COMBINING ABILITY AND HETEROSIS FOR FRUIT YIELD AND QUALITY IN MANZANO HOT PEPPER (*Capsicum pubescens* R & P) LANDRACES

M. Pérez-Grajales[1¶]; V. A. González-Hernández[2]; A. Peña-Lomelí[1]; J. Sahagún-Castellanos[1]

[1]Departamento de Fitotecnia, Universidad Autónoma Chapingo. Km. 38.5 Carretera México-Texcoco. Chapingo, Estado de México, C. P. 56230. MÉXICO. Correo-e: perezgm@hotmail.com ([¶] Autor responsable).
[2]Especialidad de Genética, Colegio de Postgraduados, Montecillo, Estado de México. C. P 56230. MÉXICO.

SUMMARY

Hybridization as a method for plant breeding may create improved varieties with higher fruit yield and quality by taking advantage of the combining ability and heterosis between the crossed parents. Six landrace varieties (five collected in Mexico and one in Peru) of manzano hot pepper (*Capsicum pubescens* R & P) and all their possible direct single crosses were evaluated, for heterosis and general and specific combining abilities (GCA and SCA) for fruit yield and quality. Plants were grown under greenhouse conditions and drip irrigated with a complete nutrient solution. Analyses for GCA, SCA and heterosis were based on the Griffing's fixed model of diallel design method II, and on analysis II of Gardner and Eberhart. Significant GCA effects were found for fruit yield, fruit volume, pericarp thickness, seed number and weight per fruit, and on locule number per fruit. The highest GCA values were registered in landrace 'Puebla'. The highest heterosis relative to the best parent was found in the cross 'Zongolica x Puebla' for fruit yield (51 %), in 'Peru x Chiapas' for fruit volume (33 %), in 'Puebla x Peru' for seed number (22 %), and in 'Puebla x Chiapas' for seed weight (38 %) and locule number (18 %). These hybrids also showed high SCA values. 'Puebla' was the best landrace as a parent in hybrids. It had the highest frequency of high yielding hybrids with high fruit volume and pericarp thickness, compared with the other five landraces. Thus, hybridization can be a useful method for breeding manzano hot pepper to exploit combining abilities and heterosis.

ADDITIONAL KEY WORDS: Plant breeding, chili pepper, vegetables.

APTITUD COMBINATORIA Y HETEROSIS EN RENDIMIENTO Y CALIDAD DE FRUTOS DE CHILE MANZANO (*Capsicum pubescens* R & P) CRIOLLO

RESUMEN

La hibridación como método de mejoramiento genético puede ser útil en la obtención de variedades de alto rendimiento y calidad de fruto, aprovechando la capacidad combinatoria y heterosis en el cruzamiento de progenitores. Se evaluaron seis variedades criollas (cinco colectadas en México y una en Perú) de chile manzano (*Capsicum pubescences* R y P) y todas sus posibles cruzas directas, en relación con la heterosis intervarietal y la aptitud combinatoria general y específica (ACG y ACE) para rendimiento y calidad de frutos. Tanto para las cruzas como para la evaluación de ellas, las plantas fueron cultivadas en invernadero de cristal con riego por goteo y solución nutritiva balanceada. El análisis de ACG, ACE y heterosis se basaron en el modelo fijo de Griffing método II y en el análisis II de Gardner y Eberhart. La ACG mostró efectos significativos en el rendimiento de fruto, volumen de fruto, grosor de pericarpio, peso y número de semillas por fruto, número de lóculos por fruto, y el valor más alto se registró en la variedad "Puebla". La mayor heterosis, en relación con el mejor progenitor, se encontró en la cruza 'Zongolica x Puebla' para rendimiento de fruto (51%), en 'Perú x Chiapas' para volumen de fruto (33 %), en 'Puebla x Perú' para número de semillas (22 %), y en 'Puebla x Chiapas' para peso de semillas (38 %) y número de lóculos (18 %). Estos híbridos también mostraron altos valores de ACE. "Puebla" fue el mejor progenitor, ya que generó el mayor número de híbridos de alto rendimiento, alto volumen de fruto y grosor de pericarpio, en comparación con los otros cinco progenitores. Por lo tanto, la hibridación es un método conveniente en el mejoramiento genético de chile manzano para explotar la ACE y heterosis.

PALABRAS CLAVE ADICIONALES: *Capsicum pubescens*, mejoramiento genético, heterosis varietal, heterosis específica.

Recibido: 31 de mayo, 2007
Aceptado: 10 de enero, 2008

INTRODUCTION

Vegetable breeding is still scarce in Mexico, most particularly in minor species. There is, however, the need to create better varieties with higher yield and quality to satisfy a growing demand. Manzano hot pepper (*Capsicum pubescens* R & P) is one of those minor vegetables lacking improved varieties. But modern production techniques with drip irrigation under greenhouse conditions (Pérez and Castro, 1998) and morphological characterization of Mexican landraces (Pérez *et al*., 2004), are already available for this crop. It is used mainly as a fresh vegetable and for hot sauces in the Mexican temperate regions where it is produced, but it is also exported to Los Angeles, USA.

According to Pérez *et a*l. (2004), the main traits describing the morphological variation in manzano hot pepper are fruit size, seed number per fruit and seed number per locule, days to fruit initiation, and flower number per node, because these are heterogeneous and polymorphic traits. Hybridization between contrasting genotypes of this species could produce a high heterotic response in fruit yield and size, as proposed by Falconer and Mackay (1996) and Márquez (1988). Knowledge of heterosis among parental landraces could be used for breeding manzano hot pepper by hybridization.

In crops, heterosis or hybrid vigor is usually expressed as an increase in grain yield or by a reduction in the number of days to flowering. According to Duvick (1999), heterosis in plants has been used on a large scale for the past 75 years, as carefully selected and reproduced hybrid cultivars. Field crops such as maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L. Moench) and sunflower (*Helianthus annuus* L.) are produced as hybrids in the industrialized world, and in increasing amounts in the developing world. Hybrid rice (*Oriza sativa* L.) is grown extensively in China, and increasingly in India (Virmani, 1994). Many commercial vegetable and flower crops are grown almost entirely as hybrids. Heterosis is credited for large increases in production per unit area, thus sparing large amounts of land for other uses (Duvick, 1999).

In a group of p parental varieties there will be p^2 progenies produced by single crosses among them, a mating strategy called a complete diallel design (Christie and Shattuck, 1992). This design may be used to determine general and specific combining abilities (GCA and SCA, respectively), as proposed by Griffing (1956), and also to estimate additive and dominant genetic effects, as indicated by Gardner and Eberhart (1966). GCA estimates the mean performance of one parent relative to all its hybrid combinations and indicates additive genetic effects. SCA measures the specific behavior of each hybrid relative to their corresponding parents and estimates dominant genetic effects (Sprague and Tatum, 1942). The Griffing (1956) method II includes p parents and their $p(p-1)/2$ hybrids, and provides information about GCA, SCA and heterosis, very useful parameters in a hybrid breeding program (Singh and Singh, 1984; Christie and Shattuck, 1992).

In this study we evaluated six manzano hot pepper landraces, five from Mexico and one from Peru, together with their 15 one-way single crosses, under a Griffing method II diallel design. The objective was to estimate the combining abilities of the six landraces as parents for hybrids and the intervarietal heterosis for fruit yield characteristics and quality with the hypothesis that hybridization could be a useful method for breeding manzano hot pepper.

MATERIALS AND METHODS

Agronomic management

The study was conducted during two consecutive growing seasons. The first one (May 2002 to February 2003) was for making the 15 direct single crosses or hybrids among the six parental landraces, and the second one (March 2003 to November 2003) for evaluating fruit yield and quality of both hybrids and parents. In the two seasons, plants were grown under greenhouse conditions at the Universidad Autonoma Chapingo, located in Chapingo, Mexico. Seedlings (60 days old) were transplanted to black polyethylene bags (40 cm in diameter x 45 cm high) containing red volcanic gravel as substrate (Pérez and Castro, 1998), and drip irrigated with a complete nutrient solution (Steiner, 1984). A black mesh shadecloth (50 % shading) was placed 2 m above the soil (550 ì $mol \cdot m^{-2} \cdot s^{-1}$; Pérez *et al*., 2004). The potted plants were 50 cm apart in rows separated by 80 cm, for a density of 25,000 plants per hectare. After subtracting the area of corridors (20 %), the actual density in the greenhouse was 20,000 plants per hectare.

Diallel design

Six manzano hot pepper landraces ('Zongolica', 'Huatusco I', 'Huatusco II', 'Puebla', 'Chiapas' and 'Peru'), described by Pérez *et al*. (2004), were used to obtain all possible one-way single crosses. For these crosses, the five best plants of each landrace were selected among the 60 plants established in the first growing season.

The 21 genotypes (15 hybrids + 6 parental varieties) were evaluated in the second growing season, under a completely randomized block experimental design with three replications. Each replication included 21 plants per genotype.

Measured variables

Mature fruit yield (g), fruit number per plant and fruit volume (ml) were measured in 30 plants per genotype (10 plants per replication), across three harvest dates 25 days apart. Pericarp thickness (mm), seed weight (g), seed number per fruit, and locule number per fruit, were measured

in 90 fruits per genotype (10 fruits x 3 plants x 3 replications).

Statistical analyses

General and specific combining abilities (GCA and SCA) mean squares were estimated by the quantitative genetic analyses corresponding to the fixed model of the partial diallel design method II (Griffing, 1956). The GCA and SCA effects were calculated with the algorithm developed by Burow and Coors (1994), a computer program that provides both the analysis of variance and the estimated values of GCA and SCA, based on the diallel design method II.

The analysis II proposed by Gardner and Eberhart (1966) was used to estimate several types of heterosis, as described by the model: $Y_{ij} = \mu_v + (v_i + v_j)/2 + \varphi h_{ij} = \mu_v + (v_i + v_j)/2 + \varphi (h + h_i + h_j + he_{ij})$, where Y_{ij} = mean of a parent when $i = j$, or mean of a single cross when $i \neq j$; μ_v = mean of all parents; v_i, v_j = effect of parent i or j, measured as deviation from μ_v, so that Σv_i or $\Sigma v_j = 0$; h_{ij} = heterosis of the cross $v_i v_j$, estimated as the difference between the cross and the average of its two parents, so that $\Sigma h_{ij} = 0$; h = mean heterosis, estimated by the difference between the average of all crosses and μ_v; h_i, h_j = mean heterosis of v_i or v_j in all crosses, also named varietal heterosis, measured as deviations from h, so that Σh_i or $\Sigma h_j = 0$; he_{ij} = specific heterosis of the cross $v_i v_j$, estimated as the difference $h_{ij} - (h+h_i+h_j)$, so that $\Sigma he_{ij} = 0$; φ = zero when $i = j$, or = 1 when $i \neq j$. Heterosis with respect to the best parent (h_{bp}) was estimated by the difference between the cross $v_i v_j$ and the highest parent mean.

Statistical significances for varietal heterosis were obtained by orthogonal contrasts between each parent and the average of all their hybrids (Steel and Torrie, 1960) with the option 'Contrast' in the General Linear Model procedure of SAS for Windows (SAS, 1996). To compare genotypic values of heterosis relative to the best parent (h_{bp}), the Tukey test for multiple means comparison was used (Steel and Torrie, 1960). This test was applied also to compare the genotype means in all measured variables. Pearson's correlation coefficients (SAS, 1996) between variables of fruit yield and quality were also calculated.

RESULTS

Analyses of variance and means comparisons

Significant GCA effects were detected for fruit yield per plant, fruit volume, and pericarp thickness, and significant SCA effects were found for six of the seven variables (Table 1). Coefficients of variance ranged from 5 to 10 %, which indicate low experimental errors and data consistency.

There were no significant differences among landraces for fruit yield (1.66 to 1.85 kg/plant), although they varied significantly for fruit number and volume (Table 2), probably due to a compensatory effect between number and size. For example, landrace 'Peru' produced the highest number of fruits (63) with the smallest size (31 ml), while landrace 'Puebla' formed the least amount of fruits (33) with the largest volume (78 ml). There were also significant differences among landraces in seed number (SN)and seed weight (SW) per fruit, but not in pericarp thickness (PT) or locule number (CN).

Although landraces were similar in fruit yield, hybrids varied significantly from 1.38 to 2.69 kg/plant (Table 2). The highest yielding hybrid was 'Zongolica x Puebla', due to its relatively high values of both fruit number (52) and fruit volume (70 ml), whereas the hybrids with the highest number of fruits (57, in 'Zongolica x Peru') or largest fruit size (90 ml, in 'Puebla x Peru') produced yields similar to those of their parents. Some hybrids, such as 'Huatusco I x Peru', produced fewer or smaller fruits than their parents, thus suggesting a low combining ability for fruit yield and those quality traits.

The best landrace for hybridization was 'Puebla' (Table

TABLE 1. Mean squares for fruit yield and quality traits for six varieties (landraces) of manzano hot pepper, as obtained by the analyses of variance of the fixed model of the diallel desing method II by Griffing (1956).

Source of Variation	Degrees of Freedom	Fruit Yield[y]	Fruit Number	Fruit Volume	Pericarp Thickness	Seed Number	Seed Weight	Locule Number
Crosses	20	169*	296,359*	767*	0.0041*	234*	0.1192*	0.1961*
GCA[z]	5	436*	472,723	2,316*	0.0120*	348	0.2270	0.3414
SCA	15	80*	237,571*	251*	0.0015	196*	0.0832*	0.1477*
Error	40	6	12,899	6.8	0.0006	19.8	0.0129	0.0222
VC (%)		5	6	5	5	7	10	5

Significance of the F test ($P \leq 0.05$)
[y]Fruit yield and fruit number were measured per plant. Seed number, seed weight and locule number were measured per fruit.
[z]GCA: general combining ability; SCA: specific combining ability; VC: coefficient of variability.

TABLE 2. Mean values of fruit yield and quality traits in six manzano hot pepper landraces and their 15 single hybrids.

[w]E	[x]Pi(♀)	Pj(♂)	Fruit yield (g/plant)	Fruit number per plant	Fruit volume (ml/fruit)	Pericarp thickness (mm)	Seed number per fruit	Seed weight (g/fruit)	Loculenumber per fruit
1	Zong[y]	Zong	1,775[z] e-j	47 c-f	60 d	4.8 b-e	74 ab	1.04 cd	3.1a-d
2	Zong	HuaII	1,538 ij	51 b-e	47 fgh	4.5 b-e	55 de	1.04 cd	2.7 de
3	Zong	Pue	2,687 a	52 bcd	70 c	5.2 ab	70 abc	1.31ad	3.3 ab
4	Zong	Hual	1,611 e-j	55 abc	46 gh	4.3 de	53 e	0.89 d	2.8 cde
5	Zong	Perú	1,734 e-j	57 ab	48 fgh	4.5 b-e	57 cde	1.03 cd	2.9 be
6	Zong	Chis	1,980 b-g	56 ab	54 def	4.8 b-e	61 b-e	1.15ad	2.6 e
7	HuaII	HuaII	1,774 e-j	47 c-f	46 gh	4.6 b-e	63 a-e	1.13ad	3.0 b-e
8	HuaII	Pue	2,371 ab	44 ef	79 b	5.2 ab	73 ab	1.32ad	3.2 abc
9	HuaII	Hual	1,582 hij	54 bcd	44 h	4.1 e	53 e	0.91d	2.9 b-e
10	HuaII	Perú	1,588 g-j	46 def	53 d-g	4.8 b-e	71 abc	1.31ad	2.5 e
11	HuaII	Chis	2,003 b-f	54 bcd	55 def	5.0 b-e	69 a-d	1.26ad	2.7 de
12	Pue	Pue	1,717 e-j	33 g	78 b	5.2 ab	63 a-e	1.14ad	3.0 b-e
13	Pue	Hual	2,249 bc	44 ef	77 bc	4.9 a-d	70 abc	1.32ad	3.3 abc
14	Pue	Perú	2,091 b-e	35 g	90 a	5.6 a	77 a	1.52ab	2.9 b-e
15	Pue	Chis	2,179 b-d	39 fg	84 ab	5.2 ab	69 abc	1.57a	3.5 a
16	Hual	Hual	1,665 f-j	56 ab	42 h	4.5 b-e	49 e	0.95 d	3.0 b-e
17	Hual	Perú	1,383 j	49 b-e	42 h	4.4 cde	52 e	1.01 cd	2.6 e
18	Hual	Chis	1,651 f-j	53 bcd	49 e-h	4.8 a-e	69 abc	1.26ad	2.9 b-e
19	Perú	Perú	1,778 f-j	63 a	31 I	4.6 b-e	49 e	0.92d	2.6 de
20	Perú	Chis	1,944 c-h	53 bcd	56 de	4.7 b-e	73 ab	1.43ac	3.0 be
21	Chis	Chis	1,850 d-i	51 bcd	53 d-g	5.1 abc	62 b-e	1.1 bd	3.0 be
	LSD	(%)	396	8.7	8	0.08	14	0.45	0.47

[z]Means (n = 3) with the same letter in a column are not statically different (Tukey, 0.05).
[y]Zong: 'Zongolica'; HuaII: 'Huatusco II'; Pue: 'Puebla'; Hual : 'Huatusco I'; Chis: 'Chiapas'.
[x]Pi: Parent *i*; Pj: Parent *j*.
[w]E: Entry.
LSD: least significant difference.

2) because all of its crosses produced big fruits (70 ml), high yields (2.0 kg/plant), thick pericarps (4.9 mm), a high number of seeds per fruit (63) and a high number of locules per fruit (2.9). That is, 'Puebla' seems to be the landrace with the largest dominant and overdominant effects in those traits, as proposed by Márquez (1988) for positive heterosis.

Genetic analyses of parents (landraces)

Fruit yield

For fruit yield only 'Puebla' and 'Chiapas' had positive and significant GCAs (Table 3). 'Puebla' showed the highest GCA for fruit yield as well as the highest varietal heterosis for both fruit yield and number. Mean heterosis for fruit yield, averaged over the six landraces, was significant and equivalent to an increase of 146 g/plant or 8 %, due to hybridization. Mean heterosis for fruit number was zero; similar results for fruit size were obtained by Peña *et al*. (1998) in *Physalis ixocarpa* Brot. The high values of varietal heterosis suggest that the non-additive genetic effects involved in fruit yield are important and that hybridization could be an useful technique for breeding manzano hot pepper.

Fruit quality

As in fruit yield, landrace 'Puebla' showed the highest GCA for fruit volume, pericarp thickness, seed number and weight, and locule number (Table 4). 'Puebla' surpassed the other landraces in varietal heterosis for seed and locule numbers per fruit, while for fruit size and seed weight the highest varietal heterosis was found in 'Peru', and for pericarp thickness in landrace 'Chiapas'. Therefore, non-additive genetic effects are important for these traits and may be used advantageously for crossbreeding manzano hot pepper. The mean heterosis values (across landraces) were significant for fruit volume, seed number and seed weight, and average gains of 13, 8 and 15 %, respectively, were achieved when hybrids among these landraces were formed.

Specific combining ability and hybrid heterosis

The highest SCA value for fruit yield (equivalent to 571 g/plant) was observed in 'Zongolica x Puebla', whereas for fruit quality the hybrid 'Puebla x Peru' showed the highest SCA values for fruit volume, pericarp thickness and seed number and weight (Table 5). Two hybrids, 'Huatusco II x

TABLE 3. Effects of general combining ability (GCA) and varietal heterosis (VH) for fruit yield and fruit number in six manzano hot pepper landraces.

Parental landraces	GCA		VH	
	Fruit yield (g/plant)	Fruit number per plant	Fruit yield (g/plant)	Fruit number per plant
'Zongolica'	6	2.3*	-11	7
'Huatusco II'	-53*	-0.4	-103	3
'Puebla'	245*	-8.4	452*	10
'Huatusco I'	-155*	2.6*	-116	-5
'Peru'	-94*	2.5*	-176	-15
'Chiapas'	51*	1.4*	-46	0
MH[z]			146*	0
MH (%)			8*	0

*Significant value ($P \leq 0.01$).
[z]MH: Mean heterosis.

Puebla' and 'Puebla x Huatusco I', combined positive and relatively high SCA values both for fruit yield and fruit quality. Ten hybrids had non-significant or negative SCA values for yield, thus lacking dominant and overdominant genic effects in this trait. Two hybrids, 'Puebla x Chiapas' and 'Zongolica x Huatusco II' had low SCA values for yield and the five quality traits.

As in the SCA results, the hybrids 'Zongolica x Puebla', 'Huatusco II x Puebla' and 'Puebla x Huatusco I', had the highest heterosis with respect to the best parent, with values of 51, 34 and 31 %, respectively, for fruit yield (Table 6). However, no hybrid showed significant positive heterosis for fruit number. Instead, the hybrid 'Puebla x Perú' had negative heterosis in fruit number (-44 %) but positive

TABLE 4. Effects of specific combining ability (SCA) and varietal heterosis (VH) in six manzano hot pepper landraces regarding variables of fruit quality.

Parental landrace	SCA					VH				
	FV[y]	PT	SN	SW	LN	FV	PT	SN	SW	N
Zong[z]	-2.07*	-0.009*	0.03	-0.08*	0.01	-15.0	-0.014	-18.4	-0.116	-0.234
HuaII	-3.81*	-0.010*	0.36	-0.01*	-0.04	1.8	0.012	-4.2	-0.142	-0.180
Pue	19.25*	0.03*	5.06*	0.01*	0.21*	-6.0	0.002	12.0	0.086	0.236
HuaI	-7.15*	-0.025*	-6.04*	-0.11*	-0.00	1.6	0.000	3.8	-0.052	-0.096
Peru	-6.45*	-0.005	-1.96*	-0.00	-0.14*	19.0	-0.020	5.4	0.170	0.094
Chis	0.24	0.013*	2.54*	-0.08*	-0.03	-1.4	0.020	1.2	0.054	0.180
MH						8*	0.0	5*	0.18*	0.05
MH (%)						13*	0	8*	15*	2

[z]Zong: 'Zongolica'; HuaII: 'Huatusco II'; Pue: 'Puebla'; HuaI: 'Huatusco I'; Chis: 'Chiapas'.
[y]FV: Fruit Volume; PT: Pericarp Thickness; SN: Seed Number per fruit; SW: Seed Weight per fruit; LN: Number of Locules per fruit; MH: Mean Heterosis.
*Significant value ($P \leq 0.01$).

TABLE 5. Effects of specific combining ability (SCA) in 15 intervarietal hybrids formed among six parental landraces of manzano hot pepper.

Hybrid	Fruit yield ($g \cdot plant^{-1}$)	Fruit Number	Fruit Volume ($ml \cdot fruit^{-1}$)	Pericarp Thickness (mm)	Seed Number	Seed Weight ($g \cdot fruit^{-1}$)	Locule Number
[z]Zong x HuaII	-280 *	-0.08	-4.17*	-0.007	-8.96*	-0.032	-0.178*
Zong x Pue	571 *	8.56*	-4.90*	-0.014	1.45	0.084	0.158*
Zong x HuaI	-104	0.46	-1.64	-0.012	-4.66*	-0.077	-0.100
Zong x Perú	-42	2.78*	-1.11	-0.015	-4.46*	-0.044	0.067
Zong x Chis	-43	-4.42*	5.38*	0.006	5.85*	0.026	-0.112
HuaII x Pue	314*	3.20*	6.47*	0.015	4.04*	0.019	0.157*
HuaII x HuaI	-74	2.17	-1.84	-0.03*	-4.50*	-0.138*	-0.004
HuaII x Perú	-130*	-5.47*	5.68*	0.015	9.06*	0.159*	-0.170*
HuaII x Chis	155*	1.9	-2.60	0.010	1.28	0.003	0.021
Pue x HuaI	295*	0.28	7.80*	0.000	7.18*	0.121*	0.141*
Pue x Perú	77	-8.56*	19.93*	0.047*	10.11*	0.220*	-0.070
Pue x Chis	-619*	-3.70*	-11.20	-0.004	-12.32*	-0.135*	0.003
HuaI x Perú	-231*	-5.40*	-1.35	-0.012	-3.20	-0.038	-0.156*
HuaI x Chis	-186*	-7.04*	-2.42	0.030*	-1.35	0.132*	-0.152*
Perú x Chis	225*	8.11*	-9.3*	-0.02*	-1.35	-0.057	0.304*

*Significant value ($P \leq 0.05$).
[z]Zong: 'Zongolica'; Pue: 'Puebla'; HuaI and HuaII: 'Huatusco I and II'; Chis: 'Chiapas'.

TABLE 6. Heterosis with respect to the best parent of 15 intervarietal hybrids of manzano hot pepper.

Hybrid	Fruit yield (g·plant^{-1})	Fruit number	Fruit volume (ml·fruit^{-1})	Pericarp thickness (mm)	Seed number (n·fruit^{-1})	Seed weight (g·fruit^{-1})	Locule number (n·fruit^{-1})
[z]Zong x HuaII	-13	9	-22	-6	-26*	-8	-13
Zong x Pue	51*	11	-10	0	-5	14	6
Zong x HuaI	-9	-2	-23	-17*	-28*	-14	-9
Zong x Perú	-2	-10	-20	-13	-23*	-6	-8
Zong x Chis	7	10	-10	-6	-18	5	-16
HuaII x Pue	34*	-6	1	0	16	16	8
HuaII x HuaI	-11	-4	-4	4	-16	-19	-5
HuaII x Perú	-11	-27	15	9	13	16	-15
HuaI x Chis	8	6	4	-2	9	12	-11
Pue x HuaI	31*	-21	-1	-6	11	16	11
Pue x Perú	18	-44*	15	8	22*	33*	-1
Pue x Chis	18	-24	8	0	10	38*	18*
HuaI x Perú	-22	-22	0	-2	6	6	-12
HuaI x Chis	-11	-5	6	-6	11	15	-2
Perú x Chis	5	-16	33*	-8	18	30*	11

*Significant value ($P \leq 0.05$).
[z]Zong:'Zongolica'; Pue: 'Puebla'; HuaI and HuaII: 'Huatusco I and II'; Chis: 'Chiapas'.

and significant heterosis in seed number and seed weight, with values of 22 and 33 %, respectively; these two traits are desirable for higher yield and seed production. Regarding fruit volume, only the hybrid 'Perú x Chiapas' showed a positive and significant heterosis. There was no heterosis for pericarp thickness, and only the hybrid 'Puebla x Chiapas' had a positive and significant heterosis for locule number.

DISCUSSION

Two landraces, 'Puebla' and 'Chiapas', showed a positive and significant general combining ability for fruit yield and for at least two quality traits. Three hybrids, 'Zongolica x Puebla', 'Huatusco II x Puebla' and 'Puebla x Huatusco I', had positive and significant values of both specific combining ability and heterosis relative to the best parent for fruit yield, while for fruit quality the hybrid 'Peru x Chiapas' had the best heterotic values in fruit volume and seed weight. These results demonstrate that hybridization may be a convenient breeding method for manzano hot pepper because it would take advantage of the high values in combining ability and heterosis for fruit yield and quality traits.

The highest fruit yield was produced by the hybrid 'Zongolica x Puebla', and the best fruit quality was found in the hybrid 'Puebla x Perú'. It was not possible in this work to combine the highest fruit yield with the highest fruit quality in a single hybrid. This goal may be achieved through a backcross breeding program. In fact, parental fruit yields obtained from selected plants in the previous generation were at least triple the yield of the same landraces without selection (Pérez *et al*., 2004).

'Puebla' is the best landrace for intervarietal hybrids of manzano hot pepper, because it combines better with the other landraces in direct crosses and exploits the non-additive effects of the genes involved in fruit yield and fruit quality, as suggested by McArdle and Bouwcamp (1983). The additive effects of genes may also be exploited by selection techniques to breed this specie, particularly for fruit volume, pericarp thickness and other fruit quality traits, because these traits show a low frequency of positive heterosis and specific combining ability. 'Puebla' and 'Peru' would be the best landraces for breeding manzano hot pepper by recurrent selection or for producing inbred lines with high fruit quality.

Since fruit volume and seed number correlated with fruit yield (r = 0.68 and 0.60, respectively), these characteristics might be used as selection criteria for increasing fruit yield in manzano hot pepper. The high correlation between yield and seed number suggests the necessity to secure ovule pollination when growing this species, mainly under greenhouse conditions where populations of pollinating insects may be not sufficient (Pérez and Castro, 1998).

A non significant correlation (r = -0.24) was found between fruit yield and fruit number, while correlation between yield and fruit volume was positive and significant (r = 0.68). Fruit size appears as the most important yield component in manzano hot pepper. In addition, fruit number was negatively correlated with all the fruit quality variables. Rylsky (1973) also found a direct linear relation between the number of seeds per fruit and final fruit size. Conditions which negatively influence overall plant growth can reduce the fruit size. As fruit number per plant increases, the size of individual

fruits tends to be smaller (Wien, 1997). Conversely, restricting fruit set allows the plant to develop the retained fruits to a larger size (Rylski and Spigelman, 1986).

CONCLUSIONS

Significant values of heterosis (relative to the best parent in the cross) were found in some intervarietal hybrids of manzano hot peppers. Heterosis was highest in 'Zongolica x Puebla' for fruit yield (51 %), in 'Peru x Chiapas' for fruit volume (33 %), in 'Puebla x Peru' for number of seeds per fruit (22 %), and in 'Puebla x Chiapas' for seed weight (38%) and locule number (18 %). These hybrids also showed high values of specific combining ability. Therefore, it may be useful to breed manzano hot pepper by hybridization in order to exploit its heterotic responses.

'Puebla' was the best parent in this study because it produced the highest frequency of high yielding hybrids of good fruit quality when crossed with the other five landraces. Fruit volume was more important than fruit number as a yield component.

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