reduction of vitamin A and C deficiency. Therefore, these varieties should be widely distributed to farmers of the testing locations and similar areas of the region.

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