International Journal of Biochemistry, Biophysics & Molecular Biology
2021; 6(1): 6-10
http://www.sciencepublishinggroup.com/j/ijbbmb
doi: 10.11648/j.ijbbmb.20210601.13
ISSN: 2575-5889 (Print); ISSN: 2575-5862 (Online)

Yield Stability Analysis of Elite Irish Potato (*Solanum tuberosum* L.) Varieties in Western Ethiopia

Tilahun Wondimu Fufa*, Abraham Negara Fufa

Department of Horticulture, Bako Agricultural Research Center, Oromia Agricultural Research Institute, Bako, Ethiopia

Email address:
bekatilahun@gmail.com (T. W. Fufa), abrahamgdr@gmail.com (A. N. Fufa)
*Corresponding author

To cite this article:
Tilahun Wondimu Fufa, Abraham Negara Fufa. Yield Stability Analysis of Elite Irish Potato (*Solanum tuberosum* L.) Varieties in Western Ethiopia. *International Journal of Biochemistry, Biophysics & Molecular Biology*. Vol. 6, No. 1, 2021, pp. 6-10.
doi: 10.11648/j.ijbbmb.20210601.13

Received: December 31, 2020; **Accepted**: January 16, 2021; **Published**: April 16, 2021

Abstract: Potato is one of the most important horticultural crops widely grown in mid and high lands of Ethiopia. Several potato genotypes has been introduced and tested in different parts of western Ethiopia. However, the stability and performance of these genotypes under different parts of the regions were not yet assessed. Therefore, the objective of this study was to determine the effect of genotype, environment and their interaction for tuber yield and identify stable potato genotypes for possible recommendation. The study was conducted using nine potato genotypes during rainy seasons of 2016 and 2017 at three locations (Gedo, Shambu and Arjo) of western Ethiopia. The experiment was arranged in Randomized complete block design replicated three times. Among the testing locations, high yield (26.56 tha^{-1}) was recorded at Arjo while, low (21.51 tha^{-1}) at Shambu. Similarly, among the tested genotypes CIP39158.30 was showed high yield (36.41 tha^{-1}) followed by CIP384321.30 (35.15 tha^{-1}) while, CIP39264 showed low yield (13.3t/ha). Combined analysis of variance showed the main effect due to environments, genotype and genotype by environment interaction were highly significant ($P \leq 0.01$) for tuber yield. The genotype and genotype by environment interaction (GEI) was partitioned using GGE biplot model. The first two principal components obtained by singular value decomposition of the centred data of tuber yield explained 99.75% of the total interaction caused by genotype and genotype by environment interaction (GGE). Out of these variations PC1 and PC2 accounted 77.65% and 22.10%, respectively. Generally, the mean tuber yield, GGE biplot and regression slope identified CIP384321.30 as high yielding and stable genotype in the study area.

Keywords: Yield, Genotype, Genotype by Environment Interaction, Potato, *Solanum tuberosum*.

1. Introduction

Genotypes by environment interactions (GEI) is of the most importance to plant breeders [1]. Knowledge of the type and extent of GIE effects for a particular crop allows for efficient utilization of resources, accurate characterization of genotypes and to determine the selection gain over time [2]. GEI has also important implications for variety testing and variety recommendations [3, 4]. Besides, multi- environment yield trials are crucial to identify adaptable high yielding varieties and discover sites that best represent the target environment [5].

The association between the environment and the phenotypic expression of a genotype constitute the GEI [6, 7]. The GEI determines if a genotype is widely adapted for an entire range of environmental conditions or separate genotypes must be selected for different sub environments [8, 9]. When GEI occurs, factors present in the environment (temperature, rainfall, etc.), as well as the genetic constitution of an individual (genotype), influence the phenotypic expression of a trait [10]. The impact of an environmental factor on different genotypes may vary implying that the productivity of crop may also vary among environments [11].

GEI is almost universally considered by plant breeders to be among the main factors limiting response to selection and in general, the efficacy of breeding programs. According to Ngeve [12] the presence of GEI effects is serious problem in comparing the performance of individual cultivars across the environments. It reduces the efficiency of genetic progress and leads to unreliable recommendation in terms of yield and adaptability of genotypes. The analysis of GEI, therefore, becomes an important statistical tool employed by plant breeders not only evaluating varietal adaptation but also in the selection of parents for base population, in classifying environments and improving genotypes with desired adaptability [13, 14]. This study used the additive mean effects and multiplication interaction (AMMI) model and regression analysis to assess and rank potato genotypes for tuber yields, their stability, GEI effects and adaptability in three potato growing areas of western Ethiopia.

Among root and tuber crops in Ethiopia, potato ranks first in volume of production and consumption [14]. Potato has been considered as a strategic crop by the Ethiopian government aiming at enhancing food security and economic benefits to the country as, potato has a high potential to supply a cheap and quality food within a relatively short period [15, 16]. But, a number of production problems that accounts for low regional as well as national yield have been identified. The major ones are lack of stable, well-adapted, disease and insect pests' tolerant varieties [16, 17]. Farmers and researchers want successful potato varieties that show high performance for yield and other essential agronomic traits. Their superiority should be reliable over a wide range of environmental conditions also over years. The basic cause of differences between genotypes in their yield stability is the occurrence of GEI [1].

One of the most important characteristics of an ideal cultivar is stable and high yielder under inconsistent environmental conditions [18]. Moreover, improved crop cultivars need to be superior in yield as well as in other characteristics and this superiority should be expressed in the principal areas where the crop is grown [19]. However, so far less has been done to investigate the stability of superior elite potato genotypes tested in different growing environments in the western part of Ethiopia. Accordingly, a total of eight elite Irish potato genotypes were evaluated against the standard check to identify stable high yielding variety and understand the nature and magnitude of GEI.

2. Materials and Method

The experiment was conducted for two years (2016 and 2017) at three locations (Arjo, Gedo and Shambu) in western parts of Ethiopia. These sites represent major potato growing areas of the country. Eight potato genotypes introduced from international potato center (CIP); namely CIP384321.30, CIP38502, CIP39016, CIP39158.30, CIP39261, CIP39264, CIP39328, CIP90142 were tested with Jallane potato variety as standard check. The experimental set-up was randomized complete block design with three replications at each site during all seasons. The plot size was four rows of 3 m long, 0.75 m spacing between row and 0.30 m between plants. Weeding and hilling were carried out as recommended. Dehaulming was done at 90 days after planting and harvesting 10-14 days later. At harvest, data were recorded for fresh marketable tuber weight for all genotypes across locations. Genotypes, Environments (year and location combinations) and GEI were considered during the analysis.

The Additive Mean effects and multiplicative interaction (AMMI) model was used for data analysis and interpretation of GEI effects on tuber yield. Genstat software version 16th (http://www.genstat.co.uk/) was used to perform the AMMI calculation and to draw the biplot. The AMMI biplot was developed by placing both genotypes and environment means (main effects) on the x-axis or abscissa and the respective Eigen vectors or score of the first principal component (IPCA1) on the y-axis or ordinate [20]. Furthermore, Finlay and Wilkinson [21] suggested that the mean yield and regression coefficient (b) of genotypes over environments provide further insight into genotypes and environment stability. The locations were considered random and Genotype as a fixed effects and a mixed effect model analysis of variance (ANOVA) was used for statistical analysis. The treatment was broken down into three components: G, E and GEI effects in the following equation [22].

$$Y_{ijr} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + b_j + \varepsilon_{ijr}$$

Where yijr, is the average value of the dependent variable of genotype i in environment j and block r, μ is a grand mean, αi is the effect of the ith genotype. Bj, is the effect of the jth environment, αβij is the effect of the ith genotype by the jth environment, bj is the block effect at the jth environment and, is the residual error term ijr

3. Results and Discussion

There were highly significant (P<0.001) difference among genotypes, year, environment, and the interactions (year x locations, year x genotype, locations x genotype, year x location x genotype) (Table 1). Statistically, G x E interactions occurs if the performance of genotypes varies significantly across environments. The present study is in agreement with the work reported by Byarugaba *et al*. [6].

Table 1. *Analysis of variance table for tuber yield for Nine Irish potato genotypes tested over three environments for two years in western Ethiopia.*

Source variation	DF	SS	MS
Replication (R)	2	137.28	68.64**
Year (Y)	1	205.53	205.53**
Location (L)	2	665.80	332.90**
Genotypes (G)	8	9155.88	1144.48**
Y*L	2	1549.41	774.71**
Y*G	8	90.71	11.34ns
L*G	16	976.48	61.03**
Y*L*G	16	1105.91	69.12**
Error	106	1389.03	13.10
Total	161	15276.03	

Mean = 24.15 tha^{-1}, CV (%) = 14.98, R^2= 91% and LSD=2.39

Results in the Table 2 indicate across years the highest yield was recorded at Gedo during 2017 cropping season (29.38 tha^{-1}), followed by Arjo in 2017 (27.28 tha^{-1}), Arjo in 2016 (25.86 tha^{-1}), Shambu in 2016 (24.04 tha^{-1}) but least at Gedo in 2016 and Shambu in 2017 (19.17 tha^{-1}) each. Considering the individual locations, the highest total yield was recorded at

Arjo (26.57 tha^{-1}) while the lowest total yield recorded at Shambu (21.61 tha^{-1}). Besides, maximum tuber yield was recorded in 2017 (25.28 tha^{-1}) while the lowest was recorded in 2016 (23.02 tha^{-1}). The highest yielding genotype was CIP39158.30 (36.41 tha^{-1}) followed by CIP383421.30 (35.40 tha^{-1}) while, CIP39264 (13.3 tha^{-1}) was the least yielding genotype. Only four tested genotypes (CIP 90142, CIP 39261, CIP 39328 and CIP 39262) recorded lower total yield than the standard check, Jalane (24.81 tha^{-1}). The result implied that the performance of Irish potato genotypes varied among genotypes, across locations and years. The significant differences in the performance of the genotypes across year and locations could therefore, be attributed to differences in the genetic potential of the tested materials, differences in agro-ecological conditions and also genotypes x environmental interactions. Similar results were reported by Nakitandwe *et al*. [22].

Table 2. *Mean fresh tuber yield (tha^{-1}) of Nine Irish potato genotypes and one standard check across two years (2016 and 2017) at three locations in western Oromia.*

Genotypes	Arjo			Gedo			Shambu			Grand Total
	2016	2017	total	2016	2017	total	2016	2017	total	
CIP39158.30	35.54	32.71	34.13	33.51	44.46	38.99	38.74	33.51	36.12	36.41a
CIP384321.30	36.28	35.24	35.76	32.46	40	36.23	35.99	32.46	34.22	35.40a
CIP39016	29.17	32.62	30.9	20.87	30.48	25.68	25.43	20.87	23.15	26.57b
CIP38502	25.8	26.67	26.24	16.35	38.57	27.46	27.22	16.35	21.78	25.16b
JALANE	25.8	28.73	27.27	18.02	33.01	25.52	25.27	18.02	21.64	24.81b
CIP90142	22.39	26.51	24.45	13.41	30.95	22.18	21.93	13.41	17.67	21.43c
CIP39261	18.62	20.32	19.47	12.06	24.92	18.49	18.76	12.06	15.41	17.79d
CIP39328	24.17	29.36	26.77	14.13	7.14	10.64	9.95	14.13	12.04	16.48d
CIP39264	14.97	13.33	14.15	11.75	14.92	13.33	13.09	11.75	12.42	13.30e
Mean	25.86	27.28	26.57	19.17	29.38	24.28	24.04	19.17	21.61	24.15
CV (%)										14.98
R^2 (%)										91
LSD										2.93

The G x E interaction was further studied using the additive mean effects and multiplicative interactions (AMMI) model. AMMI analysis for tuber yield across environments showed highly significant differences among genotypes performances (Table 3). This revealed that the genotypes response varied from one environment to another. The analysis of variance results partitioned the main effect treatments in to genotype (G), environment (E) and G x E interactions with highly significant differences among all the components. It also partitioned the G x E interaction effects into principal components, where IPCA-I and IPCA-II explained highly significant G x E interactions.

Table 3. *Analysis of variance table for AMMI of tuber yield for Nine Irish potato genotypes tested over three environments for two years in 2016 and 2017 in western Ethiopia.*

Source	df	Sum square	Mean square
Total	161	15276	94.9
Treatments	53	13750	259.4**
Genotypes (G)	8	9156	1144.5**
Environments (E)	5	2421	484.1**
GxE Interactions	40	2173	54.3**
IPCA 1	12	1675	139.6**
IPCA 2	10	492	49.2**
IPCA 3	8	5	0.6ns
Residuals	10	0	0
Error	96	1112	11.6

Table 4. *Stability coefficient for Genotype by Environment of nine Irish potato genotypes in 2016 and 2017 in western Ethiopia.*

Gen	Mean	CS	SS	WEco.	MR	MADPR	VR
CIP384321.30	35.4a	2.50 (2)	7.92 (2)	20.70 (4)	1.67 (2)	0.53 (2)	0.27 (4)
CIP38502	25.16b	78.30 (4)	68.42 (8)	104.72 (8)	4.42 (4)	1.43 (8)	1.44 (7)
CIP39016	26.57b	62.50 (3)	24.98 (5)	13.19 (2)	3.67 (3)	1.20 (7)	1.47 (8)
CIP39158.30	36.41a	0.60 (1)	20.30 (3)	75.71 (7)	1.33 (1)	0.53 (2)	0.27 (4)
CIP39261	17.79d	186.30 (7)	24.90 (4)	7.03 (1)	7.67 (8)	0.53 (2)	0.27 (4)
CIP39264	13.3e	284.30 (9)	2.05 (1)	46.09 (6)	8.67 (9)	0.53 (2)	0.27 (2)
CIP39328	16.48d	262.80 (8)	73.21 (9)	398.42 (9)	6.67 (7)	2.27 (9)	3.87 (9)
CIP90142	21.43c	128.50 (6)	49.24 (7)	41.63 (5)	6.50 (6)	0.87 (6)	0.70 (6)
JALANE	24.81b	78.70 (5)	35.23 (60	16.88 (3)	4.42 (4)	0.57 (5)	0.24 (1)

CS= Cultivar Superiority, SS= Static Stability, WEc=Wricke's Eco valence, MR=Mean Ranks, MADPR= Means absolute difference of pairs of ranks and VR=Variance of ranks. Note: Numbers in brackets give the position of each genotype, ranked according to the stability coefficient in the previous column (running downwards from 1 = best).

The AMMI results are presented in table 5 which allows visualization of relationships between the Eigen values for the first principal component axis (PCA1) and the genotypes and the environment means (main effects). It also shows the variation in genotypes responsible to the environmental changes. Genotypes or environments which appear almost on a perpendicular line have similar means; those falling on horizontal line have similar interaction effects [23]. Genotypes or environments on the same parallel line relative to the Y-axis have similar yield and genotypes or environment on the right side of the midpoint of the axis has higher yield than those on the left side. According to Crossa *et al*. [24], the abscissa reflects the overall quality for environment and general improvement status for genotypes while the ordinate discriminate early (positive PCA scores) to late (negative PCA) maturing genotypes and correspondingly the length of growing season of locations. Basing on this argument, test genotypes CIP39158.30, CIP384321.30, CIP 38502, CIP 39016 and Jalane (the standard check) were displayed on the right hand side of the midpoint for the x-axis and were thus the high yielding than CIP 90142, CIP39264, CIP39262 and CIP39328 which were on the left hand side. CIP39158.30 at the extreme right and CIP39264 extreme left side were the best and least yielder genotypes. Test genotypes CIP39158.30, CIP384321.30, CIP 38502 and Jalane were categorized as early, but CIP39264 were considered as late maturing Genotypes or environments with large first PCA scores (either positive or negative) have large interaction; those with value close to zero have small interaction and are considered stable [25]. When the PCA values of genotypes and environments are close to zero, the entry has small interaction effects and its general response pattern across the environments parallel the mean of all genotypes in the trial and is thus considered stable [25]. According to Finlay and Wilkinson [20], mean yield of entries across environments and regression coefficents are important indecators of cultivar adaptation. This is in agreement with the ANOVA and AMMI results reported aelier.

Table 5. *Regression slope and principal component of nine irish potato genotypes in 2016 and 2017 in western Ethiopia.*

Genotype	Mean	bi	S^2di	IPCAg [1]	IPCAg [2]	IPCAg [3]
CIP384321.30	35.40a	0.61	-2.18	0.133	-1.258	0.001
CIP38502	25.16b	1.12	-0.90	1.904	1.184	-0.898
CIP39016	26.57b	1.82	7.11	-0.529	0.714	0.194
CIP39158.30	36.41a	0.64	12.22	1.193	-1.812	0.030
CIP39261	17.79d	0.32	8.36	0.524	0.152	0.317
CIP39264	13.30e	0.30	-3.31	-0.549	-1.744	-0.127
CIP39328	16.48d	1.16	-2.64	-4.086	0.542	-0.249
CIP90142	21.43c	1.64	-2.66	0.804	1.428	0.417
JALANE	24.810b	1.34	-3.02	0.605	0.795	0.314

4. Conclusion

Eight elite potato varieties were evaluated for their adaptability and stability with standard check in western Ethiopia at three locations for two consecutive years. AMMI and Regression coefficient showed genotype CIP384321.30 was high yielder and stable genotype implying general adaptation for same genotype. On the other hand, CIP38502 and CIP39158.30 showed specific adaptation to the environments with positive interaction. In conclusion genotype with general adaptation can be grown at all trial locations and similar environment in western Ethiopia while, genotypes with specific adaptation are better at specific.

Acknowledgements

The authors acknowledge all team members of Horticulture Department for their active participation on field work.

References

[1] Allard, R. W. and A. D. Bradshaw, Implications of genotype-environmental interactions in applied plant breeding 1. Crop science, 1964. 4 (5): p. 503-508.

[2] Dudley, J. and R. Moll, Interpretation and use of estimates of heritability and genetic variances in plant breeding 1. Crop science, 1969. 9 (3): p. 257-262.

[3] Kanua, M. and C. Floyd, Sweet potato genotype x environment interactions in the highlands of PapuaNew Guinea. Tropical Agriculture, Trinidad and Tobago, 1988. 65 (1): p. 9-15.

[4] Mulema, J., et al., Yield stability analysis of late blight resistant potato selections. 2008.

[5] Yan, W., et al., Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Science, 2000. 40 (3): p. 597-605.

[6] Byarugaba, A. A., et al., Genotype by environment interaction (GxE) as a measure of yield stability of Dutch potato varieties in Uganda. African Journal of Agricultural Research, 2018. 13 (17): p. 890-896.

[7] Kang, M. S., 15 Genotype–Environment Interaction: Progress and Prospects. Quantitative genetics, genomics, and plant breeding, 2002. 219.

[8] Bekeko, T. M. a. Z., Current advances in GxE analysis models and their interpretations, an implication for genotype selection for multiple environments. A review. Journal of Genetic and Environmental Resources Conservation, 2017. 5 (2): p. 64-72.

[9] Gedif, M. and D. Yigzaw, Genotype by environment interaction analysis for tuber yield of potato (Solanum tuberosum L.) using a GGE biplot method in Amhara region, Ethiopia. Agricultural Sciences, 2014.

[10] Welu, G., Genotype x Environment interaction of food barley. Ecoprint: An International Journal of Ecology, 2014. 21: p. 41-48.

[11] Annicchiarico, P., Genotype x environment interactions: challenges and opportunities for plant breeding and cultivar recommendations. 2002: Food & Agriculture Org.

[12] Ngeve, J., Regression analysis of genotype x environment interaction in sweet potato. Euphytica, 1993. 71 (3): p. 231-238.

[13] Lin, C.-S. and M. R. Binns, A superiority measure of cultivar performance for cultivar× location data. Canadian journal of plant science, 1988. 68 (1): p. 193-198.

[14] Getahun, A., Adaptability and stability analysis of groundnut genotypes using AMMI model and GGE-biplot. Journal of crop science and biotechnology, 2017. 20 (5): p. 343-349.

[15] Dessalegn, Y., F. Mengistu, and T. Abebe, Performance stability analysis of potato varieties under rainfed and irrigated potato production systems in northwestern Ethiopia. Ethiopian Journal of Science and Technology, 2008. 5 (2): p. 90-98.

[16] Woldegiorgis, G., Potato variety development strategies and methodologies in Ethiopia. Seed potato tuber production and dissemination: experiences, challenges and prospects, 2013.

[17] Becker, H. and J. Leon, Stability analysis in plant breeding. Plant breeding, 1988. 101 (1): p. 1-23.

[18] Kendal, E., GGE biplot analysis of multi-environment yield trials in barley (Hordeum vulgare L.) cultivars. Ekin Journal of Crop Breeding and Genetics, 2016. 2 (1): p. 90-99.

[19] Zobel, R., A powerful statistical model for understanding genotype by environment interaction. Genotype by environment interaction and plant breeding'.(Ed. MS Kang) pp, 1990: p. 126-140.

[20] Finlay, K. and G. Wilkinson, The analysis of adaptation in a plant-breeding programme. Australian journal of agricultural research, 1963. 14 (6): p. 742-754.

[21] Ding, M., et al., Application of GGE biplot analysis to evaluate Genotype (G). Environment (E) and GxE interaction on P. radiata: a case study. 15p, 2007.

[22] Nakitandwe, J., et al., Resistance to late blight and yield of population B3 potato selection in Uganda. African Crop Science Journal, 2005. 13 (2): p. 95-105.

[23] Zobel, R. W., M. J. Wright, and H. G. Gauch Jr, Statistical analysis of a yield trial. Agronomy journal, 1988. 80 (3): p. 388-393.

[24] Crossa, J., Statistical analyses of multilocation trials, in Advances in agronomy. 1990, Elsevier. p. 55-85.

[25] Hill, J., H. Becker, and P. Tigertedt, Quantitative and ecological aspects of plant breeding. 275pp. 1998.