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Research Article

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Parental Value for Tuber Yield in Potato Under High Temperature Environments in Climate Change Conditions

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Abstract: Potato crop is expanding to areas with temperatures higher than those required. Climate change is increasing temperatures in traditional areas of potato production, thereby affecting tuber yield. The International Potato Center has developed a population adapted to these new conditions, being more tolerant to high temperatures, resistant to late blight, virus PVX and/or PVY and early maturity. In breeding programs it is very important to know the parental value of the progenitors. The parental value of 34 selected potato clones was determined through general combining ability for marketable, total yield and average tuber weight under high temperatures. Using the line by tester mating design, the potato clones were crossed as lines and varieties Katahdin, Huagalina and clones CIP398098.204 and CIP302533.31 as testers. The field experiments were carried out in three locations in Peru: San Ramon, La Molina and Majes, where average temperatures at night were between 15.25 to 21.65°C, and during the day fluctuated between 21.47 to 27.20°C. We used a randomized complete block design, with three replications. At harvest the number and weight of marketable and non-marketable tubers were taken. Then the average tuber weight, marketable and total yield per hectare was calculated. 18 potato clones were identified with high parental value for marketable yield, seventeen for total tuber yield and 11 for average tuber weight; nine of them combine high parental value for the three characteristics studied. These clones with late blight resistance, heat tolerant, adapted to medium altitudes, growing period of 90 days and high parental value can be used as parents in breeding programs, to obtain new varieties under the new climate change scenarios with high temperatures. 12 crosses that presented high SCA are the most promising for the development of superior clones.

Keywords: Potato, Climate Change, Heat Tolerance, Combining Ability, Late Blight

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1 Introduction

Potato crop is expanding to areas where conditions are not ideal for production due to high temperatures, which is one of the most significant factors affecting potato yield (Muthoni et al. 2015). Changes in temperates are brought on by climate change, which is affecting weather patterns in traditional areas for this crop (Levi and Villeux 2007), where unpredictable rains and pressure from pests and diseases are increasing farmers' risk. In anticipation of these changes, the International Potato Center (CIP) has developed a population to obtain clones with Late Blight resistance and Heat Tolerance, named LBHT population and they are available for use by developing countries in the selection of new varieties or as parents in their breeding programs (Gastelo et al. 2012, 2015; CIP, 2014).

The potato crop is highly heterozygozus, the most important economical characters are governed by additive and non-aditive genes. General Combining Ability (GCA) is considered important for additive traits and Specific Combining Abiltity (SCA) for non-additive traits (Falconer 1981).

A breeding program for yield improvement is successful, when clones with high parental value are used, which is not only measured by its phenotypic value, but it is necessary to know its combining ability as an indicator of parental value (Luthra et al. 2006), selecting clones that when crossed with testers with a broad genetic base, have a high GCA value and can transmit it to their progeny to obtain high yields (Plaisted et al. 1962). High parental value (GCA) of these clones for tuber yield under high temperatures will allow to have a high percentage of the

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progenies eligible for variety selection (Thompson and Mendoza 1984; Mendoza 1989).

Combining ability analysis is a method very useful for choosing better parents, and in the formulation of a crossing plan for a breeding program. GCA is one of the powerful tools in identifying clones with high parental value that can be used in crosses (Garafolo et al. 2005; Tai 1976; Gopal 1998; Mondal and Hossain 2006).

In various studies in potato, it has been found that the additive effects (GCA), are predominant for overall tuber yield, and average tuber weight (Reis et al. 2017). Da Silva et al. (2013), in a study to determine the combined capacity for tuber yield, found that General Combining Ability (GCA), was significantly superior than Specific Combining Ability (SCA), suggesting the predominance of additive effects of the genes in the control of this trait. Hirut et al. (2017), found that GCA was more important than SCA for total tuber yield, marketable tuber yield, average tuber weight under stress conditions. Beserra et al. (2001), found that the effects of GCA were more important than the effects of SCA for the yield in heat tolerant potato clones, indicates that the use of high GCA parents in a breeding program would allow us to obtain heat tolerant potato clones. Muhinyuza et al. (2016) in a study in Rwanda to estimate combining ability effects, for yield related traits and late blight resistance in potato, they found that additive gene action was predominant over non-additive gene action for both traits. Also Neele et al. (1991), found that for tuber yield, the number of tubers and the average tubing weight in potato, the general combining ability (GCA) was predominant, although the specific combining ability effects present were greater at late than at early harvests. In a study done by Manivel et al. (2009), to determine the effects of GCA and SCA on dry matter in potato, they found that there were variations of the effects of GCA and SCA through the potato generations, attributing to the genotype x environment interaction, recommending that the selection of the best parents for breeding Potato should be done based on years and generations.

However, in other studies, it has been found that the GCA and SCA effects are important for tuber yield, tuber number and average tuber weight in seedlings and clonal generations (Ruiz et al. 2006). Haydar et al. (2009), found that GCA and SCA are important for yield per plant, controlled by the additive and non-additive genes respectively.

This study documents the parental value of 34 advanced potato clones from LBHT population, through the estimation of GCA and SCA of average tuber weight, marketable and total tuber yield under high temperatures conditions and select the best parents and hybrids combinations to be included in breeding programs for heat tolerance under climate change scenarios in Asia, Africa and Latin America.

2 Materials and Methods

Three sets of 34 advanced clones from the LBHT population (Table 1), with resistance to late blight,which was evaluated in previous experiments under natural field conditions with high disease pressure (Gastelo et al. 2015), were evaluated to determine their parental value through their GCA and SCA , http://www.cipotato.org/catalogue. Set 1, 2 and 3 had 19, 6 and 9 clones respectively. In all sets, the line by tester mating design was used, (Hallauer and Miranda 1982; Kempthorne 1957; Singh et al. 1985). We used as testers the varieties Kathadin (*Solanum tuberosum* spp *tuberosum*), an improved heat tolerant and Huagalina, a native variety. (*Solanum tuberosum* spp *andigena*), non-tolerant to heat and advanced potato clones CIP398098.204 and CIP302533.31 from LBHT population (mix solanum species: *Solanum tuberosum*, spp *tuberosum*, spp *andigena*, *Solanum, demisum*, etc.). The crosses were carried out under greenhouse conditions in 2012 and 2013, generating 57, 18 and 27 progenies in sets 1, 2 and 3 respectively.

In 2013, the botanical seeds of sets 1 and 2, were sown under greenhouse with the objective of obtaining seed tubers. We planted 200 botanical seed (genotypes) per progeny, at harvest, we took one tuber from each of the 120 best plants, these were divided into three groups of 40 seed tubers each for field experiments, which were seeded in spring-summer growing season 2013-2014.

In 2015, we planted seeds in set 3 and proceeded the same as set 1 and 2. The field experiments were started in the spring-summer growing season 2015-2016.

The field experiments of the three sets, were carried out in three warm environments in Peru: San Ramon, La Molina and Majes. Average temperatures at field in these sites at the time that the experiments at night, were between 15.65 and 21.65°C, and in the day were between 21.47°C and 27.20°C (Table 2). The air temperature was taken one meter above the ground. Night temperature is very important, since the night-time process of tuberization is inhibited above 20°C. In all experiments, we used randomized complete block (RCB) with three replications of 40 plants (genotypes) each. The sowing was done manually, the distance between rows and plants was 0.90 and 0.30 m respectively. The dose of fertilization was 180-180-160 NPK, applying a half dose of nitrogen to the planting

Table 1: Characteristics of Advanced Potato clones from LBHT population

#	Clones	Pedigree		Color		Tuber shape	Eyes	Resistance			Tolerance	
		Female	**Male**	**Skin**	**Flesh**			**LB**	**PVX**	**PVY**	**H**	**D**
SET 1												
1	CIP398098.205	CIP393371.58	CIP392639.31	Cr	Cr	El	S	R		ER	T	NT
2	CIP398098.231	CIP393371.58	CIP392639.31	Cr	Cr	Ov	S	R		ER	T	NT
3	CIP398098.570	CIP393371.58	CIP392639.31	Cr	Cr	Rd	S	R	ER		T	NT
4	CIP398098.65	CIP393371.58	CIP392639.31	Cr/Pi	Cr	Ele	S	R			T	NT
5	CIP398180.289	CIP392657.171	CIP392633.64	Cr	Cr	Ov	S	R	ER		T	T
6	CIP398180.292	CIP392657.171	CIP392633.64	Cr	Cr	Ob	S	R	ER		T	T
7	CIP398190.615	CIP393077.54	CIP392639.2	Cr	Cr	Ov	S	R	ER		T	NT
8	CIP398190.89	CIP393077.54	CIP392639.2	Cr	Cr	Ov	S	R			T	NT
9	CIP398192.213	CIP393077.54	CIP392633.54	Cr/Pi	Cr	Ov	S	R	ER		T	T
10	CIP398192.553	CIP393077.54	CIP392633.54	Cr/Pi	Cr	Ov	S	R	ER		T	NT
11	CIP398193.158	CIP393077.54	CIP392633.64	Cr/Pi	Cr	Ov	S	R	ER		T	NT
12	CIP398193.511	CIP393077.54	CIP392633.64	Cr	Ye	El	S	R	ER		T	NT
13	CIP398201.510	CIP393242.50	CIP392633.64	Pi	Cr	Ob	S	R	ER	ER	T	NT
14	CIP398203.5	CIP393280.82	CIP392633.64	Re	Cr	El	S	R	ER		T	NT
15	CIP398208.219	CIP393371.58	CIP392633.64	Cr	Cr	El	S	R	ER	ER	T	T
16	CIP398208.33	CIP393371.58	CIP392633.64	Cr	Cr	Ob	S	R	ER		T	T
17	CIP398208.620	CIP393371.58	CIP392633.64	Cr	Cr	El	S	R	ER		T	NT
18	CIP398208.670	CIP393371.58	CIP392633.64	Cr	Cr	Ob	S	R	ER	ER	T	NT
19	CIP398208.704	CIP393371.58	CIP392633.64	Cr/Pie	Cr	Lg	S	R	ER		T	T
SET 2												
1	CIP302531.43	CIP393280.82	CIP396272.43	Re	Ye	Ov	S	R	ER		T	NT
2	CIP302533.40	CIP393371.159	CIP396272.43	Cr	Cr	El	S	R	ER	ER	T	NT
3	CIP302533.49	CIP393371.159	CIP396272.43	Cr/Pie	Cr	Lg	S	R	ER	ER	T	NT
4	CIP302533.74	CIP393371.159	CIP396272.43	Cr	Cr	El	S	R	ER	ER	T	NT
5	CIP302534.17	CIP393371.159	CIP396272.18	Cr	Cr	El	S	R		ER	T	NT
6	CIP304079.10	CIP393075.54	Granola	Cr	Cr	Ov	S	R	ER	ER	T	NT
SET 3												
1	CIP398017.53	CIP391002.6	CIP392639.31	Cr	Cr	Ov	S	R			T	NT
2	CIP398098.203	CIP393371.58	CIP392639.31	CR	Cr	Ov	S	R			T	T
3	CIP398098.204	CIP393371.58	CIP392639.31	Cr/Pi	Ye	El	S	R			T	NT
4	CIP398190.200	CIP393077.54	CIP392639.2	Cr/Pi	Cr	Ob	S	R			T	NT
5	CIP398190.605	CIP393077.54	CIP392639.2	Cr/Pi	Cr	Ov	S	R			T	NT
6	CIP398192.592	CIP393077.54	CIP392633.54	Cr	Cr	Ov/Fl	S	R	ER		T	NT
7	CIP398208.505	CIP393371.58	CIP392633.64	Cr/Pie	Cr	Ov	S	R	ER	ER	T	NT
8	CIP302551.26	CIP393385.47	CIP396272.8	Cr/Pi	Ye	Ov	S	R	ER	ER	T	NT
9	CIP304081.44	CIP393075.54	Monalisa	Cr	Cr	Ov	S	R		ER	T	NT
TESTERS												
1	CiIP302533.12			Cr/Pi	Cr	Ob	S	R			T	NT
2	HUAGALINA			Cr/Re	Ye	Ov	I	S			S	NT
3	KATAHDIN			Cr	Cr	Ov	S	S			T	NT

LB = Late blight, H = Heat, D = Drought, S = Susceptible, ER = Extreme resistance, R = Resistant,T = Tolerant, NT = Non-tolerant, Cr = Cream, Cr/Pi = Cream with pink, Cr/Pie = Cream with pink eyes, Pi = Pink, Re = Red, Ye = Yellow, Cr/Re = Cream with red, Ov = Oval, OB = Oblong, Lg = Large, El = elliptic, Rd = Round and the other half to the hilling. In La Molina the irrigation was by the furrows, in San Ramon it was by sprinkling and in Majes by dripping. Pest control was done in a timely manner using Decis 2.5EC (Deltametrin) for *Liriomyza huidobrensis* and *Epitrix sp*; for *Pthorimaea operculelella* was applied Vertimec 1.8Ec (Abamectin). No fungicide was applied to control diseases. The harvest was done 90 days after sowing.

At harvest the number and weight of marketable and non-marketable tubers per plot was taken. Then was calculated, the average tuber weight (ATW), weight of marketable and total tubers per hectare in tons (MTYha, TTYha).

The simple and combined analysis of variance of line (clones) by tester mating desing were performed with statistical software, SAS V. 9.4 (SAS Institute Inc., Cary, NC, USA.). Proc anova and determination of the estimate effects of combining ability (GCA and SCA) were performed with Microsoft Office Excel 2013, using the formulas described by Singh and Chaudhary (1985). (Table 3). The following linear additive model was used for the analysis of variance of line x tester in an environment.

$$Y_{ijk} = \mu + R_k + G_i + G_j + S_{ij} + \varepsilon_{ijk}$$

Where

Yijk = observed value in the i^{th} line, j^{th} tester and k^{th} replication

i = number of lines

j = number of testers

k = number of replication

R_k = effect of the k^{th} replication

G_i = GCA effect of the i^{th} line

G_j = GCA effect of the j^{th} tester

S_{ij} = SCA effect of the crossing between the i^{th} line and j^{th} tester

ε_{ijk} = effect of experimental error in the ijk^{th} observation

Linear additive model combined across environments

$$Y_{ijkl} = \mu + E_l + R(E)_{kl} + G_i + G_j + S_{ij} + GE_{il} + GE_{jl} + SE_{ijl} + \varepsilon_{ijkl}$$

Where

Y_{ijkl} = observed value in the i^{th} line, j^{th} tester, k^{th} replication and l^{th} environment

$R(E)_{kl}$ = effect of the k-th replication within l^{th} environment

GE_{il} = GCA effect of the interaction i^{th} line and l^{th} environment

GE_{jl} = GCA effect of the interaction j^{th} tester and l^{th} environment

SE_{ijl} = SCA effect of the crossing between the i^{th} line and j^{th} tester

ε_{ijkl} = effect of experimental error in the $ijkl^{th}$ observation

3 Results

The analyzes of variance of the three sets in each locality, show highly statistically significant differences for clones, testers and the interaction of clones by testers ($P<0.01$) for marketable and total tuber yield, and average tuber weight. In the experiment performed in san Ramon of the Set 3, there was no statistical differences for testers in average tuber weight (Table 4).

Combined analysis of variance for marketable and total tuber yield per hectare (MTYha and TTYha) and average tuber weight (ATW), showed highly statistically significant differences ($P<0.01$) for Clones and testers, which are associated with the GCA, also the interaction of clones by tester associated with SCA, presented high statistical significance, except for ATW in experiment 1. The interaction with the environment was highly significant for clones and testers × environments, and clones × testers × environments (Table 5).

The combining ability analysis was performed based on the combined analysis, the GCA showed a wide range of variability for clones and testers. In set 1, ten clones showed high significant effects of GCA for MTYha and TTYha and 8 for ATW ($P<0.01$). Seven clones

Table 2: Coordinates and average temperature of the experimental sites for potato field experiments in Peru

Site	Altitude masl	Latitude	Longitude	Agroecological Zone	Temperature Average °C		Temperature °C		
					Day	Night	Min.	Max.	Average
San Ramon	828	11°08'S	75°20'W	Humid Tropical Mid-elevation	27.20	21.65	19.57	28.15	24.84
La Molina	150	12°05'S	76°56'W	Arid Tropical Lowland	25.28	21.53	19.47	26.68	23.35
Majes	1294	16°28'S	72°06'W	Arid tropical Mid-elevation	21.47	15.25	14.02	22.01	18.39

Table 3: Formulas to estimate the effects of combining ability (GCA and SCA) and its standard error (SE)

Effects and Standar Error	One Environment	Across Environments
GCA (Lines (Clones))	Xi../rt – X.../rlt	Xi.../rte – X..../rlte
GCA (Testers)	X.j./rl – X.../rlt	X.j../rle – X..../rlte
SCA	Xij./r – Xi../rt – X.j./rl + X.../rlt	Xij./re – Xi.../rte – X.j../rle + X..../rlte
SE (GCA for line (clone))	$(MSe/rt)^{1/2}$	$(MSe/rte)^{1/2}$
SE (GCA for tester)	$(MSe/rl)^{1/2}$	$(MSe/rle)^{1/2}$
SE (SCA)	$(MSe/r)^{1/2}$	$(MSe/re)^{1/2}$
SE (GCAi - GCAj line (clone))	$(2MSe/rt)^{1/2}$	$(2MSe/rte)^{1/2}$
SE (GCAi - GCAj tester)	$(2MSe/rl)^{1/2}$	$(2MSe/rle)^{1/2}$
SE (SCAij - SCAkl)	$(2MSe/r)^{1/2}$	$(2MSe/re)^{1/2}$

Where:
Xi.. = sum of the i-th line
X.j. = sum of the j-th tester
X... = total sum
Xij. = total sum of the cross of the i-th clone with the j-th tester
MSe = Mean Square of error
r = replications
t = testers
e = environments

Table 4: Analysis of variance of three sets in three sites for ATW, MTYha and TTYha

		La Molina			Majes			San Ramon		
SET 1										
Source of Variation	df	ATW	MTYha th^{-1}	TTY ha th^{-1}	ATW	MTYha th^{-1}	TTYha th^{-1}	ATW	MTYha th^{-1}	TTYha th^{-1}
Replications	2	114.13**	2.64**	0.88ns	401.10**	4.42ns	11.19	381.37ns	51.20**	99.47**
Clones	18	158.63**	20.02 **	22.91 **	457.50**	123.88**	147.50**	1055.71**	45.19**	48.17**
Testers	2	24.46 **	262.27**	295.96**	37785.35**	693.274**	131.96**	21625.41**	506.34**	340.07**
Clones x Testers	36	80.30 **	6.63**	7.34**	104.4ns	78.30**	99.04**	380.94**	36.01**	42.04**
Error	112	10.27	0.35	0.46	108.01	10.34	13.96	229.99	5.06	6.53
C.V. %		3.53	3.46	3.81	12.12	17.64	17.71	17.75	15.44	15.90
SET 2										
Replications	2	198.57	1.47**	4.16**	1202.02**	11.66**	19.06**	1406.35**	18.79**	13.77**
Clones	5	1831.36**	221.15**	225.22**	1049.66**	55.01**	79.39**	994.11**	27.82**	43.64**
Testers	2	3593.35**	756.76**	801.92**	801.19**	110.50**	19.72**	12348.13**	99.73**	93.68**
Clones x Testers	10	752.62**	32.20**	30.97**	1473.41**	45.98**	60.93**	2039.40**	31.33**	42.63**
Error	34	230.10	0.47	0.73	308.08	3.66	4.92	430.59	3.17	2.67
C.V. %		22.07	6.13	7.24	16.79	12.03	11.69	20.64	14.16	11.16
SET 3										
Replications	2	9.85ns	0.45ns	0.45ns	125.28**	4.65**	6.31ns	21.15ns	0.93ns	1.17ns
Clones	8	267.03**	10.43**	10.43**	676.87**	123.75**	125.17**	28.06**	2.39**	3.39**
Testers	2	483.15**	190.93**	190.93**	11588.79**	948.56**	776.88**	9.15ns	10.46**	8.04**
Clones x Testers	16	443.21**	2.86**	2.86**	221.73**	28.80**	42.25**	30.22**	2.59**	3.33**
Error	52	45.74	0.34	0.34	41.98	1.60	2.64	11.74	0.47	0.62
C.V. %		10.01	4.33	4.33	7.93	6.89	7.72	3.88	4.79	5.34

MTYha = Marketable tuber yield per hectare, TTY ha = Total tuber yield per hectare, * = highly statistically significant ($P<0.01$)

Table 5: Combined analysis of variance for average tuber weight, marketable and total tuber yield

Source of variation	Square Mean											
	SET 1				SET 2				SET 3			
	df	ATW	MTYha th^{-1}	TTY ha th^{-1}	df	ATW	MTYha th^{-1}	TTY ha th^{-1}	df	ATW	MTYha th^{-1}	TTY ha th^{-1}
Environment (E)	2	1556.27**	609.02**	1121.55**	2	20775.41 **	313.59 **	707.55 **	2	8954.96**	542.60**	1310.92**
Replication/E	6	298.87	19.42**	67.18**	6	935.65**	10.64**	12.33**	6	52.10	2.01	2.65
Clones	18	720.51 **	89.58**	101.27**	5	1377.97**	145.36 **	165.64 **	8	390.7 9**	46.05**	46.16**
Testers	2	39164.67 **	1271.99**	587.42 **	2	13010.54 **	610.03 **	214.20 **	2	2763.06**	754.27**	655.18**
Clones x Testers	36	228.14**	62.83**	77.34**	10	2241.85**	34.13**	48.36**	16	213.08**	12.80**	19.04**
Clone x E	36	475.66**	49.76**	58.65**	10	1248.58**	79.31**	91.30**	16	290.59 **	45.26**	46.42**
Tester x E	4	10135.28 **	94.95**	90.82**	4	1866.06**	174.86 **	350.56 **	4	4659.01**	197.84**	160.33**
Clones x Tester x E	72	168.75	29.05**	35.54**	20	1011.79**	37.69**	43.09**	32	234.94 **	10.39**	14.18**
Pooled Error	336	116.09	5.25	6.98	102	322.92	2.43	2.77	156	32.87	0.80	1.19
C.V. %		12.34	13.74	14.44		19.69	11.79	11.01		7.23	5.82	6.67

of them with heat tolerance and high resistance to late blight: CIP398098.570, CIP398098.65, CIP398192.213, CIP398201.510, CIP398208.620, CIP398203.5, and CIP398208.670, showed significant effects GCA, for the three characteristics under study. In set 2, three clones showed significant effects of GCA for MTYha and TTYha and one for ATW ($P<0.01$) and in set 3, five clones showed significant effects of GCA for MTYha, four for TTYha and 2 for ATW ($P<0.01$). The clones CIP398098.203 and CIP304081.44, showed significant effects GCA, for MTYha, TTYha and ATW (Table 6).

The testers, CIP398098.204 and the heat tolerant variety, Katahdin, presented good effects of GCA, for the three characteristics in study in the three sets. The tester Huagalina, a variety not tolerant to heat, did not present significant GCA effects (Table 7).

The clones CIP302533.74 from Set 2, CIP398017.53 and CIP398192.592, both from set 3, presented significant effects of GCA for ATW, but they were not significant effects of GCA for MTY and TTY, probably because of the tubers despite having a good average weight, but the number of tubers per plant was very low resulting in low tuber yield.

11 progenies showed high effect of SCA, statistically significant, for ATW, MTYha and TTYha in the three sets,pooled over locatons: CIP398180.292xHuagalina, CIP398190.615 x CIP398098.204, CIP398190.89 x Huagalina, CIP398193.158 × Huagalina, CIP398208.704 × Katahdin, CIP302531.43 × Kathadin, CIP302533.40 × Huagalina, CIP302533.74 × CIP302533.31, CIP304079.10 × Huagalina, CIP304081.44 × CIP398098.204, and CIP398017.53 × Kathadin (Table 8).

4 Discussion

The potato clones (LBHT), used in this study, are adapted to high temperatures in warm environments. Temperature is a very important factor that affects the production of tubers in the potato crop under climatic change conditions.

The potato crop is highly heterozygous and the tuber yield is governed by additive and non-additive genes, associated with the GCA and SCA respectively, in this study the analysis of variance shows significant differences between clones and testers, associated with the GCA, indicating us that there is enough variability for the parental value (GCA), allowing the identification of clones with high parental value. Likewise, significant differences

Table 6: Estimates of General Combining Ability (GCA) effects for lines (clones), pooled over locations for average tuber weight, marketable and total tuber yiel in three sets of clones from LBHT population

#	Lines (Clones)	Traits Average tuber weight	Marketable Tuber Yield th^{-1}	Total Tuber Yield th^{-1}
	SET 1			
1	CIP398098.205	-3.38	-0.63	-0.42
2	CIP398098.231	-3.70	-1.71	-1.57
3	CIP398098.570	2.23*	0.54*	0.82*
4	CIP398098.65	3.90*	1.34*	1.05*
5	CIP398180.289	-3.01	-1.18	-0.91
6	CIP398180.292	0.66	0.01	-0.08
7	CIP398190.615	-9.34	-4.11	-4.62
8	CIP398190.89	-10.03	-3.56	-3.63
9	CIP398192.213	6.58*	1.39*	1.30*
10	CIP398192.553	5.11*	0.59*	-0.29
11	CIP398193.158	-5.48	-1.05	-1.19
12	CIP398193.511	0.71	-0.65	-0.67
13	CIP398201.510	10.08*	0.87*	0.85*
14	CIP398203.5	3.99*	0.65*	0.74*
15	CIP398208.219	-2.86	0.57*	0.54*
16	CIP398208.33	0.00	2.56*	2.63*
17	CIP398208.620	2.99*	1.33*	1.14*
18	CIP398208.670	2.15*	3.18*	3.75*
19	CIP398208.704	-0.28	0.29	0.62*
	S.E gca	2.07	0.44	0.51
	S.E (gi-gj)	2.93	0.62	0.72
	SET 2			
1	CIP302531.43	-6.00	1.44*	1.19*
2	CIP302533.40	3.00	-0.63	-0.53
3	CIP302533.49	-9.00	-2.45	-1.95
4	CIP302533.74	11.00*	-2.88	-3.59
5	CIP302534.17	2.00	2.09*	2.06*
6	CIP304079.10	0.00	2.41*	2.83*
	S.E gca	3.45	0.30	0.32
	S.E (gi-gj)	4.89	0.42	0.45
	SET 3			
1	CIP302551.26	0.23	0.45*	0.24
2	CIP304081.44	5.30*	0.59*	0.58*
3	CIP398017.53	0.86	-0.77	-0.60
4	CIP398098.203	5.15*	2.12*	1.70*
5	CIP398098.204	-7.58	-2.14	-2.18
6	CIP398190.200	-1.99	1.29*	1.68*
7	CIP398190.605	-1.95	-1.08	-0.91

Table 6 continued: Estimates of General Combining Ability (GCA) effects for lines (clones), pooled over locations for average tuber weight, marketable and total tuber yiel in three sets of clones from LBHT population

#	Lines (Clones)	Traits Average tuber weight	Marketable Tuber Yield th^{-1}	Total Tuber Yield th^{-1}
8	CIP398192.592	0.93	-0.91	-1.15
9	CIP398208.505	0.19	0.87*	0.99*
	S.E gca	1.10	0.17	0.30
	S.E (gi-gj)	1.56	0.24	0.21

*Clones with significant high parental value $P<0.05$

Table 7: Estimates of General Combining Ability (GCA) effects for testers, pooled over locations for average tuber weight, marketable and total tuber yield, in three sets of clones from LBHT population

	Testers	Average tuber weight	Marketable Tuber Yield th^{-1}	Total Tuber Yield th^{-1}
	SET 1			
1	CIP398098.204	9.62 *	2.11 *	1.67 *
2	Huagalina	-17.45	-3.08	-1.99
3	Katahdin	7.82 *	0.98 *	0.31 *
	S.E. gca	0.22	0.18	0.2
	S.E. (gi-gj)	0.32	0.25	0.29
	SET 2			
1	CIP398098.204	13.74 *	2.76 *	1.83 *
2	Huagalina	-16.70	-3.74	-2.12
3	Katahdin	3.78 *	0.97 *	0.30 *
	S.E. gca	2.44	0.21	0.23
	S.E. (gi-gj)	3.45	0.30	0.32
	SET 3			
1	CIP398098.204	2.47 *	1.36 *	1.46 *
2	Huagalina	-7.03	-3.69	-3.45
3	Katahdin	4.05 *	2.04 *	1.74 *
	S.E. gca	0.64	0.10	0.12
	S.E. (gi-gj)	0.90	0.14	0.17

*Clones with significant high parental value $P<0.05$

in the progenies (clone by tester interaction) allow us to identify promising progenies to develop clones with high yield potential under environments with high temperatures in climate change conditions.

The high parental value for tuber yield under high temperature conditions found in this study, coincides with the results by Beserra et al. (2001), who found that in clones with heat tolerance, the GCA was more important, indicating that the use of clones with high parental value

Table 8: Estimates of Specific Combining Ability (SCA) effects in progenies, statistically significant pooled over locations for average tuber weight, marketable and total tuber yield

CIPNUMBER	Female	Male	Average tuber weight	Marketable Tuber Yield th^{-1}	Total Tuber Yield th^{-1}
SET 1					
CIP313072	CIP398098.205	Huagalina	-1.99	2.32*	2.45*
CIP313073	CIP398098.205	Katahdin	-0.50	1.11*	1.35*
CIP313075	CIP398098.231	Huagalina	2.88	2.61*	2.72*
CIP313079	CIP398098.570	Katahdin	-2.97	1.40*	1.85*
CIP313070	CIP398098.65	CIP398098.204	1.36	1.23*	1.57*
CIP313070	CIP398098.65	Katahdin	3.18	0.81*	1.01*
CIP313082	CIP398180.289	Katahdin	2.11	1.54*	1.31*
CIP313084	CIP398180.292	Huagalina	7.90*	1.04*	1.12*
CIP313122	CIP398190.615	CIP398098.204	3.87*	3.30*	3.83*
CIP313089	CIP398190.89	CIP398098.204	-0.76	1.62*	2.05*
CIP313087	CIP398190.89	Huagalina	9.09*	2.81*	2.67*
CIP313091	CIP398192.213	Katahdin	1.69	2.24*	2.31*
CIP313125	CIP398192.553	CIP398098.204	0.37	2.23*	3.18*
CIP313124	CIP398192.553	Katahdin	3.26	2.78*	3.29*
CIP313093	CIP398193.158	Huagalina	3.70*	1.77*	1.61*
CIP313098	CIP398193.511	CIP398098.204	-3.87	1.57*	1.23*
CIP313096	CIP398193.511	Huagalina	1.19	1.80*	2.30*
CIP313116	CIP398201.510	CIP398098.204	1.60	1.13*	1.15*
CIP313100	CIP398203.5	Katahdin	-1.21	2.69*	2.59*
CIP313106	CIP398208.33	Katahdin	1.34	0.94*	0.59
CIP313121	CIP398208.620	CIP398098.204	1.15	3.39*	3.72*
CIP313108	CIP398208.670	Huagalina	2.29	3.61*	4.58*
CIP313112	CIP398208.704	Katahdin	4.17*	3.45*	3.12*
S.E sca			3.59	0.76	0.88
S.E (sij-skl))			5.08	1.08	1.25
SET 2					
CIP313147	CIP302531.43	CIP302533.31	-7.63	0.64*	1.23*
CIP313149	CIP302531.43	Katahdin	11.11*	2.74*	2.62*
CIP313154	CIP302533.40	Huagalina	14.37*	0.78*	1.20*
CIP313157	CIP302533.49	Huagalina	5.26	1.79*	1.45*
CIP313159	CIP302533.74	CIP302533.31	32.15*	1.52*	1.88*
CIP313151	CIP304079.10	Huagalina	8.81*	1.45*	2.53*
S.E sca			5.99	0.52	0.55
S.E (sij-skl))			8.47	0.73	0.78
SET 3					
CIP315021	CIP302551.26	CIP398098.204	-6.69	0.59*	0.93*
CIP315020	CIP302551.26	Katahdin	1.51	0.67*	0.58*
CIP315024	CIP304081.44	CIP398098.204	6.12*	1.24*	1.14*
CIP315025	CIP398017.53	Huagalina	1.17	1.98*	2.27*
CIP315026	CIP398017.53	Katahdin	2.65*	0.81*	0.96*
CIP315005	CIP398098.204	Katahdin	-5.35	0.94*	1.32*
CIP315009	CIP398190.200	CIP398098.204	-2.14	1.22*	1.23*
CIP315015	CIP398190.605	CIP398098.204	-2.06	0.09	0.63*

Table 8 continued: Estimates of Specific Combining Ability (SCA) effects in progenies, statistically significant pooled over locations for average tuber weight, marketable and total tuber yield

CIPNUMBER	Female	Male	Average tuber weight	Marketable Tuber Yield th^{-1}	Total Tuber Yield th^{-1}
CIP315013	CIP398190.605	Huagalina	0.43	2.05*	1.83*
CIP315016	CIP398192.592	Huagalina	0.32	0.43*	0.38*
CIP315017	CIP398192.592	Katahdin	1.13	0.68*	0.81*
CIP315012	CIP398208.505	CIP398098.204	3.23*	0.33*	0.13
CIP315010	CIP398208.505	Huagalina	-4.27	0.34*	0.57*
S.E sca			1.91	0.30	0.36
S.E (sij-skl))			2.70	0.42	0.51

*Progenies with significant SCA $P<0.05$

in breeding programs will allow us to obtain a high percentage of heat tolerant potato clones.

Identification of clones with high parental value (GCA), for MTYha, TTYha and ATW, in this study, will allow to have the best parents that transmit these traits to their progenies, increasing the frequency of favorable genes and genotypes in potato crop for variety selection. These characters are affected considerably for high temperatures in climate change scenarios.

Some clones presented high GCA for ATW, but they do not have good GCA for MTYha or TTYha, probably because despite having tubers of adequate size, the number of tubers per plant is low, decreasing yields, this being frequent when clones are evaluated for heat tolerance. So is important to select parental potato clones that combine high GCA for ATW and MTYha and TTY under warm conditions.

The GCA is more important when selecting clones with high parental value, but it is also found that there are very promising crosses for their high value of SCA, which will allow us to select superior clones for the characteristics under study, coinciding with the results found by Ruiz de Galarreta et al. (2006), who found that both GCA and SCA were important for tuber yield, tuber number and average tuber weight, but differ from the results found by Da Silva et al. (2015), Hirut et al. (2017), who suggest the predominance of additive effects (GCA).

12 crosses with significant SCA, 50 percent of them were crosses by testers Katahdin and CIP398098.204 and the other half with Huagalina, probably because the clones crossed to Katahdin and the clone CIP398098.204 that are tolerant to the heat, increase the frequency of alleles for high yields against heat stresses, and crosses with Huagalina, would be exploiting the effect of heterosis by crossing two genetically divergent sources.

The resistance to the PVX and / or PVY viruses present in some of the clones with high GCA, could have influenced their capacity of performance, since under conditions of high temperatures the presence of insect vectors of virus is greater, being this characteristic very important when selected for heat tolerance, especially resistance to PVY virus.

In all sets, 18 potato clones were identified with high parental value for MTYha, 17 for TTYha and 11 for average tuber weight under high temperatures; nine of them combine high parental value for the three characters studied pooled over sites

These clones with high parental value, high levels of late blight resistance, heat tolerant, adapted to tropical mid-elevation, a growing period of 90 days and high parental value can be used as parents in breeding programs of countries where these limitations exist in Africa, Asia or Latin America, in order to obtain progenies with high potential for new varieties with heat tolerance, high resistance to late blight, high tuber yield , tuber weight of suitable marketable value, under the new scenarios of high temperatures, as an effect of climate change.

The progenies that presented high SCA are the most promising for the development of superior clones for ATW, MTYha and TTYha.

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References

[1] Beserra M.C., Pinto C.A.B.P., Lambert E.S., Combining Ability of Potato Genotypes for Cool and Warm Seasons in Brazil. Crop Breeding and Applied Biotechnology, 2001, 1(2), 145-157, http://dx.doi.org/10.13082/1984-7033.v01n02a06

[2] Centro Internacional de la Papa (International Potato Center), Catalogue of potato varieties and advanced clone, 2014, http://www.cipotato.org/catalogue

[3] Da Silva G.O., Gonçalves N.V., Reis T.L., Da Silva P.A., Akiyoshi S.F., Combining ability of potato parents for tuber appearance and yield traits Rev. Ceres, 2013, 60 (4), 489-497,

[4] http://dx.doi.org/10.1590/S0034-737X2013000400007

[5] Falconer D.S., Introduction to Quantitative genetics. New York: Longman, 1981

[6] Garafolo J., Andrade H., Cuesta J., Evaluation of general and specific in 21 potato progenies Solanum phureja for resistance to late blight Phytophthora infestans. Thesis of pre-grade, Central University of Ecuador, Faculty of Agricultural Sciencies, Quito – Ecuador, 2005, [In Spanish]

[7] Gastelo M., Diaz L., Landeo J.A., Bonierbale M., New elite potato clones with heat tolerance, late blight and virus resistance to address climate change. In: Low, J.; Nyongesa M., Quinn S.,Parker M. (eds). Potato and sweetpotato in Africa. Transforming the value chains for food and nutrition security. Oxfordshire(UK). CABI International. ISBN 978-1-78064-420-2, 2015, 143-152

[8] Gastelo M., Landeo J., Diaz L., Bonierbale M., Nuevos clones elite de papa con resistencia al tizón tardío tolerancia desarrollados por el CIP para enfrentar el cambio climático. Población LBHT. In Memorias del XXV Congreso de la Asociación latinoamericana de la Papa ALAP. Uberlandia, SP, Brasil, 2012

[9] Gopal J., General combining ability and its repeatability in early generations of potato breeding programmes. Potato Research, 1998, 41, 21-28

[10] Hallauer A., Miranda J.B., Quantitative Genetics in Maiz Breeding. The Iowa State University Press, 1982

[11] Haydar A., Alam M.K., Khokan E.H., Ara T., Khalequzzaman M., Combining Ability and Genetic Variability studies in Potato. J.Soil.Nature, 2009, 3(2), 01-03

[12] Hirut B., Shimelis H., Fentahun M., Bonierbale M., Gastelo M., Asfaw A., Combining ability of highland tropic adapted potato for tuber yield and yield components under drought. PLoS ONE, 2017, 12(7), https://doi.org/10.1371/journal.pone.0181541

[13] Kempthorne O., An Introduction to Genetics Statistics. John Wiley and sons. Inc. New York, 1957

[14] Levy D., Veilleux R.E., Adaptation of Potato to high Temperatures and Salinity. A Review. In American Journal of Potato Research, 2007, 84, 487-506

[15] Luthra S.K., Pandey S.K., et al., Potato breeding in India. CPRI Technical bulletin Nº 74 Central Potato Research Institute, Shimla, Himachal Pradesh, India, 2006, p.90

[16] Manivel P., Pandey S.K., Singh S.V., Repeatabilty of general and specific combining ability effects of seedling and clonal generations in potato., Electronic Journal of Plant Breeding, 2009, 1, 43-46, http://www.ejplantbreeding.org/index.php/EJPB

[17] Mendoza H.A., Population Breeding as a tools for germoplasm enhancement. American Potato Journal, 1989, 66, 636-653

[18] Mondal M.A.A., Hossain M.M., Combinig ability in Potato (Solanum tuberosum L.). Bangladesh Journal Bot. 2006, 35(2), 125-131

[19] Muhinyuzza J.B., Hussein S., Melis R., Sibiya J., Ndambe N. M., Combining ability analysis of yield and late blight [Phytophthora infestans (Mont.) de Bary] resistance of potato germplasm in Rwanda. Australian Journal Of Crop Science, 2016, 10(6), 799-807, http://dx.doi.org/10.21475/ajcs.2016.10.06.p7303

[20] Muthoni J., Kabira J.N., Potato Production in the hot tropical areas of Africa: Progress made in breeding for haet tolerance. Journal of Agricultural Science, 2015, 7(9), 220-227, http://dx.doi.org/10.5539/jas.v7n9p220

[21] Neele A., Nab H., Louwe K., Identification of superior parentes in a potato breeding programme. Theoretical and Applied Genetics, 1991, 82(3), 264-272, http://dx.doi.org/10.1007/BF02190611.

[22] Plaisted R.L., Sanford L., Federer W.T., Kehr A.E., Peterson L.C., Specific and general combining ability for yield in potatoes. American Potato Journal, 1962, 39, 185-197

[23] Reis T.L., Emerson A.L., Rocha D., Cerioli M., Da Silva P.A., Combining ability of Potato parents for tuber appareance and tuber yield component traits. Crop Breeding and Applied Biotechnology, 2017, 17, 99-106, http://dx.doi.org/10.1590/1984-70332017v17n2a16

[24] Ruiz de Galarreta J.I., Ezpeleta B., Pascualena J., Ritter E., Combining ability and correlations for yield components in early generations of potato breeding. Plant Breeding, 2006, 125, 183-186

[25] SAS 9.4 Copyright (c) 2002-2012 by SAS Institute Inc., Cary, NC, USA. All Rights Reserved

[26] Singh R. K., Chaudhary B. D., Biometrical Methods in Quantitative Genetics Analysis, Kalyani Publishers,1985, pp.318

[27] Tai G.C.C., Estimation of General and Specific combinig abilities in Potato. Canadian Journal of Genetics and Cytology, 1976, 18(3), 463-470

[28] Thompson P.G., Mendoza H.A., Genetic variance estimates in heterogeneous potato populations propagated from true seed(TPS). Amer. Potato Journal, 1984, 61, 697-702