Colegio de Postgraduados

Effects of the combining ability on *mirador* chili (*Capsicum annuum* L.) populations native to Veracruz, Mexico

López-Benítez, Alfonso[1]; **Gayosso-Barragán, Odilon**[2*]; **Alcalá-Rico, Juan S.G.J.**[3]; **Chávez-Aguilar, Griselda**[2]; **Martínez-Osorio, Ana**[1]

[1] Universidad Autónoma Agraria Antonio Narro, Departamento de Fitomejoramiento, Buenavista, Saltillo, Coahuila, México, C.P. 25315.
[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Centro Nacional de Investigación Disciplinaria en Agricultura Familiar, Ojuelos de Jalisco, Jalisco, México, C.P. 47540.
[3] Campo Experimental Las Huastecas, Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarias, Altamira, Tamaulipas, México, C.P. 89610.
* Correspondence: gayosso_0188@yahoo.com.mx

ABSTRACT

Objective: To evaluate the effects of the general and specific combining abilities on the agronomic traits of the native populations of *mirador* chili and to identify potential genotypes for the genetic improvement of this crop.

Design/Methodology/Approach: The general and specific combining abilities were calculated to determine the agronomic traits and yield of five *mirador* chili populations, using Griffing's method 2, model I, which includes parental lines and direct crosses.

Results: The P1, P4, and P3 genotypes recorded the highest and positive values. They also recorded a significative difference regarding the general combining ability. Meanwhile, the P1×P5 and P4×P5 crosses recorded the highest specific combining ability values.

Study Limitations/Implications: We were not able to establish diverse evaluation environments and genomic selection studies using molecular markers.

Findings/Conclusions: Information about the yield potential of five *mirador* chili was generated. These results are important for the development of a genetic improvement program and for the selection of the method that will be used.

Keywords: genetic improvement, native populations, yield.

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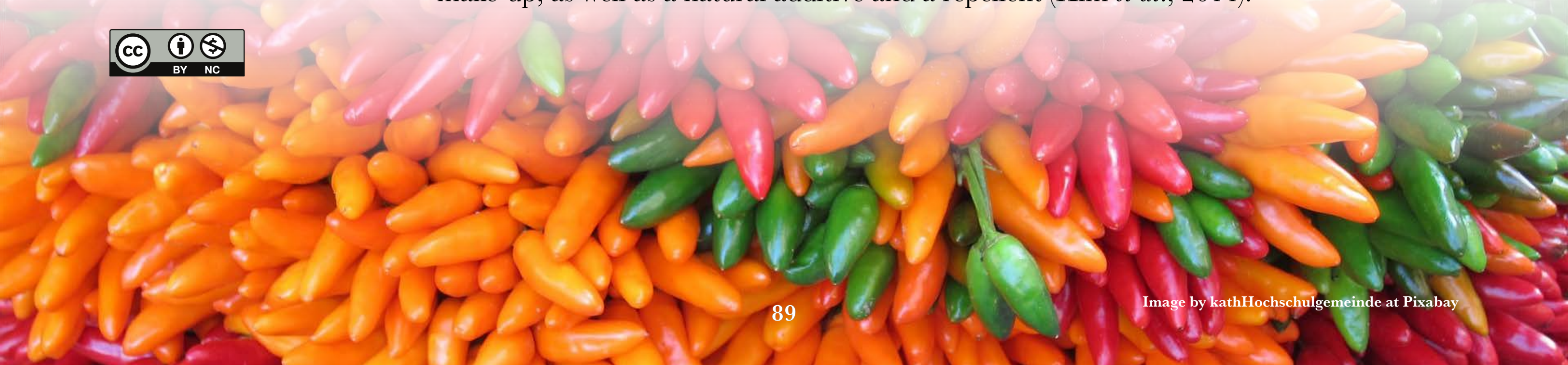
INTRODUCTION

Chili is an important crop worldwide, grown in tropical and subtropical areas. The genus *Capsicum* has a wide genetic diversity. It is made up of 38 species, including several worldwide domesticated species, such as *C. annuum*, *C. frutescens*, *C. baccatum*, *C. chinense*, and *C. pubescens* (Csilléry, 2006). Regarding its nutritional value, chili is an excellent source of essential vitamins, minerals, and nutrients, which make a major contribution to human health (Gupta *et al.*, 2019). Additionally, chili is used to manufacture pharmaceuticals and make-up, as well as a natural additive and a repellent (Kim *et al.*, 2014).



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Mexico is the center of origin, domestication, and diversification of *Capsicum annuum* L.; no other species is grown, produced, commercialized, and consumed more around the world (Kraft *et al.*, 2014). The importance of this crop in Mexico is the result of its great diversity of shape, color, flavor, aroma, and uses. For over 8,000 years, *Capsicum annuum* L. has been subjected to different selection and domestication processes by different human populations, using both wild and domesticated varieties, from the different subregions of Central and South America, including Mexico and Mesoamerica (Perry and Flannery, 2007). Different species and varieties of chili are grown in Mexico, including ancho, jalapeño, serrano, poblano, sweet red pepper, and *mirador*. The last chili is native to the middle Huasteca region of Veracruz, where it is grown in small areas, as monocrop or associated with corn. The plants are medium-sized (60-130 cm height). The plants bear erect or pendulous fruits that are 2.5-6.0 cm long and 0.6-2.0 cm wide (Ramírez *et al.*, 2018, Martínez, 2011).

The use of hybrid varieties is common among producers, as a result of their high yield (Muthumanickam and Anburani, 2017); consequently, the selection of inbred lines is a major step in an improvement program, because there is a huge opportunity to improve yield and fruit quality (Singh *et al.*, 2014). During the selection process of the inbred lines, the identification of heterotic groups and the analysis of the combining ability play an important role in chili cultivation improvement, allowing the selection of specimens with features of interest and a wide genetic variability (Hallauer and Miranda, 1981).

The combining ability of a genotype is its capacity to transfer a higher yield trait to its crosses (Thilak *et al.*, 2019). There are two types of combining abilities: general combining ability (GCA) and specific combining ability (SCA). Even before the beginning of the process, these two abilities are part of the genetic improvement. The GCA is mainly the consequence of the additive genetic action, while the SCA is the result of the non-additive genetic action (Singh, 2015). The analysis of the GCA enables the appropriate identification of the parental lines that can transmit their desirable characteristics. Meanwhile, the SCA allows to determine the outstanding F1 hybrid combinations, resulting from crosses between varieties or lines. Likewise, this type of analysis provides information about the type of genetic action that determines the expression of a characteristic, which is fundamental to identify which improvement method will be used.

The studies about GCA and SCA of the inbred lines have shown that the nature of the genetic action in the expression of a particular characteristic helps to identify the best crosses based on a parental line combination (De Sá Mendes *et al.*, 2019).

The objective of this study was to determine the general and specific combining abilities of agronomic traits in *mirador* chili native varieties and to identify potential genotypes for future genetic improvement programs.

MATERIALS AND METHODS

Vegetal material

Five *mirador* chili populations were collected in the state of Veracruz. Subsequently, along with their ten F1 potentially direct crosses, they were evaluated, using a diallel design, which involves their parents (Griffing's Method 2 (1956)). In order to carry out the hybridization process, the seeds were placed in 200-cell polystyrene boxes, filled with Peat-Moss commercial substratum (one seed per cavity). Forty days after the germination, the seedlings were planted in 4-L pots, following the regular agronomic handling recommended for this crop (Barrentes, 2010). They were placed under greenhouse conditions in the Universidad Autónoma Agraria Antonio Narro, in Buenavista, Saltillo, Coahuilla, Mexico (25° 21' 18" N and 101° 04' 48" W), at 1,781 m.a.s.l. Before the hybridization took place, the female flowers were emasculated and the pollen was extracted from the male flowers and carefully released on the stigma. To avoid cross-pollination, the female flowers were covered after the hybridization. Each cross was labelled with the name of the genotypes involved in the hybridization and the date in which it took place.

Establishment of the experiment in the field

Fifteen genotypes (parents and F1 crosses) were planted in a field using a random block experimental design, with four replicates. This procedure took place after the seedlings developed three or four true leaves and reached a height of 25 cm. The field was located in the Campo Experimental Las Huastecas of the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP) (22° 33' 59" N and 98° 09' 45" W), at 18 m.a.s.l. The experimental unit included five plants per 2-m long furrow, with 90 cm of separation between the furrows and 30 cm between plants.

Evaluated variables

Five plants with complete competence were evaluated per parent and cross. The following elements were recorded: days to flowering (DF), days to harvest (DH), plant height (PH), fruit diameter (FD), fruit length (FL), number of fruits (NF), and fruit weight (FW). DF was measured as the days from the transplant until 50 % of the plants blossomed (flowering stage). DH was the time when fruits reached their commercial ripeness. PH was measured from the base of the stem to the tallest part of the plant. The value of FD and FL was measured in cm. Finally, NF and FW were determined.

Genetic model

In order to calculate the general and specific combining abilities (GCA and SCA), the Griffing's method 2, model I was used (Griffing, 1956). This method includes parents and direct crosses, with $\left[p\left(p+1\right)\right]/2$ combinations. The following analytic model was used for the combining ability:

$$X_{ijk} = \mu + g_i + g_j + s_{ij} + b_k + \left(gb\right)_{ijk} + 1/bc\sum\sum e_{ijk}$$

Where: X_{ijk} = observed phenolic value; μ = general experimental mean; g_i and g_j = GCA effect of the parents; s_{ij} = SCA effect of the $i \times j$ ($s_{ij} = s_{ji}$) crosses; b_k = k block effect; $\left(gb\right)_{ijk}$ = effect of the interaction between the ij genotype and the k block; $1/bc\sum\sum e_{ijk}$ = residual effect of ijk.

Statistical analysis

The Dialel-SAS (Zhang and Kang, 2003) procedure of the SAS v. 9.0 statistical software was used to analyze the genetic effects of the GCA and the SCA.

RESULTS AND DISCUSSION

Diallel analysis

Highly significant differences ($p \leq 0.01$) were recorded regarding the genotypes and the general and specific combining abilities in all the evaluated characteristics (Table 1). The statistical difference shown by the genotypes can be a consequence of the genetic diversity of the evaluated populations. This difference leads to the identification of crosses with significative high yields. This result is important to measure the behavior of the agronomic traits in response to the hybrid combinations.

The statistical difference recorded for the GCA and SCA effects shows the importance of the additive and non-additive genetic effects in the evaluated variables, enabling the identification of those parental lines with the ability to transmit the desirable characteristics and the establishment of those outstanding F1 hybrid combinations. In addition, these values are an efficient tool for the appropriate selection of the improvement method to be used (Reyes *et al*., 2004).

Chakrabarty *et al.* (2019), Rodrigues *et al.* (2012), and Silva *et al.* (2017) recorded significative differences regarding the effect of GCA and SCA in the agronomic variables, using different chili parents and diverse evaluation environments. For their part, Ramesh *et al.* (2013) registered significatively high GCA and SCA values in chili, regarding the following characteristics: days to flowering, total yield, fruit length, fruit weight, plant height, pericarp thickness, number of seeds per fruit, and weight of 1,000 seeds. Meanwhile, Jindal *et al.* (2015) recorded significatively positive GCA and SCA dry matter, ascorbic acid, and capsaicin content. Finally, Rodrigues *et al.* (2012) recorded that fruit length, days to flowering, yield, number of fruits per plant, number of seeds per fruit, and fruit average weight had a significatively desirable GCA.

Effects of the general combining ability (GCA)

Table 2 shows the effects of the general combining ability in the fruit weight variable; the P1, P4, and P3 parents had the highest and positive values, with a significative

Table 1. Mean squares of the diallel analysis used to determine the yield characteristics of five *mirador* chili populations and their ten crosses.

Variation sources	Degree of freedom	Days to flowering	Days to harvest	Plant height	Fruit diameter	Fruit length	Number of fruits	Fruit weight
Repetitions	3	8.81 ns	19.39 ns	17.5 3 ns	0.01 ns	0.11 ns	631.51 ns	0.02 ns
Genotypes	14	329.34**	234.82**	190.03**	0.65**	1.03**	80682.7**	4.76**
GCA	4	93.12**	97.75**	196.02**	0.59**	0.95**	52451.58**	1.67**
SCA	9	423.83**	289.65**	187.63**	0.67**	1.06**	91975.19**	5.99**
R^2		95%	91%	57%	90%	75%	77%	70%

GCA (ACG): general combining ability; SCA (ACE): specific combining ability; *, ** Significative at 0.05 and 0.01 of probability, respectively, ns: not significative.

difference: 0.28, 0.06, and 0.05, respectively. P1 also obtained a positive and significative GCA regarding the diameter (0.08) and fruit length (0.31) variables. Likewise, P6 recorded positive and significative values for the fruit diameter variable (0.16). According to Zewdie and Bosland (2000), the GCA positive values can be understood as an expression of the variability found in the parents, which can be transmitted to their lineage.

In this study, P1 recorded outstanding characteristics, which can be taken into account as a good germplasm source for future improvement programs, as a result of the positive GCA values found in the fruit weight, plant height, fruit diameter, and fruit length variables. On the one hand, a low GCA value shows that the average of a parent in the cross with another parent does not vary much from the general average of the cross. On the other hand, a high GCA value shows that the average of the parents is higher or lower than the general average. Consequently, there is a strong proof of a desirable gene flux from parents to sons. This information about the concentration of mainly additive genes is highly relevant (Franco *et al.*, 2001). A high estimation of GCA indicates a higher inheritability and less environmental effects. It also can result in less genetic interactions and a higher selection gain (Topal *et al.*, 2004; Chigeza *et al.*, 2014).

On the one hand, a parent with outstanding agronomic traits may not necessarily produce the best hybrids during the hybridization process; on the other hand, if the other parent is appropriately selected, a parent with few outstanding agronomic traits can generate an appropriate combination (Bao *et al.*, 2009; Shukla and Pandey, 2008; Tyagi and Lal, 2005). Pessoa *et al.* (2021), Pech *et al.* (2010), and Hernández *et al.* (2021) recorded highly positive GCA values in the yield variables of several chili varieties. They also selected the genotypes with the highest potential to start an improvement program.

Effects of the specific combining ability (SCA)

According to Griffing (1956), the high absolute values of SCA indicate which parents were better or had a higher average than the GCA of both parents. In this study, the highest SCA values were recorded for the fruit weight variable, with the 1×5 and the 4×5 crosses, obtaining 1.61 and 1.36 values, respectively (Table 3). The specific combining ability reveals the best cross combination between genotypes for the development of hybrids with the desired characteristics. The results show that the right combinations can express those characteristics. The crosses with the highest fruit weight values can be the result of the additive effects of both parents and the interaction of the dominant alleles of one parent

Table 2. Effects of the general combining ability (GCA) on the agronomic traits of five parents of *mirador* chili.

Genotypes	Days to flowering	Days to harvest	Plant height	Fruit diameter	Fruit length	Number of fruits	Fruit weight
P1	0.53	−0.57	3.77	0.08*	0.31*	−20.67	0.28*
P2	1.53	2.20	0.74	−0.11	−0.12	13.71	−0.01
P3	0.85	0.95	−0.22	−0.18*	0.00	68.78	0.05*
P4	0.21	0.20	−0.75	0.16*	−0.05*	−20.07	0.06*
P5	−3.14	−2.79	−3.54	0.04	−0.14	−41.75	−0.38

Table 3. Effects of the specific combining ability (SCA) on the agronomic traits of ten crosses.

Crossing	Days to flowering	Days to harvest	Plant height	Fruit diameter	Fruit length	Number of fruits	Fruit weight
1×2	8.76	5.57	0.01	−0.21	0.19	−70.20	−0.55
1×3	−10.05	−8.17	10.22*	0.59*	0.71*	−45.02	0.54
1×4	−5.91	−3.17	10.26*	0.17	0.17	−124.16	−1.33
1×5	−2.30	−2.42	−0.45	0.19	0.28	110.51	1.61*
2×3	−11.55	−7.71	3.51	−0.09	−0.04	−260.91	−1.79
2×4	−8.66	−6.96	1.29	0.42*	0.71*	−4.30	0.30
2×5	−6.55	−6.46	1.58	0.45	−0.14	−56.38	0.19
3×4	5.26	4.53	3.51	−0.43	−0.74	−97.88	−0.29
3×5	−8.38	−5.21	−5.20	0.09	−0.37	118.29*	0.45
4×5	15.01*	15.53*	−2.16	0.29	0.25	116.90*	1.36

combined with recessive alleles of the other parent (Falconer, 1989). In the first case, the cross with highest SCA for the fruit weight variable was the result of crossing two parents with a high GCA (P1 and P3). Meanwhile, the second outstanding cross was the result of crossing a parent with a low GCA and a parent with a high GCA (P5 and P3). These results match the findings of Escorcia *et al.* (2010) and Guerrero *et al.* (2011), who pointed out that a simple cross can obtain a high yield if both parents or at least one of them have high GCA values and high positive SCA effects.

CONCLUSIONS

Information about the yield potential of five *mirador* chili populations was generated. This information can play a fundamental role in the development of genetic improvement programs and for the selection of the method that will be used. The P1, P4, and P3 parents obtained the highest and positive total fruit weight values, with significant differences regarding general combining ability, while the 1×5 and 4×5 crosses recorded the highest values regarding the specific combining ability.

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