Article

Agronomic and nutraceutical behavior of F2 populations developed of interracial crosses of pepper

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Abstract

Every day it is more difficult to satisfy the world food demand, for this reason the importance of working in the development of new varieties of high yield and fruit quality, taking advantage of the genetic resources of Mexico, for the development and use of superior varieties that allow to reduce the production costs of protected agriculture systems since, in Mexico in these systems a significant percentage comes from foreign companies at high costs. However, small producers sow creole seed of low yield and fruit quality. In this work, the RTF and its components (NFP, PPF), in addition to some quality characters (CAA, CT and CAPs) and agronomic (ADP, DBT, DAF, and DAC) of nine pepper hybrids in their F2 generations and their respective parents, which were established in a greenhouse, under an experimental design complete random blocks with three replications. The variance analyzes exhibited significant differences ($p< 0.01$) between parents and F2 populations in all the variables studied. In RTF, the F2 populations ($P_{1,7}$ and $P_{3,4}$) exceeded their F1 by 7 and 5% respectively, the latter being the one that presented the highest RTF in this generation with 2 764 g plant^{-1}. All F2 populations presented intermediate amounts and positive values in DEP in CT, CAA and CAPs. Concluding that in the F2 generation there were promising populations for the development of new varieties, since they increased yield and fruit quality from F1 to F2, with an estimated yield greater than 100 t ha^{-1}.

Reception date: November 2020
Acceptance date: January 2021

Introduction

At present, world agriculture faces serious problems, such as rapid population growth, the increasingly unpredictable climate, increasing urbanization and land degradation, are the main factors that affect and make it increasingly difficult to meet the global food demand (Lenaerts *et al*., 2019).

For this reason, the need arises to work on genetic improvement to develop new varieties, with greater adaptation to these conditions, in order to obtain high-yield cultivars and high fruit quality, for this genetic improvement continues to be the starting point more insurance and the best strategy to achieve a medium-term solution to the main problems of low crop yields (García *et al*., 2003).

Mexico is considered one of the largest producers of pepper (*Capsicum annuum*), occupying the second place in production with 157 540 ha of planted area, generating 3 239 318 t, it also ranks first as an exporter worldwide (SIAP-SAGARPA, 2018). It is a crop of great economic, social and productive relevance in the country, with more than 12 thousand producers throughout the Mexican Republic who dedicate to this crop generating up to 30 million wages per year.

For 2019, the crop generated foreign exchange for 985 million dollars, this due to large consumption, reporting up to 18.1 kilogram per capita per year (SIAP-SAGARPA, 2018). However, despite the continuous growth of the crop both in production and in planted area, the market demand, which is increasingly high and demanding, is not being satisfied. While the yields are still low in relation to the productive potential of the species.

Currently, the average yield of green pepper, mainly serrano, jalapeño or ancho type at the national level is 20.63 t ha^{-1} (SIAP-SAGARPA, 2018) and the state of Sinaloa is the one with the highest productivity with 39 t ha^{-1}, due to its technification, although it is considered low, since at an experimental level yields of 48.8 t ha^{-1} (Inzunza *et al*., 2007) and up to 65.4 t ha^{-1} (Duarte *et al*., 2012) are reported, suggesting that the crop it has greater potential, but work on it is required to optimize it.

In addition to this, the pepper faces other problems related to the limited supply of national cultivars with greater adaptability to horticultural agroecosystems and the hybrid seed comes from transnational companies at very high costs Hernández-Leal *et al*. (2013), which forces producers to use seed from subsequent generations (F2 or F3) derived from commercial hybrids to reduce costs, under the assumption that the yield and quality of the fruit is not diminished in those subsidiary generations.

Although F2 is a segregating generation, when the farmer sows this seed, the resulting plants differ from each other, which implies drawbacks, such as drastic reduction in productivity, reduction in resistance to insects and diseases, uneven maturation and lower quality industrial among others (De Miranda and Anderson, 2001).

In addition, in autogamous species, the segregation in the hybrid's F2 induces a reduction in the yield and quality of the fruit, because the degree of heterozygosity is reduced by half Poehlman and Allen (2003). Likewise, inbreeding depression or loss of adaptation and vigor of genotypes is induced (Jarne and Charlesworth, 1993).

Based on the problem of low availability of varieties of pepper with high yield and fruit quality, the general objective of this work was to select F2 populations of interracial crosses, high yield and fruit quality, to satisfy the current demand for this fruit. Under the hypothesis that in the studied F2 populations, outstanding materials will be identified.

Materials and methods

This work was carried out at the Autonomous Agrarian University Antonio Narro (UAAAN), located at 25° 21’ 19” north latitude, 101 01’ 48” west longitude, at an altitude of 1 779 masl in Buenavista, Saltillo, Coahuila (SMN, 2018) during the summer of 2017.

The plant material used were 17 genotypes (8 parents and 9 F2 populations) of different types of *Capsicum annuum* described in Table 1.

Table 1. Genetic material used: parents, F1 hybrids and F2 populations derived from crosses between the parents of *C. annuum*.

Genotypes	Description	
Female Parents		
P_1. UANJal	Jalapeño type dark green	
P_2. Creole Mirador	Mirador type of the state of Veracruz	
P_3. Tampiqueño 74	Serrano type of commercial origin	
Male Parents		
P_4. UANOg	Orange pepper of origin selection	
P_5. UANRd	Red pepper of origin selection	
P_6. UANShw	Green pepper, high vigor	
P_7. UANYw	Yellow pepper of selection origin	
P_8. UANCn	Well-behaved green pepper in open ground	
Hybrids F1	Description	F2 populations derived from F1
P_1xP_4	Crosses UANJal x UANOg	$P_{1,4}$
P_1xP_5	Crosses UANJal x UANRd	$P_{1,5}$
P_1xP_6	Crosses UANJal x UANSHw	$P_{1,6}$
P_1xP_7	Crosses UANJal x UANYw	$P_{1,7}$
P_2xP_4	Crosses Mirador x UANOg	$P_{2,4}$
P_2xP_5	Crosses Mirador x UANRd	$P_{2,5}$
P_2xP_6	Crosses Mirador x UANSHw	$P_{2,6}$
P_3xP_4	Crosses Serrano x UANOg	$P_{3,4}$
P_3xP_8	Crosses Serrano x UANCn	$P_{3,8}$

Description based on the characteristics of the genotypes.

The agronomic evaluation was carried out in a multi-tunnel type greenhouse with a plastic cover, which has extractors, heaters, a humid wall and temperature control, registering minimums of 18 °C and maximums of 36 °C and an average relative humidity of 60%.

Establishment and management of progenitors and populations derived from F_1

The seed of the parents and of the populations derived from the resulting crosses of the first generation, was extracted and conditioned for sowing on May 10, 2017. The seed of the 17 genotypes was sown in polystyrene trays of 200 cavities, depositing two to three seeds per cavity, using as substrate Peat (Premier Sphagnum Peat Moss, from Angeles Millwork & Lumber Co) and mineral perlite (Hortiperl from Termolite) in a 70:30 ratio respectively.

At 50 days after sowing, the transplant was carried out in beds with white plastic padding and a strip for localized irrigation, the beds with 25 cm high and a separation of 1.60 m and 30 cm between plants, establishing a double row in a staggered pattern, resulting in a plantation density of 41 667 plants ha^{-1}. Two-stem pruning and Dutch-type tutoring were carried out. The initial drip irrigation was 0.5 L plant^{-1} day^{-1}, with a gradual increase to 3.5 L plant^{-1} day^{-1}, the nutrition was based on a nutrient solution proposed by Steiner (1984) applied to irrigation water, modifying it throughout the crop cycle according to the phenological stages of the genotypes.

A sanitary control and foliar applications were carried out to correct any type of deficiencies. The work was established under a randomized block experimental design with three repetitions. Each experimental plot consisted of 12 plants. Irrigation was carried out every third or fourth day depending on the needs of the crop, foliar fertilizer was applied to correct deficiencies due to some nutritional element. A sanitary control was carried out applying biweekly active ingredients such as Imidacoprid, abamectin, thiamethoxam, chlorpyrifos, among others, against white fly, paratrioza, jumping aphid and thrips, in addition to *Bacillus subtilis* and *Trichoderma harzianum* against fungal diseases.

Yield and yield components

The variables evaluated were: total fruit yield (RTF) in kg, adding the weight of fruit obtained throughout the crop cycle, the average fruit weight (PPF) in grams and the total number of fruits per plant (NFP) was estimated by counting all the fruits harvested throughout the production cycle and divided by the number of plants harvested. The three variables were estimated from a random sample of 12 plants in each one of the treatments and in the three repetitions in twenty cuts at intervals of 10 to 11 days.

Fruit quality measurements

The fruit quality variables were determined in fresh fruits, in the Laboratory of Plant Nutrition and Tissue Culture of the Department of Horticulture of the UAAAN. The content of ascorbic acid (CAA) in the fruits of the parents and F2 populations was estimated using the AOAC (2000) methodology by means of color change titration.

For the quantification of total carotenes (CT), the technique described by Silverstein *et al*. (1998), based on the colorimetric method, with a Genesys 10S UV-Vis spectrophotometer (Thermo Scientific, Waltham, MA USA 0245.1) which was adjusted to a wavelength of 454 nm to quantify the absorbance of the analyzed samples, which were read in triplicate and the content was obtained by the following formula: $\text{mg}/\,0.1\ \text{kg} = \frac{\%\ \text{ABS}_{454}\ \times 3{,}85 \times \text{V} \times 100}{\text{P}}$. Where: %Abs454= percentage of absorbance at 454 nm; V= volume measured in the specimen; P= weight of the sample in grams.

The quantification of the content of capsicinoids (CAPs) was determined in pepper fruits in the stage of physiological maturity by the method described by Bennett and Kirby (1968), in a Bio-145025 BIOMATE-5 spectrophotometer (Thermo Electron Corporation, Madison, USA) at a wavelength of 286 nm. To determine the concentration of capsaicin in the samples, a calibration curve of this compound (Sigma, Co.) was constructed within a range of 0 to 1.2 mg ml^{-1}. The readings were made in triplicate for each sample and the capsaicin content was expressed in Scoville units (SHU).

Estimation of agronomic variables

To estimate the days to flowering (DAF) and days to harvest (DAC), the days from transplanting to the first flowering and the first fruit harvest were counted. Plant height (ADP) was measured with a tape measure, at the end of the production cycle (240 ddt), it was taken from the base of the stem to the apex of the plant. The basal stem diameter (DBT) was measured at 3 cm above the soil surface with an Autotec digital Vernier.

Statistical analysis

For each variable, an analysis of variance and a comparison of means were performed using the Tukey test ($p \leq 0.01$) using the statistical program SAS® V. 9.0 (SAS Institute Inc., 2002). The statistical model was in accordance with the experimental design of complete random blocks, using the general linear model (PROC GLM). Inbreeding depression (DEP, in%) was estimated with the averages of the differences (F_1-F_2) /F_1, expressed in percentage, and multiplied by (-1) to indicate a decrease in the magnitude of the variable to be evaluated (Hernández-Leal *et al*., 2013).

Results and discussion

Yield and yield components

The analysis of variance applied to parents and F2 populations, exhibited significant differences ($p < 0.01$) between genotypes in RTF, NFP and PPF. The comparison of means (Table 2) shows that the populations F2, $P_{1,\,5}$ and $P_{3,\,4}$ were the ones that presented the highest yield per plant with 2 735.5 and 2764.0 g pl^{-1} respectively.

Table 2. Mean values of plant yield components, in parents and F2 populations of *C. annuum*.

Genotypes	RTO (g plant^{-1})	NFP	PPF (g)
P_1. Jalapeño	1 095 abc	90.3 abc	14.77 f
P_2. Mirador	412.6 c	77.72 bcd	11.35 f
P_3. Serrano	972.9 bc	154.67 a	8.28 f

Genotypes	RTO (g plant^{-1})	NFP	PPF (g)
P_4. UANOg	1 708.9 abc	14.56 d	124.16 b
P_5. UANRd	1 661 abc	13.67 d	142.54 b
P_6. UANShw	1 882.5 abc	11.31 d	197.44 a
P_7. UANYw	2 312.2 ab	18.53 cd	148.66 b
P_8. UANCn	1 542.3 abc	15.67 d	142.67 b
$P_{1, 4}$	2 520.9 ab	47.44 bcd	52.83 d
$P_{1, 5}$	2 735.5 a	40.67 bcd	78.59 c
$P_{1, 6}$	1 338.2 abc	53.67 bcd	21.25 ef
$P_{1, 7}$	2 123.4 abc	48.64 bcd	41.77 de
$P_{2, 4}$	1 926.9 abc	47.89 bcd	30.92 def
$P_{2, 5}$	1 737.1 abc	55.08 bcd	30.17 def
$P_{2, 6}$	2 723.2 ab	100 ab	28.18 def
$P_{3, 4}$	2 764 a	95 ab	26.17 ef
$P_{3, 8}$	2 675.5 ab	93.5 ab	27.8 def
DMS	1 759.2	133.21	25.48

Elaboration based on field data.

The aforementioned populations were significantly superior to the maternal and paternal parents under study; however, they do not differ significantly from the rest of the F2 populations, even so, they are promising for the development of varieties of Jalapeño and Serrano pepper. The genotype that presented the lowest RTF was $P_{1, 6}$ with a yield of 1 338.2 g pl^{-1}. It should be noted that there are differences compared to its first filial generation (F1), due to the fact that most of the F2 populations show a loss of vigor, clearly caused by homozygosity (Table 3).

Table 3. Mean yield values and inbreeding depression in F2 populations of *Capsicum annuum* observed in two daughter generations.

Genotypes	RTF 2017 (g plant^{-1}) 2016-2017	RTF 2018 (g plant^{-1})	Depression DEP (%) Endogamic (DE%)
P_1. Jalapeño	1098 bc	1 095 abc	-0.3
P_2. Mirador	551 c	412 c	-25.1
P_3 Serrano	831 c	972 bc	17.1
P_4. UANOG	1 664 bc	1 708 abc	2.7
P_5. UANRD	1 482 bc	1 661 abc	12.1
P_6. UANSHW	1 243 bc	1 882 abc	51.4
P_7. UANYW	1 293 bc	2 312 ab	78.8
P_8. UANCN	1 227 bc	1 542 abc	25.7
	F1	F2	
P_1xP_4	2 586 abc	2 520 ab	-2.5
P_1xP_5	3 584 a	2 735 a	-23.7
P_1xP_6	2 991 ab	1 338 abc	-55.3

Genotypes	RTF 2017 (g plant^{-1}) 2016-2017	RTF 2018 (g plant^{-1})	Depression DEP (%) Endogamic (DE%)
P_1xP_7	1 980 abc	2 123 abc	7.2
P_2xP_4	2 764 abc	1 926 abc	-30.3
P_2xP_5	2 828 abc	1 737 abc	-38.6
P_2xP_6	3 247 a	2 723 a	-16.1
P_3xP_4	2 633 abc	2 764 a	5
P_3xP_8	2 781 abc	2 675 ab	-3.8

Elaboration based on field data.

The results obtained allow to indicate that the generational advance, caused inbreeding depression, which resulted in the decrease of the average yield of the F2 populations in 19.1% compared to their F1; however, the maximum yields of 2 764 g pl^{-1}, obtained from the population F2($P_{3,\ 4}$) with a density of 41 667 plants ha^{-1}, allowed to estimate yields of up to 115 167 t ha^{-1}, where even having 10% of failures or 10% of non-usable space exceed 100 t ha^{-1}, therefore the F2 populations ($P_{1,\ 5}$; $P_{2,\ 6}$; $P_{3,\ 4}$ and $P_{3,\ 8}$) are considered promising for commercial production In protected environments, this characteristic is maintained in the segregating F2 generation, so that small pepper producers could use the F2 seed for commercial plantings, without the fruits significantly detracting from the yield, although morphological variability was observed, which is why recommends continuing to work with the advancement of filial generations in order to standardize these characteristics.

These results coincide with Gaytán-Bautista *et al*. (2009) in the cultivation of corn, who mentions that the generational advance from F1 to F2 reduced the average yield of corn grain and dry forage by 22 and 8%, respectively, in 22 commercial hybrids studied. In this sense, Hernández-Leal *et al*. (2013) mentions that the yield reduction in the F2 generations in saladette tomato was minimal, when evaluating seven commercial genotypes and their respective F2, finding DEP for total weight between 17.5 and 66.1%, which suggests that the inbred depression of one generation F2 depends particularly on the genetic makeup of the lines that have given rise to the commercial hybrid.

In this research, the highest DEP observed was -55.3%, which according to what was indicated by Hernández-Leal *et al*. (2013) is minimal, it is also important to note that the populations $P_{1,7}$ and $P_{3,4}$ did not show PED, they exhibited an increase of 7.22 and 5% respectively in RTF when going from F1 to F2 (Table 3), this also it may be due to the fact that the genotypes adapted well to the greenhouse conditions, although heterozygosity was reduced, which efficiently exploits hybrid vigor, coinciding with Martínez *et al*. (2010); Duarte *et al*. (2012). These authors mentioned that the plants studied under controlled conditions favor the expression of genes related to fruit yield or that the inbreeding depression in autogamous species is relatively small compared to what would be expected in cross-pollinated species (Charlesworth and Charlesworth, 1987), this is because in self-pollinated species the self-fertilization process has a purifying effect of deleterious recessive alleles.

It should be noted that together with the improvement and selection of hybrids and their respective F2 populations, progress was also made in the improvement of the parents originally used, as mentioned in (Table 3) that the parents do not present an adverse effect due to inbreeding depression, on the contrary, with the exception of P2 (Mirador), all present positive PED values, which indicates that as generational advances they adapt better to the protected environment or progress was made in the intra-family selection process that led to the selection of the best individuals within each family, reducing genetic variability but conserving the best individuals.

An important component of yield is the number of fruits per plant. Table 2 shows that the Tampiqueño maternal parent has a greater quantity of fruits per plant; however, it should be noted that the average weight of these fruits is 8.28 g, therefore the total yield is low; however, in the same statistical group are the populations F2, $P_{3,\ 4}$ and $P_{3,\ 8}$, which share the Tampiqueño as a maternal parent, which indicates that said parent is very productive, a characteristic that was inherited from their descendants who in this case they presented 95 and 93.5 fruits per plant respectively.

The average NFP of the female parents is 107.5, the male parents 14.7 and the F2 populations is 64.6, so it can be observed that they have an increasing trend compared to their paternal parents; however, they do not reach the NFP of the maternal parents, but they do exceed their PPF. The F2 $P_{2,6}$ population stands out in the NFP with 100 fruits per plant, however, it does not exceed the average of the female parents, but that of the male parents in 85%, therefore, this segregating that also presents low depression inbred, it may be one of the most promising for the development of a new variety of *C. annuum* for greenhouse production.

The results indicate that there was high production of fruits, with respect to the paternal parents. Researchers such as May *et al*. (2010) report that they obtained from 5.8 to 12.2 pepper fruits per plant and in this investigation, they were obtained from 11.31 to 18.5, which represents more than 51% the highest value recorded.

For the PPF variable, it was found that the male parents continue to show the highest weights as expected; however, the UANShw, had a value of 197.44 and was significantly higher than the rest of the male parents, the female parents and the F2 populations. The PPF of female parents was 11.46 g while of the male parents 151.09 g and the F2 populations have an average of 37.52 g. The progeny is outside the range of both parents for this characteristic, this great difference may be due to the fact that transgressive segregation can be very common in some self-pollinated species such as pepper and tomato.

Fruit quality

The analysis of variance applied to the fruit quality variables, show significant differences between parents and F2 populations ($p \leq 0.01$). Regarding the content of CT, the comparison of means (Table 4) shows that the populations $P_{2,\ 4,}$ $P_{2,\ 5}$ and $P_{2,\ 6,}$ were significantly higher than the rest of the F2 populations, and parents, where the mean of the three F2 indicated exceeded the female parents by 320.9% and the male parents by 249.9%.

Table 4. Mean values of fruit quality variables of parents and F2 populations of *Capsicum annuum*.

Genotypes	CT (mg/0.1 kg)	CAA (mg/0.1 kg)	CAPs (SHU)
P_1. Jalapeño	1 121.5 g	97.900 g	12 706.1 b
P_2. Mirador	1 363.8 fg	92.833 g	12 697.2 b
P_3. Serrano	1 750.4 ef	121.333 f	14 531.7 a
P_4. UANOg	1 291.8 fg	136.633 def	963.6 h
P_5. UANRd	1 195.3 g	137.467 def	832.1 h
P_6. UANShw	1 976.4 e	172.8 ab	764.5 h
P_7. UANYw	2 105.7 e	158.633 bc	557.3 h
P_8. UANCn	1 749.5 ef	146.233 cde	637.9 h
$P_{1,\ 4}$	2 060.5 e	130.167 ef	9 898.2 cd
$P_{1,\ 5}$	6 544.4 b	186.667 a	7 153.1 f
$P_{1,\ 6}$	2 091.8 e	130.4 def	8 672.8 ed
$P_{1,\ 7}$	5 573 c	135.3 def	7 538.9 ef
$P_{2,\ 4}$	7 210 a	170.633 ab	8 321.1 ef
$P_{2,\ 5}$	7 272.2 a	135.2 def	4 659.8 g
$P_{2,\ 6}$	7 620.8 a	146.3 cde	7 918.1 ef
$P_{3,\ 4}$	4 985.8 d	147.1 cd	8 415.1 def
$P_{3,\ 8}$	6 427.2 b	131.5 def	10 866.7 c
DMS	506	16.78	506.5
CV	4.51	3.92	7.14

Elaboration based on laboratory data.

In this sense, it is possible to mention that the mean CT content of the female parents was 1 411.9 mg/0.1 kg, that of the male parents was 1 663.7 mg/0.1 kg, and that of the F2 populations was 5 531.7 mg/0.1 kg, which is summarized in that the F2 populations contain 292% more CT content compared to the female parents and 232.5% more than the male parents. It should be noted that the F2 populations show more promise regarding this antioxidant pigment, effective in the prevention of certain degenerative diseases of the human being.

The most outstanding F2 populations have the same maternal parent in common, however, the mirador pepper does not present high amounts of CT (1 363.8 mg/0.1 kg), which we can attribute to the presence of genes that combined favorably to present high CT values. Table 5 shows that the genotypes (F1 and F2 populations) had positive DEP % values for CT, which indicates that they all increased the content of this antioxidant from one generation to another (F1 to F2), with the F2 populations being $P_{1,\ 4}$ and $P_{1,\ 6}$ those with the lowest values 19.4 and 31.6% respectively, with respect to the rest of the populations; however, the rest of the populations had a 208.5 to 426.3% increase in these important pigments for human health, with respect to their first filial generation, which makes them attractive for their advancement and selection in later generations.

Table 5. Mean values of the nutraceutical quality components of the fruit and inbreeding depression of the *Capsicum annuum* genotypes observed in two daughter generations.

Genotypes	Total carotenes (mg/0.1 kg)			Ascorbic acid (mg/0.1 kg)			Capsaicin (SHU)		
	2017	2018	DEP (%)	2017	2018	DEP (%)	2017	2018	DEP (%)
P_1. Jalapeño	6 430	1 121.5	-82.6	74.87	97.9	30.8	11685	12706	8.7
P_2. Mirador	742	1363.8	83.8	55.82	92.8	66.3	11381	12697	11.6
P_3 Serrano	5 494	1750.4	-68.1	101.27	121.3	19.8	12138	14532	19.7
P_4. UANOg	7 498	1291.8	-82.8	184.6	136.6	-26	939	964	2.6
P_5. UANRd	7 073	1195.3	-83.1	201.94	137.5	-31.9	845	832	-1.5
P_6. UANShw	7 477	1976.4	-73.6	187.33	172.8	-7.8	740	765	3.3
P_7. UANYw	5 055	2105.7	-58.3	172.22	158.6	-7.9	547	557	1.9
P_8. UANCn	6 454	1749.5	-72.9	187.97	146.2	-22.2	713	638	-10.5
	F1	F2		F1	F2		F1	F2	
P_1xP_4	1 725	2060.5	19.4	108.72	130.2	19.7	9 375	9 898	5.6
P_1xP_5	1 764	6544.4	271	109.4	186.7	70.6	5 952	7 153	20.2
P_1xP_6	1 589	2091.8	31.6	89.42	130.4	45.8	7 385	8 673	17.4
P_1xP_7	1 380	5573	303.8	96.11	135.3	40.8	6 253	7 539	20.6
P_2xP_4	1 370	7210	426.3	109.24	170.6	56.2	7 785	8 321	6.9
P_2xP_5	1 765	7272.2	312	110.24	135.2	22.6	5 950	4 660	-21.7
P_2xP_6	2 081	7620.8	266.2	98.97	146.3	47.8	8 797	7 918	-10
P_3xP_4	1 616	4985.8	208.5	120.29	147.1	22.3	7 862	8 415	7
P_3xP_8	1 761	6427.2	265	129.79	131.5	1.3	12003	1 0866	-9.5

Elaboration based on laboratory data.

Regarding the content of CAPs, it is possible to observe that the female parents, especially the Serrano pepper, was significantly higher than the rest of the parents and F2 populations under study, with 14 532 SHU, which was 94.83% hotter than the paternal parents, the which present an average of 751.2 SHU, being these significantly lower than the rest of the genotypes studied. The F2 populations have an average of 8 160.33 SHU, the population $P_{3,\ 8}$ excelling with 10 866.7 SHU.

As can be seen, the F2 populations are not hotter than the maternal parents, however, they do present more itching when compared to the paternal parents, which is promising if it is intended to commercialize these peppers within the Mexican Republic, since the demand for high-heat products is becoming higher and *Capsicum* oleoresins have had to be imported from Africa for industrial uses (Cruz-Pérez *et al*., 2007).

In the F2 generation, the populations $P_{1,\ 5}$ and $P_{1,\ 7}$ not only maintained the F1 itch, but increased it more than 20%, however, populations such as $P_{1,\ 4}$, $P_{1,\ 6}$, $P_{2,\ 4}$ and $P_{3,\ 4}$ maintained values lower than 20% but are still positive, which indicates an increase in itching in relation to the first generation, contrary to the rest of the populations, which reduced their itching in the F2.

Agronomic variables

The analysis of variance applied to parents and F2 populations showed significant differences ($p\leq 0.01$) between the two regarding DAF and DAC. The comparison of means (Table 6) shows that in the DAF variable the F2 populations were significantly earlier than the parents, both maternal and paternal.

Table 6. Agronomic components in F2 parents and populations of *Capsicum annuum*.

Genotypes	DAF	DAC	ADP (cm)	DBT (mm)
P_1. Jalapeño	51.63 bc	141.03 ab	206.27 a	29.243 a
P_2. Mirador	88.16 a	135.66 ab	88.77 de	16.083 b
P_3. Serrano	54 bc	130.33 abcd	125.67 abcde	24.85 ab
P_4. UANOg	56.66 b	103.46 efg	97.50 cde	27.01 ab
P_5. UANRd	56.9 b	109 defg	73.1 e	22.277 ab
P_6. UANShw	49 bcd	93.7 g	70.07 e	25.523 ab
P_7. UANYw	43.63 bcde	107.16 efg	88.87 de	22.87 ab
P_8. UANCn	37.66 cdef	132 abc	61.67 e	18.39 ab
$P_{1,\ 4}$	27.56 ef	122.96 bcdef	119.9 abcde	23.067 ab
$P_{1,\ 5}$	28.2 ef	102.26 efg	193.1 ab	25.443 ab
$P_{1,\ 6}$	23.36 f	106.66 efg	168.87 abcd	23.537 ab
$P_{1,\ 7}$	26.03 ef	122.96 bcde	146.27 abcde	23.22 ab
$P_{2,\ 4}$	31.43 def	112.1 cdefg	110.7 bcde	18.543 ab
$P_{2,\ 5}$	27.66 ef	152.26 a	103.1 cde	20.303 ab
$P_{2,\ 6}$	29.9 ef	105.73 efg	183.43 abc	29.123 a
$P_{3,\ 4}$	39 bcdef	99.36 fg	164.1 abcd	26.76 ab
$P_{3,\ 8}$	31.2 def	137.5 ab	145.43 abcde	24.99 ab
DMS	18.77	22.051	89.301	12.05
CV	14.86	6.08	23.11	16.68

Elaboration based on field data.

The maternal parents presented an average of 64.4 days to flowering after transplantation, the paternal parents 48.77 days, while the F2 populations obtained their first flower on average at 29.37 days. F2 stocks follow the same trend as their first filial generation showing high precocity. The F2 populations achieved 54.33% more precocity in relation to their female parents and 39.77% in relation to their paternal parents, while in the F1 generation they presented around 54% precocity.

The F2 $P_{1,\ 6}$ population presented higher precocity, reaching flowering 23.3 days after transplantation; however, it does not differ significantly from the rest of the F2 populations. The latest female parent was the lookout, reaching its first flowering at 88 days, while the later males were UANOg and UANRd, both presenting their first flowering after 56 days.

These results differ greatly from the parameters of the crop since it is mentioned that in bell pepper the flowering period ranges between 70 and 93 days; however, in practice it is different, since in this research the paternal parents had their first flowering between 37 and 56 days, similar data obtained by Moreno-Pérez *et al*. (2011) who evaluated 13 bell pepper hybrids in the greenhouse under hydroponic conditions, finding that most of their hybrids had their first flowering 30 days after transplantation and in their latest hybrid up to 45 days after transplantation.

This can be attributed to what was described by Montes *et al*. (2004) who point out that the accumulation of heat units during the different development stages of *Capsicum* spp. It shows a difference between types of pepper and this is more evident between the different levels of domestication, which means that wild variants show a slower start in their development, compared to domesticated cultivars, so this crop is already well adapted to the greenhouse conditions and with its development during the hottest months of the year, had a greater accumulation of heat units, which were reflected in the earliness of the crop.

Therefore, the results obtained indicate that sowing in May and transplantation in June, allow flowering in July, achieving greater precocity and favorable development of the plant, and fruit production is achieved for a longer time (up to 8 months) and harvest in the coldest months of the year thus achieving high prices in greenhouse production.

It should be noted that the Jalapeño in its first filial generation only reached 117 cm in height, while in this generation it exceeded 206 cm, which may suggest that in this genotype and in this variable there was the presence of transgressive inheritance manifesting in a degree higher than the F1 generation or else this population is adapting well to greenhouse conditions, which allow greater control of environmental factors, very different conditions to which it was acclimatized or adapted, since commercially it is managed under conditions open sky. The F2 populations have a positive trend in relation to their parents, presenting higher ADP, exceeding the mean of male parents by 47.24% and 5.45% of female parents.

The analysis of variance applied to the DDT variable shows that the F2 populations were statistically equal, with the Jalapeño Mitla and the F2 $P_{2,6}$ population showing the highest values, although they were significantly equal to the F2 populations and six parents, with the exception of the Mirador progenitor, which shows the thinnest stem, which was reflected in the anatomy of the plant as it is the lowest, thinnest and most fragile genotype, which limits it to an adequate option for greenhouse production, since it is still under conditions of controlled environment, adequate irrigation and optimal health, the plant cannot develop properly.

On the other hand, the F2 populations studied indicate that as generational progresses, the plants are adapting better to greenhouse conditions, although it is soon to be certain, since they have only been a generation, but they do allow us to observe that, as in In the first generation, the plants show an indeterminate growth tendency, thicker stems, better anatomy, more rigid, erect, well-defined plants with good foliar coverage.

Conclusions

The main characteristic of the methodology used lies in the generational progress of the genotypes, in order to advance in the development of new varieties of pepper, with characteristics superior to those existing in the market. The interracial crossing technique allows to exploit the genetic variability in *Capsicum annuum* to increase the yield above 100 t ha^{-1} and increase the fruit quality.

As happened with the F2 populations $P_{1,5}$ and $P_{3,4}$ that exhibited the highest yield and increases in nutraceutical properties with respect to F1. Furthermore, the wide genetic variation observed between and within the F2 populations can be exploited by means of genetic improvement techniques by selection for the development of varieties with higher yields, agronomic characteristics and fruit quality.

Populations $P_{1,6}$, $P_{2,4}$ and $P_{2,5}$ had the highest percentage of inbreeding depression in fruit yield in the F2 generation; however, before being discarded, they may be considered in future studies since they presented increases in nutraceutical quality in F2 with respect to F1, so they could be promising to satisfy current market needs, regarding fruit quality.

Acknowledgments

The first author thanks CONACYT for the financial support granted in the form of a scholarship for postgraduate studies.

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