

Research Article

# Evaluation of Tuber Yield Performance and Stability Analysis of Irish Potato (*Solanum tubersum* L.) Genotypes Using AMMI and GGE Biplot at Bale High Lands, South Eastern Ethiopia

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## Abstract

Multi-location experiments are commonly conducted in breeding and variety performance evaluation trials to recognize stable genotype(s) with better crop stand in various environments. In this experiment twelve potato varieties were evaluated for stability across locations (Dinsho, Gobba and Sinana) in Bale Zone from 2021 to 2023 cropping season. The experiment used genotype and environment as treatments, year for replications. For this experiment design RCBD with three replications were used. The results of the AMMI ANOVA revealed that potato tuber yield were significantly ( $p \leq 0.05$ ) affected by genotype-environment interaction. This indicates that genotypes exhibits difference in tuber yield performance across varied ecologies. The result of sum squares explained presented that genotype (72.80 %) and environment (16.16%) were the leading donors to tuber yield difference, whereas the genotype-environment interaction effect (11.04 %) donated smallest to the total tuber yield difference. The AMMI, GGE biplot, and Genotype Stability Index (GSI) analysis revealed that G9 and G2 as highly performed genotypes in tuber yield, indicating high mean performance across tested locations. Thus, G9 and G2 have been selected as the best widely adaptable genotypes for growing in all experimental locations and Similar agro-ecologies.

## Keywords

Genotypes, Stability, Interaction

## 1. Introduction

The Irish potato (*Solanum tubersom* L.) is the most prominent tuber crop and it ranks fourth globally as an important staple food crop next to maize, rice, and wheat, used up by more than a billion peoples internationally. It taken as a basis of worldwide agriculture, helping as a vibrant essential crop that not only fulfill nutritive desires but also reinforces food security globally. Potatoes are produced not only for human

nutrition but also for use in animal feed, industry, and tuber seed production [10]. In the year 2020, over twenty million hectare of potato was grown in one hundred fifty countries that bring about international production of Three hundred sixty million metric tons and a yield per hectare of 18 t. China leads potato production Globally at nearly twenty five percent in 2020, with twenty eight percent of planting area.

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Potato is also important for creating employment opportunity, and to gain income in developing countries like Ethiopia; its production is increasing quickly in Africa and Asia, while it is declining in Europe and North America [17].

In Ethiopia potato farming extends from mid altitude areas to the extreme highland above three Thousand meter above sea level, where the environment prohibit the choice for growing other crops except hardy crops such as potato and Barley. This arises from the crop essential nature to grow under varied agro-ecology conditions. Such trait of potato combining with its short maturity period enables it is a strategic food security crop. Thus, potato helps as both stable food and income generating crop. Consequently, Ethiopia continually produces more potatoes throughout the year; for example, 67,367 ha were cultivated in the 2014/2015 growing season, yielding about 921,832 metric tons of tubers, whereas 85,988 hectare were grown in the 2020/2021, bring about in 1,141,834.65 metric tons of yield of tuber. Even if increasing in the total area of potato grown in Ethiopia, the yield per hectare was 13.3t during 2020/21 cropping season [6].

At present, the need for potato tuber become snowballing in correspondence with the requisite for escalating diet diversity, desires for willing food items, and a necessity for cheap foods. In recent times, because of increasing urbanization, the using of chips and cooked potato are for consumption is common [18]. The attention breeding program of the potato in Ethiopia is to improve the livelihoods of growers by endorsing and promoting high-yielder, disease-resistant/tolerant, broadly, and specifically adaptable varieties [19]. However, the present-day yield is less than the world average  $18 \text{ t ha}^{-1}$  [11] and the yield record from other countries like North America and New Zealand surpasses much larger than this average which is  $41.2 \text{ t ha}^{-1}$  and  $50.2 \text{ t ha}^{-1}$  respectively [7]. Additionally, Farmers of Ethiopia face numerous problems in potato production, comprising lacking and inaccessibility of high yielder, disease resistant cultivars and inappropriate agronomic practices [2].

The AMMI and GGE-biplot models have been suggested to determine the interaction effects of genotype-by-environment [14]. The AMMI model integrates both the multiplicative and additive components. According to AMMI, the main effect (additive) is separated from the interaction by analysis of variance (ANOVA), and the multiplicative component is more disintegrated by the interaction principal component [24]. As a visual evaluation of the interaction between genotypes, environments, and their interactions, GGE-biplot analyses use genotype and genotype-by-environment interaction effects [15]. The aim of plant breeding is to develop adaptable crops with high yielder and disease resistance [16]. Interactions between genotypes and environments can affect genotype performance in one location, possibly impacting performance in other. This highlights the necessity to think through ecological factors when evaluating capacity of genotypes. This experiment aimed at determining the effect of genotype-by-environment interac-

tions on tuber yield, as well as identifying and selecting high-yielding potatoes adapted to the study area and similar agro-ecologies.

## 2. Materials and Methods

### 2.1. Description of the Study Area

The experiment was conducted at three locations for two consecutive cropping seasons. Sinana is located  $07^{\circ}07'10.837''$  N latitude and  $040^{\circ}13'32.933''$  E longitude; and 2400 m.a.s.l. Dinsho has a latitude and longitude of  $7^{\circ}05'N$  and  $39^{\circ}45'E$  respectively and it an elevation which varies from 2000 to 3600 meters above sea level. Gobba has latitude and longitude of  $7^{\circ}0'N$   $39^{\circ}59'E$  and an elevation of 2,743 meters above sea level. These areas have bimodal rainfall patterns. Based on this there are two separate crop growing seasons locally called *bona* and *gana*. The main season *bona* extends from September to November and *gana* from March to May. The soil type of area is Vertisols. The main crops grown extensively in the area are cereals, pulses, vegetables under rain fed and irrigation.

### 2.2. Experimental Design and Treatments

In this trial a total of ten potato genotypes were tested and standard check (Wabi) were included for comparison. In this trial design randomized complete block design with three replications were used, total gross plot size of  $3\text{m} \times 3\text{m} = 9 \text{ m}^2$  and Net plot size was  $2.4\text{m} \times 1.5\text{m}$  ( $3.6\text{m}^2$ ) were used. A spacing of  $75 \text{ cm} \times 30 \text{ cm}$  between rows and plants respectively were used in this experiment. The spacing between blocks and plots were 1m and 0.5m respectively. At planting time, fertilizer rate of  $195 \text{ kg ha}^{-1}$  NPS (19 % N, 38 %  $\text{P}_2\text{O}_5$ , and 7% S) was applied for each plot. A total of  $165 \text{ kg ha}^{-1}$  of nitrogen fertilizer in the form of urea was applied two times for each treatment; half at planting time and half at four weeks after planting.

**Table 1.** Genotypes and their source used in the study.

S.No	Genotypes/Varieties	Source of material
1	CIP-308538.11	International Potato Center (CIP)
2	CIP-313033.42	International Potato Center (CIP)
3	CIP-313022.35	International Potato Center (CIP)
4	CIP-313039.13	International Potato Center (CIP)
5	CIP-308486.22	International Potato Center (CIP)
6	CIP-313038.09	International Potato Center (CIP)
7	CIP-313026.03	International Potato Center (CIP)
8	CIP-313026.43	International Potato Center (CIP)

S.No	Genotypes/Varieties	Source of material
9	CIP-313037.21	International Potato Center (CIP)
10	CIP-313037.32	International Potato Center (CIP)
11	Wabi	Released by Sinana Agricultural Research Center
12	Local	From local farmers

## 2.3. Method of Collection of Data and Its Management

**Plant height (m):** The data was taken by selecting five plants randomly from net plot and it was measured from the ground level to the apex of the plant, using a measuring tape at 90% physiological maturity.

**Stem per hill:** It was collected by taking average of the stem from five hills per net plot when the plants reach 50% physiological maturity. Main stems those that individually arose from the soil were taken; branching stem not incorporated.

**Marketable and unmarketable tubers per hill:** In each net plot, they were classified based on their size, diseases, and blemishes, and then averaged. In order to qualify as marketable tubers, they had to weigh at least 20g and show no signs of disease or insect infestation. Those tubers afflicted with disease, infested with insects, or weighing less than 20 grams were considered unmarketable [3].

**Number of tubers per hill:** This was calculated by adding both marketable and unmarketable tubers found on that particular hill.

**Tuber yield (t ha<sup>-1</sup>):** Yield was taken from the net plot area of each genotype (kg per net plot) and changed to tone per hectare.

## 2.4. Analysis of Data

### 2.4.1. AMMI ANOVA for Tuber Yield

An AMMI biplot was used to analyze tuber yield variance using additive main effects and multiplicative interactions (AMMIs). AMMI analysis of variance was developed by H.G. Gauch to regulate genotype-environment interactions using principal component analysis. AMMI's analysis of variance model below was used to analyze tuber yield:

$$Y_{ij} = \mu + G_i + E_j + \sum_{k=1}^n \lambda_k \alpha_{ik} \gamma_{jk} + \epsilon_{ij}$$

Where  $Y_{ij}$  is the yield of the  $i$ th genotype in the  $j$ th environment over all replication;  $\mu$  is the grand mean,  $G_i$  and  $E_j$  are the genotype and environment deviation from the grand mean, respectively;  $\lambda_k$  is the singular value for IPC axis  $k$ ;  $\alpha_{ik}$  and  $\gamma_{jk}$  are the genotype and environment principal component score in axis  $k$ , respectively;  $n$  is the number of principal components retained in the model; and  $\epsilon_{ij}$  is the error term.

### 2.4.2. AMMI 1 Biplot Analysis

By constructing aspects on the same axis, the AMMI 1 biplot visualized the interrelationship between genotypes and environments. Using a biplot graph, the AMMI 1 biplot evaluated genotypes, environments, and genotype-environment interactions by plotting yield means against IPCA1 scores and analyzing the data with GenStat statistical software [13].

### 2.4.3. AMMI Stability Value (ASV)

J.L. Purchase *et al.*, 2000 introduced an Ammi Stability measure that uses weighted Interaction Principal Component Analysis (IPCA1 and IPCA2) scores along with the following formula to quantify and classify genotypes based on yield stability:

$$\text{AMMI stability value} = \sqrt{\frac{\left[ \frac{\text{IPCA1 sum of squares}}{\text{IPCA2 sum of squares}} (\text{IPCA}_1 \text{ score}) \right]^2 + (\text{IPCA}_2 \text{ score})^2}$$

### 2.4.4. Genotype Stability Index (GSI) Analysis

A genotype selection index (GSI) was formulated using the equation:  $\text{GSI} = \text{RASV} + \text{RY}$ , where RASV is based on ranking derived from AMMI stability values and RY is based on genotype mean yield across various environments [12].

### 2.4.5. GGE Biplot Analysis

Genotype plus Genotype-by-Environment Interaction (GGE) biplot analysis was conducted using singular value decomposition of the first two principal components [22]. The model used in the study was:

$$Y_{ij} - \mu = e_1 \hat{f}_{i1} c_{j1} + e_2 \hat{f}_{i2} c_{j2} + \epsilon_{ij}$$

Where  $Y_{ij}$  is the measured mean of genotype  $i$  in environment  $j$ ,  $\mu$  is the grand mean;  $\hat{a}_j$  is the main effect of environment  $j$ ,  $\mu + \hat{a}_j$  is the mean yield across all genotypes in environment  $j$ ,  $e_1$  and  $e_2$  are the singular values for the first and second principal components, respectively;  $\hat{f}_{i1}$  and  $\hat{f}_{i2}$  are eigenvectors of genotype  $i$  for the first and second principal components, respectively;  $c_{j1}$  and  $c_{j2}$  are eigenvectors of environment  $j$  for the first and second principal components, respectively; and  $\epsilon_{ij}$  is the residual associated with genotype  $i$  in environment  $j$ .

## 3. Result and Discussion

### 3.1. Tuber Yield Analysis

#### 3.1.1. AMMI Analysis of Variance for Tuber Yield

A combined analysis of variance for marketable tuber yield of the twelve potato genotypes tested across six envi-

ronments is presented in Table 2. Further partitioning of the GEI was achieved by the AMMI multiplicative component into five IPCAs (interaction principal component axes). A higher percentage of variation can be explained by the first two principal components, and they contribute to a more accurate prediction of genotype by environment interactions than the remaining principal components, which do not support accurate prediction and may contribute to noise [23]. Additionally, the first two principal component axes had shown an important input to the GEI in the AMMI model. Accordingly, the dataset acquired from the interaction of twelve potato genotypes tested across six environments was best prophesied by the first two principal components. Potato tuber yields were high significantly and significantly influenced by genotype and environments respectively as is shown in table 2. This directs that there is difference in the mean performance of diverse genotypes of potatoes across various environments, showing that some potato genotypes may be better suitable to specific environmental condition,

whereas others may express their yielding potential across a range of environments. In other words, it directs that the tuber yielding capacity of potato genotypes is not only rely on their genetic traits but also affected by the specific environmental conditions where they are grown that results certain genotypes may give better yield in particular environments while reduced in others. From the total variance, the genotype (G) main effect alone accounted for 72.8%, this shows that the maximum potato yield variation was donated by genotype, followed by the environment effect which accounted 16.16%. On the other hand, the interaction effect of genotype by environment (11.04%) brings the smallest contribution to tuber yield variation (Table 2). This result in line with previous findings by [4] who reported that potato tuber yield was meaningfully affected by genotype, environment, and their interaction. From their study tuber yield difference was principally influenced by genotype, followed by environment.

**Table 2.** AMMI ANOVA for tuber yield ( $t\ ha^{-1}$ ) of potato genotypes tested across six environments.

Source of variation	DF	SS	MS	%SS explained	Proportion %
Total	209	21435	102.56		
Treatements	71	17284	243.4		
Genotypes	11	12583	1143.90**	72.80	
Environments	5	2793	558.6*	16.16	
Block	12	397	33.1 <sup>NS</sup>		
Interactions (GXE)	55	1907	34.67*	11.04	
IPCA1	15	532	35.5**		52.85
IPCA2	13	260	20.0*		25.83
Error	132	3754	28.4		

Note: NS = Non-significant, \* = Significant at 0.05, \*\* = highly significant at 0.01, DF = degree of freedom, SS = sum squares, MS = Mean squares, and IPCA = interaction principal component analysis.

**Table 3.** Mean performance of Tuber yield Using AMMI analyses for twelve potato genotypes ranked across six environments.

Genotypes	Environments												Grand mean	Rank	IP-CA1	IPCA2
	Sinana 1	Ra nk	Sinan a 2	Ra nk	Goba 1	Ra nk	Goba 2	Ran k	Dinsh o 1	Ra nk	Dinsh o 2	Ra nk				
CIP-308538.11	34.85	8	32.49	8	28.88	9	29.49	7	34.63	10	30.00	8	31.72	8	0.03	0.56
CIP-313033.42	50.91	2	50.00	2	46.78	2	49.11	2	56.79	2	45.95	2	49.92	2	0.40	-0.90
CIP-313022.35	43.48	5	35.54	7	32.17	5	31.27	6	44.68	5	33.97	5	36.85	5	-1.33	-0.91
CIP-313039.13	33.10	9	28.42	12	29.63	8	28.25	10	30.83	11	28.39	9	29.77	10	0.76	1.01
CIP-308486.22	38.59	6	36.85	5	26.39	12	24.86	12	38.20	6	33.64	6	33.09	6	-2.26	0.80

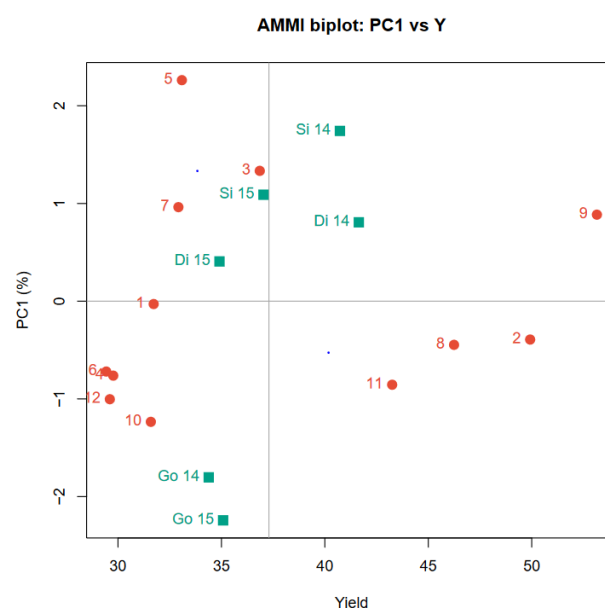
Genotypes	Environments												Grand mean	Ra nk	IP-CA1	IPCA2
	Sinana 1	Ra nk	Sinan a 2	Ra nk	Goba 1	Ra nk	Goba 2	Ra nk	Dinsh o 1	Ra nk	Dinsh o 2	Ra nk				
CIP-313038.09	30.71	12	27.23	11	28.37	10	27.94	11	35.30	9	27.03	12	29.43	11	0.72	-0.48
CIP-313026.03	37.71	7	36.47	6	28.28	11	28.79	8	35.99	8	30.29	7	32.92	7	-0.96	0.76
CIP-313026.43	48.01	3	44.77	3	40.95	4	47.51	3	53.23	3	43.00	3	46.24	3	0.45	-1.47
CIP-313037.21	61.55	1	51.09	1	48.27	1	50.30	1	58.36	1	49.33	1	53.15	1	-0.39	-0.75
CIP-313037.32	32.88	10	30.17	9	30.55	6	32.64	5	35.90	7	27.39	10	31.59	9	1.23	-0.44
Wabi	45.29	4	41.32	4	42.05	3	42.48	4	45.63	4	42.76	4	43.25	4	0.86	0.53
Local	31.44	11	30.05	10	30.32	7	28.32	9	30.15	12	27.13	11	29.40	12	1.00	1.31
Mean	40.73		37.03		34.39		35.08		41.64		34.91		37.30			
Lsd 0.05	8.60		7.30		3.30		7.00		10.30		6.50		2.94			
CV	15.06		14.06		6.84		14.22		17.65		13.29		14.30			

Note: IPCA =Interaction Principal Component Analysis

### 3.1.2. AMMI Analysis for Tuber Yield Mean Performance of Genotypes

The data in Table 3 highlights the tuber yield performances of different genotypes. In diverse environments, CIP-313037.21(G9) consistently produced the highest yields, with tuber outputs ranging from 48.27 to 61.55 t ha<sup>-1</sup>. This shows that genotype CIP-313037.21 has a high tuber yield potential across a wide range of environmental conditions. From this result it could be considered as a promising candidate for regional release. Taking into account the overall mean performance across environments, CIP-313037.21(G9) was the highest performing genotype with an average tuber yield of 53.15 t ha<sup>-1</sup>. CIP-313033.42 (G2) was the second highest performing genotype with an average tuber yield score of 49.92 t ha<sup>-1</sup> (Table 3). The results suggest that CIP-313037.21 (G9) and CIP-313033.42 (G2) were consistently productive across environments. This directs that these two potato genotypes have the potential to perform well under different growing conditions, which is a desirable trait for growing. This genotype-specific variability in tuber yield might be due to genetics rather than environmental influences. In contrast, local cultivar recorded the lowest tuber yield among the evaluated genotypes, at 29.40 t ha<sup>-1</sup> (Table 3). The average mean tuber yield of potato genotypes across environments ranged from 34.39 t ha<sup>-1</sup> at Goba1 to 41.64 t ha<sup>-1</sup> at dinsho1, with an overall mean yield of 37.30 t ha<sup>-1</sup> (Table 3). The results of this study are consistent with [20], which evaluated improved potato genotypes in different regions and identified superior genotypes for regional varietal releases.

### 3.1.3. Genotypes Tuber Yield Stability and Adaptive Analysis Using AMMI1 Biplot



**Figure 1.** AMMI 1 biplot the main and interaction (IPCA) influence of potato genotype tuber yield (t ha<sup>-1</sup>) grown across six environments.

Figure 1 shows the mean performance of genotypes and environments based on the AMMI 1 biplot analysis. In this graph, genotype and environment performance are represented by the X-axis, while interaction impact is represented by the Y-axis. As a result of genotypes and environments, the



overall mean performance was 37.30tha-1. AMMI1 biplot analysis showed that CIP-313037.21(G9), CIP-313033.42(G2), CIP-313026.43(G8), and Wabi (G11) produced higher tuber yields than the overall mean. With the exception of genotype CIP-313037.21 (G10) (well adapted to the Sinana location), other genotypes that yielded above the mean were well adapted to the Dinsho location (Figure 1). In contrast, genotypes CIP-308538.11 (G1), CIP-313022.35 (G3), CIP-313039.13 (G4), CIP-308486.22(G5), CIP-313038.09(G6), CIP-313026.03(G7), CIP-313037.32 (G10)

and local (G12) genotype produced below the overall mean performance. In a table 4, genotype stability is interpreted as; a genotypes with an IPCA score close to zero are stable genotypes those contributes minimally to interaction effects, while a genotypes with a higher absolute IPCA score are unstable and they contributes significantly to interaction effects. As a result, CIP-308538.11(G11) > CIP-313037.21(G9) > CIP-313033.42 (G2) > CIP-313026.43 (G8) were stable genotypes, while CIP-308486.22 (G5) and CIP-313022.35 (G3) were unstable genotypes (Table 4).

**Table 4.** Mean Tuber yield (t ha-1) performance across six environments, AMMI stability value, genotype selection index, IPCA1 and IPCA2.

Genotypes code	Genotypes Accession No.	Average Tuber yield	RY	ASV	RASV	GSI	IPCA1	IPCA2
1	CIP-308538.11	31.72	8	0.56	1	9	0.03	0.56
2	CIP-313033.42	49.92	2	2.57	10	12	0.40	-0.90
3	CIP-313022.35	36.85	5	1.83	5	10	-1.33	-0.91
4	CIP-313039.13	29.77	10	2.43	9	19	0.76	1.01
5	CIP-308486.22	33.09	6	1.20	2	8	-2.26	0.80
6	CIP-313038.09	29.43	12	2.88	11	23	0.72	-0.48
7	CIP-313026.03	32.92	7	1.86	6	13	-0.96	0.76
8	CIP-313026.43	46.24	3	4.70	12	15	0.45	-1.47
9	CIP-313037.21	53.15	1	1.55	3	4	-0.39	-0.75
10	CIP-313037.32	31.59	9	2.11	8	17	1.23	-0.44
11	Wabi	43.25	4	1.73	4	8	0.86	0.53
12	Local	29.61	11	1.96	7	18	1.00	1.31

Key: RY = ranking mean tuber yield, ASV = AMMI stability value, GYSI = genotype yield stability index, RASV = AMMI stability value ranking, IPCA = Interaction Principal Component Analysis

A genotype may show stability in varied environments, but its overall performance in case of yield or other characteristics is equally important. The significance of stability can be demonstrated only when it is linked with reasonable average yield performance [21]. In order to select genotypes that will be stable and perform well, a balanced approach is necessary, taking both performance metrics and stability into account. Thus, CIP-313037.21, CIP-313033.42, and CIP-313026.43 showed higher mean yield scores than the overall mean (Table 4). Consequently, these genotypes were adapted to almost all potato-growing areas in the Bale zone. In previous studies by [4], AMMI (Additive Main Effects and Multiplicative Interaction) model, mainly focused on the first interaction principal component axis, crucial insights into genotype by environment interactions (GEI) were provided. This study shows genotypes or environments with high IPCA1 scores display high interaction, which indicates their performance is highly variable and strongly influenced by the envi-

ronment. In contrast, genotypes or environments with IPCA1 scores close to origin or zero do not show much interaction, resulting in stable performance.

### 3.2. AMMI Stability Value (ASV)

AMMI stability value (ASV) and GGE biplot were used to determine the ideal Genotype. An ideal genotype should have both high mean tuber yield performance and high stability across environments [22]. The AMMI stability analysis, which measures genotype stability across different environments, is presented in Table 4. It should be noted that genotypes with lower AMMI Stability Values (ASV) tend to be more stable, whereas those with higher ASV tend to be unstable. ASV is calculated using interaction principal component analysis (IPCA) scores and gives quantitative measure of stability. With an AMMI stability value of 0.56, genotype CIP-308538.11 shows the most stability across environments

among all genotypes tested. In addition to CIP-308538.11, the CIP-308486.22 genotype also showed considerable stability with an ASV of 1.20. The CIP-313037.21 genotype exhibits moderate stability, with an ASV of 1.55. However the genotypes CIP-313026.43 and CIP-313038.09, displayed significant variability, as reflected by their higher ASV values of 4.70 and 2.88. In comparison to the other genotypes, CIP-313026.43 and CIP-313038.09 are less stable and more susceptible to environmental factors. It is similar to the results reported by [8] who reported that genotypes with a lower ASV exhibited a more stability. Based on these consistent results, the AMMI stability analysis is a reliable tool for evaluating genotype stability under variable environmental conditions.

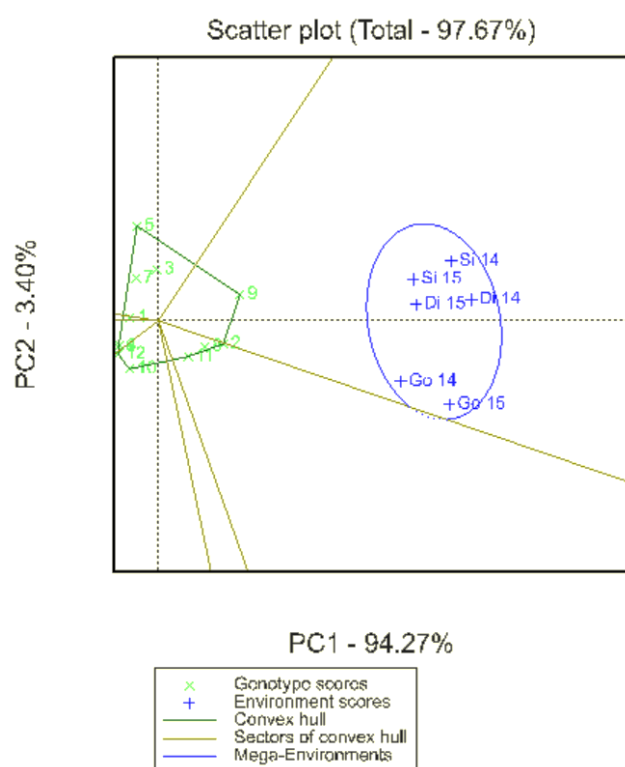
### 3.3. Genotype Stability Index (GSI) Analysis

Based on the genotype selection index methodology, [Table 4](#) shows the results of a stability analysis. To identify the most profitable genotypes for cultivation, genotype stability index (GSI) analysis integrates yield and stability. With this comprehensive approach, it is possible to confirm that selected genotypes produce high yields as well as being stable. Genotypes with the lowest GSI values are considered to have the highest mean yield and are most stable. As reported by [5], the concept of "high stability" is only relevant when it is combined with a reasonable average genotype yield. As a result, genotype stability is actually valuable when it consistently shows good yields across a various environments. Genotypes are selected based not only on their stability, but also on their average yield, making them both productive and stable. This study found that the genotype CIP-313037.21, with a GSI value of four (4), was the most stable and high-yielding. Therefore, this genotype is a reliable choice for cultivation since it consistently performs well across diverse environments. In contrast, the genotypes CIP-308486.22 and Wabi demonstrated excellent yield and stability, each with a GSI value of eight (8), indicating their ability to persist in a various environments and followed by genotypes CIP-308538.11, CIP-313022.35, and CIP-313033.42 that had the closest GSI values of nine, ten, and twelve respectively. On the other hand, the genotypes CIP-313038.09 and CIP-313039.13 were identified as unstable, each with a high GY-SI value of 23 and 19 respectively. Their high GSI value indicates substantial variability in their performance across diverse environments, indicating that they are less stable and less productive in different environments. The genotype stability index (GSI) has been proven to be a valuable tool in identifying high-yielding and stable genotypes. In order to provide an inclusive method for genotype analysis, it ranks mean yields and AMMI stability values (Additive Main Effects and Multiplicative Interactions). Research conducted by

[1], has reliably showed that integrating yield and yield stability into the selection procedure affords a more precise evaluation of genotypes performance.

### 3.4. Analysis of Genotype Adaptation Using GGE Biplot

In case of GGE biplot analysis results in [Figure 2](#) showed that the genotypes 9(CIP-313037.21), 2(CIP-313033.42), 5(CIP-308486.22), 10(CIP-313037.32), and 11(Wabi) were recognized as the vertex genotypes. This shows that these genotypes exhibited significant response to changes in environments and were specifically adapted to the environment in their respective sectors. Generally, these genotypes demonstrated robust performance and suitability in their individual environments, suggesting their potential for targeted production. Observation of genotypes like 5 (CIP-308486.22) and 10 (CIP-313037.32) being formed without clear associations with their sector environments suggests that these genotypes were inadequately adapted in some or all of the environments tested ([Figure 2](#)). Conversely, among the vertex genotypes 9(CIP-313037.21), 2(CIP-313033.42) and 11(Wabi) were identified as vertex genotypes within their respective sector environments (Dinsho, Sinana, and Goba). This indicates that 9(CIP-313037.21), 2(CIP-313033.42) and 11(Wabi) displayed the highest level of adaptation specifically tailored to their sector environments, indicating their superiority and suitability in these specific environments. Moreover, the GGE biplot results presented that the genotypes 9(CIP-313037.21) and 2(CIP-313033.42) were identified as stable with high mean tuber yield because they were located on the horizontal line (X-axis) ([Figure 2](#)). As a result of this locating, these genotypes consistently perform well across a variety of environments, making them a consistent choice for cultivation. In this study, an effective mega-environment was created by clustering all environments into one sector. In this classification, genotype by environment interactions had a minimal influence on tuber yields. Accordingly, the genotype CIP-313037.21(G9) demonstrated consistent achievements across all evaluated environments, leading to its selection as the overall winning genotype. This finding is inconformity with previous study conducted by [9], These studies exploited the GGE biplot methodology to identify leading genotypes for specific environments. By separating genotype main effects (G) and genotype by environment interaction effects (GE), the GGE biplot provides clear insights into genotype performance across different environments. In this research, vertex genotypes were found to perform best in specific sectors or environments which mean those are located at the polygon's vertices.



**Figure 2.** Which –won–where pattern of GGE biplot for yield of potato tuber.

## 4. Conclusion

The genotype high significantly influenced the potato yield which accounted for 72.8% of total variability; environment and their interaction effect were significant on potato tuber yield with 16.16% and 11.04% of the variability respectively. This indicates that the difference in potato performance across varied environments, directing the potential for selecting highly performed genotypes for narrow and wider adaptability. AMMI, GGE biplot, and Genotypes selection index (GSI) analyses showed that the genotype CIP-313037.21(G9) and CIP-313033.42(G2) were superior genotypes in tuber yield, reliably attaining high mean tuber yield potential across tested environments. Therefore, the genotypes CIP-313037.21(G9) and CIP-313033.42(G2) are selected for regional release for production in high lands of Bale and similar agro ecologies.

## Abbreviations

AMMI	Additive Main Effects and Multiplicative Interaction
GGE	Genotype Plus Genotype by Environment
ANOVA	Analysis of Variance
PCA	Principal Component Analysis
RCBD	Randomized Complete Block Design

## Conflicts of Interest

The author declares no conflicts of interest.

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