Article

Genotype-environment interaction in potato genotype yield

Víctor Vásquez Arce[1]
Pablo Huerta Fernández[2§]
Héctor Cabrera Hoyos[3]
Luis Jiménez Díaz[4]

[1]National University of Cajamarca. Jirón Los Fresnos núm. 239, Urb. El Ingenio, Cajamarca, Peru. Tel. 976301328. (vvarce@hotmail.com). [2]La Molina National Agrarian University. Madrid street no. 116, Dept. 101, Miraflores, Lima, Peru. Tel. 971129290. CP. 18. (apablohuerta@gmail.com). [3]Baños del Inca Experimental Station-INIA. Freedom passage 331, Barrio San Sebastián, Cajamarca, Peru. Tel. 974160067. (hach8@hotmail.com). [4]La Molina National Agrarian University. Monteagudo Passage no. 154, Breña, Lima, Peru. Tel. 947019953. CP. 140104. (jdl@lamolina.edu.pe).

[§]Corresponding author: apablohuerta@gmail.com.

Abstract

Eight genotypes resulting from five recurrent selection cycles of *Solanum tuberosum* were evaluated, using the design of random complete blocks with three repetitions. There are highly significant differences in total weight and total tubers of different genotypes in six environments. Combined analysis detected significant differences for environments, genotypes, and IGE. The locality effects, genotypes, genotypes x locality and genotypes x environment were highly significant. The best environmental indices for weight of total tubers and tubers were achieved in the towns of: Santa Clotilde, La Pucara, Marcobamba and Santa Margarita. Genotype 399062.115 was considered stable, consistent and high yield potential 46.01 t ha^{-1}. Genotypes: 396012.266 and 393377.159 with yields of 42.01 t ha^{-1} and 38.66 t ha^{-1}, responded better to unfavourable and consistent conditions.

Keywords: *Solanum tuberosum* L., Andina, production.

Reception date: January 2021
Acceptance date: March 2021

Introduction

A potato genetic improvement program *(Solanum tuberosum* L.) will target the yield potential, stability and resistance to *Phytophthora infestans.* The yield potential considered as a quantitative variable is an overly complex physiological process that is determined by genotype, environment and genotype x ambient interaction (Vásquez 1988; Pérez *et al*., 2010). Stability refers to the plant's ability to express its yield potential in a wide range of environments (Vásquez 2013; Lying *et al*., 2019) and the resistance will be directed to the horizontal type (Rubio *et al*., 2016). A study about the interaction of genotype x environment (IGE) for potato yield showed that all genotypes had a differential response to environmental effects (Vásquez *et al*., 2019, Tirado *et al*., 2018).

In the Cajamarca Region many genotypes (clones) are sown under different environmental conditions, very marked effects of the environment on the phenotypic expression of them were observed, so the genotypic variability that is observed is due to genetic variation plus the effect of the environment (IGE), therefore should lessen the effect of IGE; through the use of suitable experimental designs and with good agronomic management (Vásquez *et al*., 2019).

The objectives of this research were to determine the existence or non-existence of genotype x environment interaction (IGE) and its effect on tuber weight yield and total number of tubers and detect stable genotypes using the model suggested by Eberhart and Russell (1966).

Materials and methods

Of the six environments studied, three experiments were established in the province of Cajamarca, two in the province of Chota both belonging to the Cajamarca Region and an experiment in the province of Sánchez Carrión (La Libertad Region). All installed under dry conditions (campaign 2016-2017). The characteristics of the six sites are in Table 1.

Table 1. Geographical, climatic and oedafic characteristics of the five environments where the evaluation of the ten potato genotypes was carried out.

	Locality	Year	Latitude Longitude	Altitude (m)	Annual temperature (°C)	Precipitation (mm)	Soil type
Cajamarca	Santa Clotilde	2016	-7.1443438 -78.322611	2 900	13. 5	107	Loam Clay
	Santa Margarita	2016	-7.114251 -78.3041	2 950	13. 2	110. 5	Loam Sandy
Chota	Chucmar	2016	-6.409631 -78.577461	3 200	12. 1	106	Loam Clay Sandy
	Marcobamba	2016	-14.05948 -73.52772	3 036	14. 3	95. 5	Loam Clay
	La Púcara	2016	-15.97993 -71.45988	3 600	10. 2	115. 6	Loam
Sánchez Carrión	Chugay	2016	-7.7825 -77.8678	3 378	10	132. 8	Loam Clay Sandy

National Service of Meteorology and Hydrology-SENAMHI (2017).

Eight potato genotypes from Baños del Inca-Cajamarca Agricultural Experimental Station (INIA) were considered. Genotypes represent the most advanced of *S. andigena* x *S. andigena* combinations and recurrent selection for five cycles (B1C1 to C1B5) and the resulting population was improved looking for resistance to *P. infestans*, precocity, adaptation, appearance of tubers in more defined forms, superficial eyes and commercial tubers yields higher than their close relatives (Gastelo *et al*., 2010). The genotypes evaluated are shown in Table 2.

Table 2. Potato genotypes evaluated in the experiment.

Number	Genotypes	Pedigree	Group
1	399075.26	(387348.20x389746.2)	B3C1
2	399076.12	(387170.16x389746.2)	B3C1
3	396012.266	(391004.10x393280.58)	B3C2
4	399062.115	(395266(B1C4046.2)x(395235.8(B1C4015.8))	B1C5
5	393377.159	(395285.5x395282.3)	B1C5
6	399058.12	(395274.1x395319.2)	B1C5
7	393077.54	(395285.5x395282.3)	B1C5
8	399062.108	(395266.2(B1C4046.2) x395282.3(B1C406.2.3))	B1C5

For the evaluation of the eight genotypes, a random complete blocks design was used with three repetitions per environment. The experimental plot was two grooves of three meters in length separated to 30 cm between strokes and 1 m between grooves. A sprouted seed was placed per knock. The weight of total tubers and the number of total tubers were assessed at harvest.

Results and discussion

In individual variance analyses, highly significant differences were found between genotypes (p<0. 01) for total yield and number of total tubers in the six environments (Santa Clotilde, Santa Margarita, Chucmar, Marcobamba, La Púcara and Chugay). Bartlett’s test indicated that the variances were homogeneous and the assumptions of normality of the errors were fulfilled (Vasquez, 2014). The coefficients of variation ranged from 5. 23% to 2. 93%, considered good to give precision to the tests (Vásquez, 2013). There was statistical significance ($p\leq$ 0.01) for localities, genotypes and genotype x environment interaction (IGA) (Table 3). Heterogeneity between environments was mainly related to differences in altitude, soil type, temperatures and precipitation during the study years (Table 1).

Differences for genotypes showed the existence of genetic variability in total weight yield and number of total tubers. These results are consistent with Tirado *et al*. (2018) who evaluated potatoes with pigmented pulp in four environments obtaining statistical significance for environments, genotypes and IGE. IGA demonstrates that potato genotypes have different behavior in the various environments tested. These results are consistent with Vásquez *et al.* (2019), who evaluated adaptation and yield of six clones in eight environments and they found differences for genotypes and for genotype-environment interaction. Solomon *et al.* (2015), tested thirteen potato progenies in two environments, they found statistical significance at a 1% chance for progenies and for IGA.

Heterogeneity between environments was mainly related to differences in altitude, soil type, temperatures and precipitation during the study years (Table 1). It was noted that, the relationship between the ratio of the mean squares of genotypes and the average squares of the IGA is 57. 22, indicating greater importance of genotypes on interaction (Table 3). This demonstrates the existence of genetic variability, which let to select superior genotypes (Vásquez, 1988).

Table 3. Combined variance analysis (average squares) for total weight and number of total tubers.

Source of variation	Degrees freedom	Average squares	
		Total weight	Total tubers
Locality	5	4.2669**	173.7842
Rep/Loc	12	0.2132	1.4347
Genotypes	7	112.0806**	27.3993
Loc x genotypes	35	1 4734**	13.8199
Error	84	0 4168	3.556
Total	143		

R^2= 0.9608, 0.8392; CV(%)= 3.47, 12.18 $\overline{y}_{..}$= 37.11, 12.63.

According to Table 3, the environment was 2. 38% of total yield variation, genotype 87. 65% and interaction G × E 5. 76%. Based on the relative contribution of sum of squares, genotypes have a greater contribution, followed by the GxE interaction and finally the contribution of environments. For the total number of tubers, the environment represents 46.78%, genotypes 10. 31 and 25. 99% of the variation represents the IGA. These results differ with Tirado *et al*. (2018) and Solomon *et al*. (2015) who found that the largest contribution of IGE was 60.82 and 70.13%, that of the genotype of 26.03% and 10.3%.

Table 4 shows that the best environment for genotype evaluation was Chugay, Santa Clotilde and Púcara with averages 38.66, 37.16 and 37.10 t ha^{-1} respectively, statistically surpassing the remaining five locations, and also surpassing regional average 14 t ha^{-1} (MINAGRI, 2017). No statistical differences were found between the towns Marcobamba, Chucmar and Santa Margarita, whose yields ranged from 36.98 tha^{-1} to 36.24 t ha^{-1} respectively.

Table 4. Multiple comparison test (Duncan) of averages to yield (t ha^{-1}) of the genotypes under study by locality and the environmental index (Ij).

Key	Locality	Total weight		Number of tubers	
		(t ha^{-1})	Environmental index (Ij)	Number average	Environmental index (Ij)
6	Chugay	38.66 a	1.57	11.5388 d	-5.65
1	Santa Clotilde	37.16 b	0.01	17.3575 ab	2.8
5	La Púcara	37.1 b	0.01	13.8965 c	-3.31
4	Marcobamba	36.98 bc	-0.12	17.0406 b	2.2
3	Chucmar	36.5 bc	-0.59	14.2927 c	-1.55
2	Santa Margarita	36.24 c	-0.86	18.7654 a	5.5

The stability parameter model identified the town Chugay, Santa Clotilde and Pucara as the best environments to yield because the values of their environmental indices (Ij) are positive, that is to say, higher than the general average (37.11 t ha^{-1}). Environments with bad behavior were Marcobamba, Chucmar and Santa Margarita for having negative environmental indices; that is, less than the general average. For the number of total tubers, the best environments were Santa Clotilde, Marcobamba and Santa Margarita for having their positive environmental indices. These results are higher than those obtained by Gastelo *et al*. (2010) who evaluating these genotypes in four locations in Puno, achieved average yields ranging from 18 to 28 t ha^{-1}.

Stability parameters

1% probability significance was found for genotypes and G x Amb (linear) for tuber weight and total number of tubers (Table 5). No significance was found for joint deviation for the two variables in the eight genotypes. Differences between genotypes can detect those with better genetic potential. The significance of genotype x environmental interaction (linear) reveals that there is a changing differential response of genotypes through environments for the response variables studied. This suggests that it is possible to select genotypes with better genetic potential and stability in a number of environments as Eberhart and Russell (1966) point out. It should be noted that, in the average yield of the 8 genotypes, variation in productive potential was observed. This result considers the importance of conducting experiments in time and space, to observe the response of varieties and genotypes under different environmental conditions (Becker and León, 1988; Vásquez, 1988; Fikere *et al*., 2008).

Table 5. Variance analysis (average squares) for stability according to Eberhart and Russell (1966), of eight potato genotypes evaluated in six locations for total weight and total number of tubers.

Source of variation	Average squares		
	Degrees of freedom	Tuber weight	Total number tubers
Total	143		
Genotypes	7	53.74**	9806.95**M3
Amb + (G x Amb)	40	0.87	7321.4
Amb (linear)	1	10.24	292961.236
G x Amb (linear)	7	10.24**M2	46.825**M2
Joint deviation	32	0.6562 M1	4948.3324 M1
399075.26	4	1.1453*	3441.8992 ns
399076.12	4	0.2877	1294.6063 ns
396012.266	4	0.2336	15885.5058 ns
399062.115	4	0.1436	886.6341 ns
393377.159	4	1.3125**	9256.964 ns
399058.12	4	1.0756	1706.4922 ns
393077.54	4	0.7024	1348.9553 ns
399062.108	4	0.3746	5749.1537 ns
Combined error	84	0. 4168	3. 4815

Interpretation of stability parameters

Table 6 presents the classification of the potato genotypes evaluated, first considering the criteria used by Eberhart and Russell (1966), where the average behavior of the genotype through environments, its regression coefficient and regression deviation were used.

Table 6. Total weight yield and number of tubers of eight potato genotypes, including stability parameters.

#	Genotypes	Total weight			Total number tubers		
		($t\ ha^{-1}$) $^{+}$	bi	S^2_{dj}	Total tubers^{+}	bi	S^2_{dj}
1	399075.26	35.26 e	1.076**	1.001	16.77 b	1.2741	9.7718
2	399076.12	37.34 d	0.065	0.149	11.09 b	0.9165	3.0505
3	396012.266	38.63 c	1.01	0.095	16.77 a	0.6261	38.1428
4	399062.115	46 a	1.103**	0.005	11.45 a	1.0665	0.0892
5	393377.159	42.01 b	1.415	1.174	11.39 b	0.6578	20.7872
6	399058.12	32.3 g	0.617**	0.937	14.23 a b	1.2633	3.7924
7	393077.54	33.8 f	2.194	0.563	12.06 b	0.8699	1.6213
8	399062.108	31.43 h	0.582	0.236	12.89 b	1.2258	11.3696

$^{+}$= means with the same letter are statistically equal (Duncan, 0.05); $y_{..}$= 37.11 t ha^{-1}; $\overline{y}_{..}$= 12.63.

In order to identify and classify potato genotypes by their stability, based on estimators of regression coefficients (bi) and regression deviations (S^2_{di}) for the six categories proposed by Carballo and Márquez (1970), the following scenarios were considered in relation to the values of regression coefficients bi=1, bi< 1, bi> 1and regression deviations S^2_{di}= 0, S^2_{di}> 0, of these identified three of the eight possible groups (Table 6), as follows: 1) genotypes 396012.266 (3) and 399062.115 (4) had bi= 1; and S^2_{di}= 0; that is, they are considered stable genotypes (Eberhart and Russell, 1966; Carballo and Márquez, 1970), whose yields outweigh the average yield (37.11 t ha^{-1}); 2) regression coefficients bi< 1 and regression deviations S^2_{di}= 0, genotype 399076.12 (2) responds with good response in consistent unfavorable environments; and 3) genotype 393377.159 (5) presents regression coefficients bi> 1 and regression deviations S^2_{di}> 0, is a genotype with good response in favorable but inconsistent environments.

As regards the total number of tubers (Table 6) two groups of the eight genotypes evaluated were identified: 1) genotypes 399075.26 (1), 399062.115 (4), 399058.12 (6) and 399062.108 (8) had regression coefficients bi> 1 and regression deviations S^2_{di}> 0 are good response in favorable but inconsistent environments; and (2) genotypes 399076.12 (2), 396012.266 (3), 393377.159 (5) and 393077.54 (7) with bi< 1 and S^2_{di}> 0, are those genotypes with good response in unfavorable and inconsistent environments.

These results are consistent with the reports of Pérez *et al*. (2007); Vásquez *et al*. (2019), who found values that characterize genotypes with a better response to good environments, in unfavorable and consistent conditions, as well as inconsistent.

For the total number of tubers, according to Eberhart and Russell (1966), the best environments for the genotypes studied were Santa Margarita, Santa Clotilde and Marcobamba, with 5.5, 2.8 and 2.2 tubers, because had positive environmental index (Ij) values.

Conclusions

The highly significant differences observed between genotypes, between localities and their interaction (IGA) suggest that there is sufficient genetic variability to select outstanding genotypes, that the environments of the Cajamarca region are heterogeneous and that significant IGA makes it difficult to identify stable genotypes.

The best environmental indices for tubers weight and number of total tubers were in Santa Clotilde, La Púcara, Marcobamba and Santa Margarita, located in Cajamarca and Chota. The Ebarhart and Russell model identified the genotypes: 399062.115 (4), 393377.159 (5) and 396012.266 (3) with 46.01 t ha^{-1}, 42.01 t ha^{-1} and 38.66 t ha^{-1} above average (37.11 t ha^{-1}) and with bi= 1, s^2di= 0, considered as stable genotypes. Genotype 399062.115 (4) for total number of tubers had a regression coefficient of bi= 1 and a regression deviation s^2di= 0 considered a stable genotype.

Cited literature

Becker, H. C. and León, J. 1988. Stability analysis in plan breeding. Plant Breed. Review. 101(1):1-23.

Carballo, C, A. y Márquez, S. 1970. Comparación de variedades de maíz del Bajío y la Mesa Central por su rendimiento y estabilidad. Agrociencia. 5(1):129-146.

Eberhart, S. A. and Russell, W. A. 1966. Stability parameters for comparing varieties. Crop Science. 6(1):36-40.

Fikere, M.; Tadesse, T. and Letta, T. 2008. Genotype - environment interactions and stability parameters for grain yield of faba bean (*Vicia faba* L.) genotypes grown in South Eastern Ethiopia. Int. J. Sustain. Crop Prod. 3(6):80-87.

Gastelo, M.; Arcos, J.; Landeo, J. y Bonierbale, M. 2010. Nuevas variedades de papa *Solanum tubersoum* spp. andígena (B1C5), obtenidas a través de la selección participativa por los agricultores de las comunidades del altiplano, Puno-Perú. *In*: I Congreso Internacional de Investigación y Desarrollo de papas nativas. Quito-Ecuador. 137-138 pp.

Márquez, Y.; Salomon, J. y Acosta, R. 2020. Análisis de la interacción genotipo ambiente en el cultivo de la papa (*Solanum tuberosum* L.). Cultivos Tropicales. 4(1):1-14.

MINAGRI. 2017. Características de la producción nacional y de la comercialización en Lima metropolitana. Boletín pruducción nacional de papa-Perú. 30 p.

Pérez, L.; Vásquez, G. y Sahagún, J. 2007. Estabilidad del rendimiento de genotipos de papa (*Solanum tuberosum* L.). Rev. Fitotec. Mex. 30(003):279-284.

Pérez, D.; Gonzáles, A. Huerta, M.; Rivera, A.; Sahagún, J.; Balbuena, A.; Rubí, A. y Gutiérrez, F. 2010. Variabilidad genética, diversidad fenotípica e identificación de genotipos sobresalientes de papa. Rev. Mex. Cienc. Agríc. 1(4):579-592.

Rubio, C. O. A.; Cadena, H. M. A. y Flores, L. R. 2016. Comparación de la resistencia horizontal y vertical contra el tizón tardío de la papa en Toluca. Rev. Mex. Cienc. Agríc. 7(4):755-766.

Salomón, J.; Castillo, J.; Arzuaga, J. A.; Torres, W.; Caballero, A.; Varela, M. and Betancourt, V. M. H. 2015. Análisis de la interacción progenie-ambiente con minitubérculos a partir de semilla sexual de papa (*Solanum tuberosum* L.) en Cuba. Cultivos Tropicales. 36(2):83-89.

SENAMHI. 2017. Servicio Nacional de Meteorología e Hidrología. Registros meteorológicos. Lima, Perú.

Tirado, C.; Vásquez, V. y Narro, L. A. 2019. Estabilidad de rendimiento y adaptabilidad de híbridos de maíz tolerantes a suelos ácidos en base a las características del análisis GGE biplot. Aci. Avances. 11(17):50-63.

Tirado, R.; Tirado, L. y Mendoza, J. 2018. Interacción genotipo ambiente en rendimiento de papa **(***Solanum tuberosum* L.) con pulpa pigmentada en Cutervo, Perú. Chilean J. Agric. Anim. Sci., ex Agro-Ciencia. 34(3):191-198.

Vásquez, V. 1988. Mejoramiento genético de la papa. 1ra. (Ed.). Amaru editores. Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica-CONCYTEC. Lima, Perú. 149-153 pp.

Vásquez, V. 2013. Experimentación agrícola. 1ra. (Ed.). Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica-CONCYTEC. Lima, Perú. 417-436 pp.

Vásquez, V. 2014. Diseños experimentales con SAS. 1ra. (Ed.). Consejo Nacional de Ciencia, Tecnología e Innovación Tecnológica-CONCYTEC, Fondo Nacional para el Desarrollo de la Ciencia, Tecnología e Innovación Tecnológica-FONDECYT. Lima, Perú. 206-210 pp.

Vásquez, V.; Cabrera, H.; Jiménez, D. y Colunche, A. 2019. Estabilidad del rendimiento de genotipos de papa (*Solanum tuberosum* L.). Ecología Aplicada. Dpto. Académico de Biología, Universidad Nacional Agraria La Molina. Lima-Perú. 18(1):59-65.