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Research Article

Genotype by Environmental Interaction and Measurements of Stability on Eight Orange-Fleshed Sweet Potato (*Ipomoea batatas*) Varieties: East Gojjam Zone, North West Ethiopia

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Sweet potato is grown for its nature of versatility and adaptability and is a secure food crop in southern parts of Ethiopia. Therefore, this research has been conducted to determine the magnitude of GEI for yield and yield-related traits and to evaluate the adaptability and stability of eight orange-fleshed sweet potato varieties across locations in North West Ethiopia. The experiment was conducted from 2018 to 2019 under rainfed conditions in four districts of East Gojjam Zone (Baso liben, Gozamin, Gonchasiso enesie, and Enbsie Sar mider) using eight OFSP varieties (Kulfo, Kabode, Vitea, Naspot 13, Naspot 12, Nekawango, RW-11, and Mayai). Data were collected on yield and yield-related traits. Genstat statistical software was used to deploy both combined analysis of variance and meta-analysis of the collected data. The combined ANOVA revealed that environment, varieties, and their interaction affect the tested varieties significantly across locations. Debremedhanite was the high-yielding environment (35.9 t/ha), and Kulfo was the best-performing variety (30.67 t/ha) over different environments. Based on the AMMI result, the environment contributes at large (48.49%) to the total variation of variety performance followed by variety (27.18%) and their interaction (24.23%). The testing locations fall in two mega environments that implies that variety recommendation needs to be specific for each mega environment. Hence, Kulfo and Naspot 12 are recommended for Debremedhanit, Arasma, and Degesech based on yield potential and stability of the varieties, and Naspot 13 is recommended for Yelamgej, Eneba, and Getesemani testing locations. This result is useful for breeders and nutritionists who are working on breeding of sweet potatoes and nutrition.

1. Introduction

Sweet potato (*Ipomoea batatas L*) is a herbaceous dicot plant that belongs to the family Convolvulaceae [1]. It is distributed throughout the tropics and warm temperate regions since it originated in Central Tropical America. Sweet potato is considered as poor people's crop, and it is cultivated in 100 countries and used as a secure food crop. It can be grown from the sea level to 2500 m.a.s.l. with the requirement of low input and less labor than other cereal crops. Globally, sweet potato is the sixth most important crop next to wheat, rice, maize, potato, and cassava, the fifth most important crop in sub-Saharan Africa, and the third most important root and tuber crop following yam and cassava [2]. In Ethiopia, sweet potato covers 52406.4 hectares of agricultural land with a total yield of 17, 55855 tons [3, 4]; however, production and productivity of the crop in the Amhara region are not indicated in FAOSTAT and CSA reports. Ethiopia has a suitable agroecology for sweet potato production, and the estimated potential yield is 45 tons/ha [5]. Reports revealed that under research conditions, the crop yield is between 31 and 70 tons/ha, up to three-folds of small-scale farmers' yield which is up to 9–14 tons/ha [6, 7].

Sweet potato can be grown under a wider range of climatic conditions, but yield stability is highly influenced by genotype and environment interaction effect. Reports indicated that sweet potato varieties are significantly affected by the interaction effect both in yield and quality traits [8–13]. The storage root yield of most orange-fleshed sweet potato genotypes tested in southern Ethiopia is sensitive to GEI effect [12, 14]. Therefore, considering wider and specific adaptability of the varieties is important to test yield and yield-related traits of orange-fleshed varieties. Improving the root yield of sweet potatoes is important for commercial producers and small-scale farmers in poor communities in consideration of all yield components of the crop. A breeding objective with a defined selection of best-performing genotypes over different environments based on the yield components which affect root yield would make a positive breeding progress [15].

Drought and nutrition insecurity is a common phenomenon in northern Ethiopia, particularly in the Amhara region. Despite the region being one of the major cereal-producing regions, it is reported that 46% of the population is malnourished. Root and tuber crops are an important package of food security [16]. Though the Amhara region is one of the productive regions in the country with a diverse agroecology that is favorable for horticultural and cereal production, sweet potato is less known in production and consumption. This is due to the limitation of improved high-yielding varieties, well-adapted (wide and specific) varieties, disease- and pest-resistant genotypes, and lack of awareness about its nutritional values. Thus, testing orange-fleshed sweet potato varieties under different agroecology conditions of the East Gojjam Zone is vital to evaluate their performance and stability for better food and nutrition security of the people. Therefore, the objective of this study was to determine the magnitude of GEI for storage root yield and yield-related traits of OFSP varieties and also to evaluate the adaptability and stability of 8 OFSP varieties across nine locations.

2. Materials and Methods

2.1. Description of the Study Areas. The experiment was conducted in the four districts of East Gojjam Zone. The experiment was carried out in two consecutive years (2018 and 2019) across a total of nine locations. The relevant climatic information of the testing locations and the map of the four districts are presented in Table 1 and Figure 1, respectively.

2.2. Experimental Design and Treatments. Eight orange-fleshed sweet potato varieties were collected from Hawassa Agricultural Research Center (AwARC) and International Potato Center (CIP). The experiment was arranged in a randomized complete block design with replication of three times. The gross plot size of the experimental plot was 4.2 m^2. A cutting of 30 cm in length was used and planted in a 45-degree slant. Inter-row and Intrarow spacing between plants were 0.3 and 0.7 m, respectively. The descriptions of eight tested varieties are presented in Table 2.

2.2.1. Data Collection. All the data were collected from the middle two rows by picking five plants randomly to minimize the border effect. A total of 10 traits were recorded according to [20] to evaluate the growth and yield performance of sweet potatoes across locations. Days to physiological maturity, vine length (cm), above-ground fresh biomass yield (g/plant), total storage root yield (t/ha), marketable and unmarketable storage root number/plant, marketable and unmarketable storage root yield (t/ha), and dry matter content (%) were recorded. Dry matter content data were calculated from five marketable roots taken randomly, chopped, and mixed up, and finally, a sample of 200 g was weighed and oven-dried. 200 g of chopped root was oven-dried for 72 hours at 105°C and weighed again to calculate the dry matter content of the sample. The dry matter content is expressed as follows:

$$\text{dry matter content} = 100 * \left(\frac{W2}{W1}\right), \quad (1)$$

where $W2$ = the weight of dried pulp of the storage root and $W1$ = the weight of fresh pulp of the storage root.

2.2.2. Data Analysis. All the collected data were subjected to multivariate analysis using Gen-Stat [21] software to determine the performance and stability of varieties across locations and over time. Combined ANOVA, additive main effect and multiplicative interaction model (AMMI), meta-analysis (linear mixed model), and GGE Biplot were applied to partition the effects.

3. Results and Discussion

3.1. Response of OFSP Yield and Yield-Related Traits to Environment, Varieties, and GEI. Conventional combined analysis of variance and mean comparison using Tukey's method were conducted to obtain the main effect and interaction effect of environment, varieties, and season. As indicated in Table 3, all the recorded traits of OFSP were significantly affected by environment, varieties, and their interaction ($P < 0.05$). This finding is in agreement with those in [22] and by Mbwaga et al., [15, 23]. According to [24], response of OFSP varieties to growth and yield-related traits among varieties is significantly different in Ethiopia. Similarly, the study conducted in Zimbabwe indicated that total tuber yield, marketable tuber yield, unmarketable tuber yield, marketable tuber number, unmarketable tuber number, and total tuber numbers are significantly affected by environment, varieties, and genotypes by environment interaction effect [25].

3.2. Interaction Best Linear Unbiased Prediction (BLUP) Mean of TTRY over Two Growing Seasons. The best linear unbiased prediction (BLUP) mean was predicted using the linear mixed model to know the genetic value of varieties. BLUP

Table 1: Climatic conditions and soil texture of testing locations.

District	Location	Climatic data			
		Altitude (m.a.s.l.)	Min. and max. temperatures (0 C)	Average rainfall (mm)	Soil texture
Gonchasiso enesie	Arasma	2538	18 and 35	1000	Nit soil
	Getesemani	2587	12 and	900	Verti soil
	Eneba	2524	15 and	750	Cambi soil
Enbsie Sar mider	Debremedhanit	2411	16 and 30	800	Cambi soil
Baso liben	Degesech	2188	16 and 30	1000	Verti soil
	Yelamgej	2389	18 and 30	750	Nit soil
Gozamin	Aba Libanos	2211 m	15 and 27	950	Verti soil

Source: East Gojjam Zone metrological station.

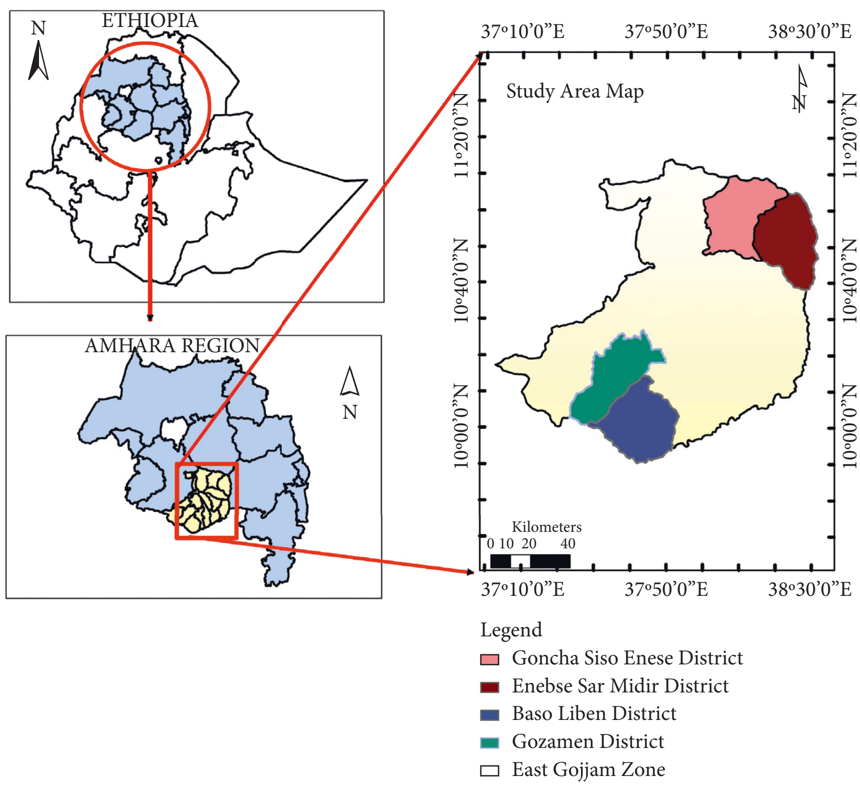

Figure 1: Map of the four testing districts.

Table 2: Description of the tested sweet potato varieties in the study areas.

No.	Variety	Year of release	Yield (t/ha)	Origin	Maturity day	Beta-carotene content (mg/g)	DMC (%)	Altitude (m.a.s.l.)
1	Kulfo	2005	27	Ethiopia	150	8.3	22.9	1600–2800
2	Vitea	2007	16.5	Uganda	120	11.3	30.1	1000–2600
3	Kabode	2007	16	Uganda	120	11.3	30.5	1000–2600
4	Naspot 12	2013	24	Uganda	120	7.23	30	1000–1600
5	Naspot13	2013	38	Uganda	120	11.3	28	1000–1600
6	Nekawango	1995	23	Uganda	140	NA	NA	1000–1600
7	Mayai	2005	10	Tanzania	120	11.3	32.5	800–2000
8	RW11-2910	2013	20	Rwanda	150	4.1	31.13	1200–1800

Note: NA denotes that data are not available. Source: [17–19].

value indicated the total tuber yield of eight tested varieties showing great variation over environments and seasons. As shown in Table 4, the highest total fresh root yield was obtained from Debremedhanite in 2018 and the poor yielding environment was Getesemani in 2018. The best-performing varieties were Kulfo, and the least performance was shown by Nekawango. The BLUP value indicated that the genetic performance of the tested varieties is affected by

Table 3: Combined ANOVA of 10 traits of OFSP varieties across nine environments and over two growing seasons.

Traits	Source of variation			
	Var	Environ.	G*E	Residue
VL (cm)	2760.644***	2380.254***	387.983***	3.139
FAGBM (kg/Pl)	25.0195***	178.7675***	9.0964***	0.1136
TRN	1361.223***	2442.351***	311.382***	2.365
TFRY (T/ha)	1000.8279***	1562.3559***	111.5257***	0.1878
MRY (T/ha)	869.5258***	1371.4807***	99.9432***	0.1885
MRN	605.197***	1306.997***	145.840***	2.677
UMRY (T/ha)	20.4948***	18.0270***	13.6786***	0.1123
UMRN	217.063***	259.188***	90.232***	1.702
DtM	1200.674***	10421.234***	40.511***	1.016
DMC (%)	185.602***	159.623***	32.632***	1.683
D.f	7	8	56	142

VL: vine length, FABGBM: fresh above-ground biomass, TRN: total root number, TFRY: total fresh root yield, MTY: marketable root yield, MRN: marketable root number, UMRY: unmarketable root yield, UMRN: unmarketable root number, DtM: days to maturity, DMC: dry matter content, and D.f: degree of freedom; ***very highly significant.

Table 4: Interaction BlUP mean of TTRY over two growing seasons.

Trait	Environ.	Varieties								Env. mean
		Ku	Na12	Na13	Vi	Ka	Rw11	Ma	Ne	
TFRY (T/ha)	Ar18	24.49	19.29	22.52	13.99	14.29	15.54	18.34	5.26	16.71
	Dm18	50.95	44.4	30.39	26.13	41.06	41.64	31.12	21.69	35.92
	En18	13.56	13.58	17.13	12.51	18.45	14.44	21.59	9.56	15.10
	Ge18	15.3	16.54	23.35	14.64	13.59	12.5	4.39	2.38	12.83
	Ar19	24.27	20.58	15.66	8.89	20.3	9.18	20.64	17.16	17.08
	Dm19	50.95	37.81	33.62	15.54	17.75	34.5	19.51	20.72	28.8
	De19	24.49	19.29	22.52	13.99	14.29	15.77	18.34	5.26	16.74
	Li19	26.9	10.29	16.31	10.44	11.39	11.38	7.72	8.82	12.90
	Ye19	45.1	30.23	44.85	15.16	13.94	19.15	26.2	12.47	25.88
	Var.mean	30.67	23.55	25.15	14.58	18.34	19.34	18.65	11.48	

TFRY: total fresh root yield, Ar18: Arasma in 2018, DM18: Debremedhanit in 2018, En18: Eneba in 2018, Ge18: Getesemani in 2018, Ar19: Arasma in 2019, Dm19: Debremedhanit in 2019, De19: Degesech in 2019, Li19: Libanos in 2019, Ye19: Yelamgej in 2019, var.mean: variety mean, env.mean: environment mean, Ku: Kulfo, Na12: Naspot O 12, Na13: Naspot O 13, Vi: Vitea, Rw11: Rw-11, Ma: Mayai and Ne: Nekawango.

the season and environment. The result is in agreement with that of [26]; fresh root yield of twenty-five Kenyan orange-fleshed sweet potatoes was significantly affected by the interaction effect of genotype, environment, and season. Breeding of sweet potatoes in sub-Saharan Africa is becoming advanced, and OFSP varieties are focused. The tested six varieties in this research gave moderate and high yields, ranging from 18 to 30 T/ha. Kulfo (30.67 T/ha) gave the highest yield across the environment and season; the lowest yield was obtained from Nekawango (11.5 T/ha). From the testing environment, Debremedhanit in 2018 (36 T/ha) was the most potential and suitable environment for OFSP production. According to [10], about 15 OFSP varieties were released in Mozambique and the yield potential of the released varieties with no fertilizer ranges from 18 to 25 t/ha.

3.3. Additive Main Effect and Multiplicative Interaction Analysis (AMMI) for Eight Sweet Potato Varieties Based on Total Fresh Root Yield. AMMI is a model widely used in stability analysis to explain the contribution of environment, variety, and genotype by environment interaction impact on the recorded traits. As the AMMI result (Table 5) revealed, varieties, environments, and their interaction significantly affected the genetic value of recorded traits. Environment (48.49%) contribution to the total variation of variety performance was high followed by genotype (27.18%) and interaction (24.23%). The AMMI model partition in to three significant interaction principal component analaysis axis (IPCA). IPCA1, IPCA2, and IPCA3 explained 46.81%, 25.94%, and 13.56%, respectively, of cummulative interaction effect on the total variation of varieties across location. This indicates thier is high genotypic variability among the tested varieties.

3.4. Stability Analysis of OFSP Varieties Using GGE Biplot

3.4.1. GGE Biplot View of Eight OFSP Varieties over Nine Environments. An acute angle indicates positive correlation among environments, a right angle indicates no correlation, and an obtuse angle indicates negative correlation. In GGE biplot view presentation, environments with relative similarity and genotypes with relative performance grouped together in the same quadrant. The origin indicates virtual genotypes that have an average performance.

Table 5: ANOVA of AMMI over environments and seasons.

Source	DF	SS	TSS (%)	G*E explained (%)	Cumulative (%)	MS
Total	215	25777				119.9
Genotypes	7	7006	27.18			1000.8***
Environments	8	12499	48.49			1562.4***
Block	18	4				0.3
Interactions	56	6245	24.23			111.5***
IPCA	14	2923		46.81%	46.81	208.8***
IPCA	12	1620		25.94%	72.85	135.0***
IPCA	10	847		13.56%	86.41	84.7***
Error	126	22				0.2

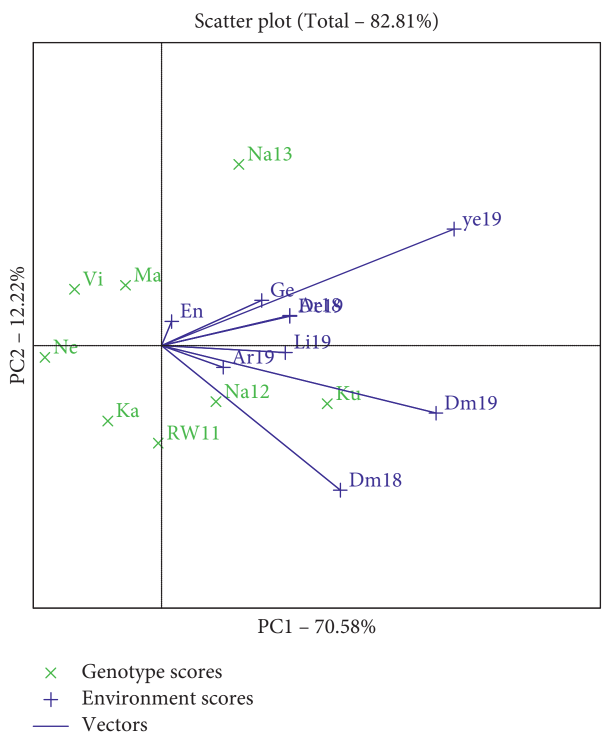

Figure 2: GGE Biplot view of eight varieties over nine environments.

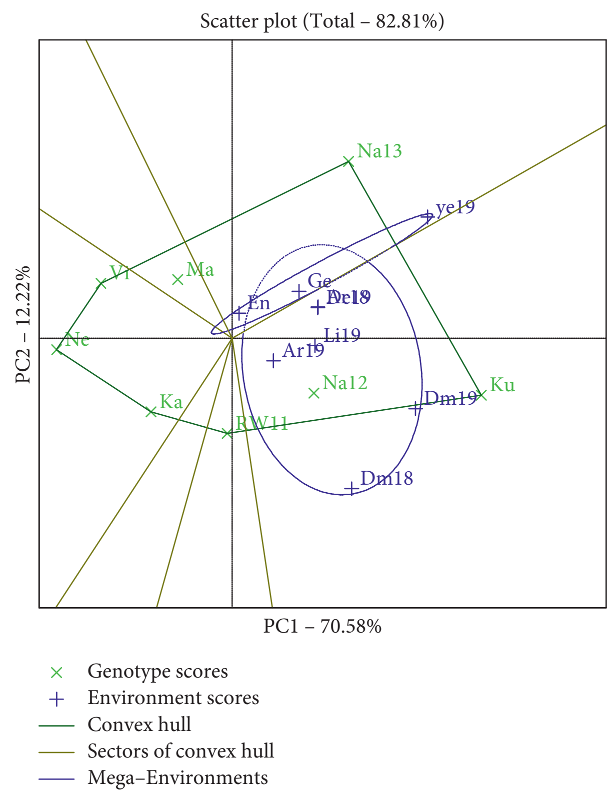

Figure 3: Which-won-where view of eight OFSP varieties over nine environments.

According to the GGE Biplot presentation (Figure 2), Eneba, Yelamgej, Getesemani, Degesech, Arasma 19, and Libanos are positively correlated. Eneba environment was negatively correlated with Debremedhanit 18. Debremedhanit 18, Debremedhanit 19, and Arasma 19 were positively correlated.

3.4.2. Which-Won-Where View of Eight OFSP Varieties. The GGE Biplot helps to identify which genotype performs best in which environment and falls in which mega environment as well. The convex hull is drawn by connecting the furthest genotypes to form a polygon that encompasses all the genotypes. Sectors are added by drawing lines from the origin perpendicular to each side of the convex hull. Ellipses are drawn around the environment within the same sector to form mega environments. As the Biplot indicates (Figure 3), here are two mega environments; in the first mega environment, Yelamgej, Eneba, and Getesemani are located, and Debremedhanit 2018 and 2019, Arasma 2018 and 2019, and Degesech are located in the second mega environment. Kulfo and Naspot 12 performed best in the second mega environment, while Naspot 13 was the best performer in the first mega environment.

4. Conclusions and Recommendations

The study presented in this report focused on categorizing mega environments, identifying wider and specific adapted varieties across locations. The performances of tested eight orange-fleshed varieties are significantly affected by variety, environment, and their interaction. Most of the varieties gave high yields at Debremedhanit in 2018 and 2019; thus, the environment and similar environs could be the best factors for high yield. Getesemani and Eneba locations are not considered as orange-fleshed sweet potato growing environments because the performance of all varieties was poor.

Kulfo and Naspot 12 has wider adaptability and stable varieties over location, while Naspot 13 has narrow adaptability for specific testing locations.

Finally, it is suggested that different varieties are needed for two mega environments; for Yelamgej, Eneba, and Getesemani, Naspot 13 genotype performs best followed by Kulfo and Naspot 12. The second mega environment contains a large number of testing environments (Debremedhanit 2018 and 2019, Arasma 2018 and 2019, Degesech, and Libanos); Kulfo, Naspot 12, and RW showed the highest performance, respectively.

This result is useful for breeders, extension workers, and policy makers who are working on improving the dissemination of sweet potatoes. Hence, orange-fleshed sweet potato is a strategic crop grown for mitigation of malnutrition.

Data Availability

The data are deposited at zendo.org and can be accessed by DOI: https://doi.org/10.5281/zenodo.5517958, titled "Best Linear Unbiased Prediction Value of Orange-Fleshed Sweet Potato Varieties Tested in East Gojjam, North West Ethiopia."

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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