Vol. 11(3), pp. 91-99, March 2019
DOI: 10.5897/JPBCS2018.0782
Article Number: 9CA079F60447
ISSN 2006-9758

http://www.academicjournals.org/JPBCS

Journal of Plant Breeding and Crop Science

Full Length Research Paper

Generation and evaluation of heterogeneous genotypes of tomato for small-scale farmers

José C. Carrillo-Rodríguez[1], José L. Chávez-Servia[2*], Ricardo Lobato-Ortiz[3] and Catarino Perales-Segovia[4]

[1]Instituto Tecnológico del Valle de Oaxaca, Ex-Hacienda de Nazareno, Santa Cruz Xoxocotlán, C. P. 71230, Oaxaca, Mexico.
[2]Instituto Politécnico Nacional, CIIDIR-Oaxaca, Hornos No. 1003, Santa Cruz Xoxocotlán, C. P. 71230, Oaxaca, México.
[3]Postgrado de Recurso Genéticos y Productividad, Colegio de Posgraduados-Campus Montecillo, km. 36.5, Carr. México-Texcoco, 56230, Texcoco, México.
[4]Instituto Tecnológico El Llano Aguascalientes, Aguascalientes, México.

Received 15 October, 2018; Accepted 20 February, 2019

Tomato is broadly distributed in tropical and subtropical America, where small farmers cultivate commercial and landraces or heirloom genotypes, which exchange genes within them when are planted in the same plot. In this context, three different genetic groups of tomato were evaluated for agromorphological and yield traits under greenhouse to assess the differences in function of the genotypic homogeneity and heterogeneity. Twenty-four non-conventional hybrids (F_1, population-x-advanced lines), seventeen landraces and six advanced lines (F_8) were evaluated in a randomized complete block design with three repetitions. Significant differences ($p \leq 0.05$) were determined among genetic groups for all variables evaluated, except in days to ripening of fruits at the fifth branch, and within genetic groups, significant differences were also detected. Six hybrids, three landraces and two advanced lines presented remarkable agronomic responses in yield per plant. The hybrids and landraces had high phenotypic variability in plant and fruit traits, with flat-rounded or lightly flattened fruit shapes, qualities demanded in the local markets, and a yield of 2 kg per plant. In Oaxaca, Mexico, small-scale farmers readily accept these heterogeneous genetic groups of tomato. High homogeneity characterized the advanced lines, with a fruit shape convenient for national and international markets.

Key words: Landraces, non-conventional hybrids, phenotypic divergences, principal component analysis.

INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is an important economic and social horticultural crop, and the cultivation of tomato promotes a dynamic economy and generates employment in exporting countries. In the last decade, approximately 4.7 million ha are annually planted to tomato (FAOSTAT, 2014), with a consequent worldwide demand for seed of improved varieties every year. However, at the country level, different production systems are in operation, and the delivered varieties are not stable over all environments and greenhouse conditions. Therefore, each country that produces tomato must develop strategies to solve the problem of access

*Corresponding author. E-mail: jchavezs@ipn.mx. Tel/Fax: (+52) 951-5170610.

for farmers to improved varieties, who demand at least two varietal groups; first, varieties for the export market and second, seeds for varieties for the national market. Unit size exploited and whether a conventional or organic production system must also be considered. To access genetic material of tomato, breeding programs have generated varieties with different genetic structure, including open-pollinated (OP) and synthetic varieties (SV), hybrids from triple (TH), double (DH) and simple (SH) crossings, non-conventional hybrids (that is, bred lines-x-OP or SV, OP-x-SV, SV/OP-x-landraces, and landrace-x-landrace, among others) and interspecific hybrids generated by cultivated and wild species using isogenic lines.

In the genetic improvement of tomato, increased yield and environmental stability across production systems are criteria used for selection. More recently, improved nutritional quality of fruit and a long shelf life were added as indispensable criteria. However, the task is complex, not simple, to join yield and nutritional-nutraceutical attributes in a variety. Traditionally, breeders use assistance from molecular markers and biochemical analysis of fruit quality to generate hybrids and synthetic or open-pollinated varieties; however, these approaches are insufficient to meet the demand for varieties (Grandillo et al., 1999, 2011). In different countries, old varieties or heirlooms of tomato are being selected and conserved by farmers, and although these farmer varieties have phenotypic heterogeneity, the fruit quality is highly preferred by consumers. Some examples of such farmer varieties are ‘Valenciano’, ‘Muchamiel’ and ‘De Penjar’ in Spain (Cebolla-Cornejo et al., 2013); ‘Pomodoro di Mercatello’ (Rocchi et al., 2016), ‘A pera Abruzzese’ (Mazzucato et al., 2010), ‘Pomodoro di Sorrento’, ‘Belmonte’, and ‘Canestrino di Lucca’ in Italy (Parisi et al., 2016); a dozen heirlooms in Brazil (Vargas et al., 2015); ‘Tomataki Santorinis’ from Santorini Island of Greece (Koutsika-Sotiriou et al., 2016); and different local varieties from Eritrea in Africa (Asgedom et al., 2011). In México, tomato landraces are commonly found from north to south, in addition to ruderal forms of S. *lycopersicum* var. *cerasiforme* (Bonilla-Barrientos et al., 2014; Chávez et al., 2011; Sanjuan et al., 2014).

For export to the international market, the producer requires hybrids that are genetically homogeneous heterozygotes producing fruit of high commercial quality. By contrast, small-scale farmers require seeds of varieties with broad adaptability to heterogeneous production systems, such as those of heterogeneous homozygotes or heterogeneous heterozygotes, but also with fruits highly preferred by regional consumers who will pay a premium price for fruit quality. This type of farmer can avoid the high cost of obtaining hybrid seed, because the farmers require only a small quantity of seed that they can reproduce themselves (Bonilla-Barrientos et al., 2014; Cebolla-Cornejo et al., 2013; Mazzucato et al., 2010; Parisi et al., 2016). Farmers know that the varieties, agroecological conditions and crop management determine the flavor, taste and nutritional quality of the tomato fruit (Cebolla-Cornejo et al., 2011). Moreover, the product destination is local or organic markets in which the quality of fruit is more important than the yield per area (Rocchi et al., 2016). Koutsika-Sotiriou et al. (2016) compared breeding between farmers and formal plant breeding using tomato heirlooms and concluded that farmers generated populations with low productivity, high fruit homogeneity and broad adaptability, whereas the breeders produced advanced lines or selected populations with high productivity, high selection efficiency and specific adaptations. Therefore, farmers start selecting their varieties only to give them gene pools with broad genetic variability, which can help to maintain independence in access to seed without intervention of seed companies.

In recent decades, the organic markets for tomato and ecological agriculture have required seeds of varieties with high tolerance or resistance to pests, diseases and abiotic stresses but also with high quality fruit based on physical and chemical aspects. To develop such varieties, breeders resort to primary pools (advanced lines from plant breeding programs), secondary pools (farmer varieties, landraces or gene banks) and tertiary genetic material such as wild species or wild relatives of the cultivated species (Lammert Van Bueren et al., 2011; Riahi et al., 2009). In this context, the aims in this work were to evaluate a collection of tomatoes composed of non-conventional hybrids of simple crossings, farmer varieties and advanced bred lines under greenhouse conditions in a local system of low input agriculture to assess the productivity of heterogeneous genetic material in developing an agronomic proposal for small-scale farmers.

MATERIALS AND METHODS

Germplasms evaluated

The tomato collection included 47 genotypes from three different genetic groups: 24 non-conventional hybrids, F_1 from population-x-advanced line crosses (H-60, H-61, H-62, H-63, H-64, H-65, H-66, H-67, H-68, H-69, H-70, H-71, H-72, H-73, H-74, H-75, H-01, H-06, H-06a, H-12, H-12a, H-19, H-22 and H-22a); 17 samples of landraces from Oaxaca, Mexico (COMP 5, X-04, X-05, X-07, X-08, X-09, X-12, X-13, X-15, I-18, I-07, I-25, I-31, I-35, I-38, I-42 and I-51); and five advanced inbred lines (the F_8, LA-106, LA-107, LA-108, LA-110 and LA-112). In the first two groups, fruits are broadly variable in size and shape, including rounded, pyriform, flattened, slightly flattened, heart-shaped and other similar shapes, with shoulders or amorphous protuberances but with three or more locules. Locally, these groups are called ‘criollo’ or ‘costilla’ in Spanish.

Experiment management

The tomato collection was transplanted (August 4, 2015) in a complete randomized block design with three replications in a greenhouse (17° 01’ 10.42’’ N, 96° 45’ 52.32’’ W, 1561 m.a.s.l. and

Table 1. Significance of the mean square from the analysis of variance of evaluated traits in non-conventional hybrids, landraces and advanced lines of tomato.

Agromorphological variable	Genetic groups	Genotypes (groups)††	Repetition	Plant (rep.)††	CV (%)
Days of transplant to flowering of the 5th branch	132.8**	15.2**	3.6ns	-	3.8
Days of transplant to setting of fruits in the 5th branch	292.32**	13.04**	17.58ns	-	3.3
Days of transplant to ripening of the 5th fruit branches	18.87ns	48.21**	24.31ns	-	3.2
Plant height at 60 days after transplanting	21540.6*	9550.6*	10730.7ns	5918.4ns	4.8
Plant height at 90 days after transplanting	3940.1**	8629.6**	2148.1*	296.3ns	9.5
Polar diameter (length) of fruit†	1536.1**	1828.3**	194.79*	25.76ns	9.7
Equatorial diameter (width) of fruit†	156.01*	322.25**	35.99ns	63.51ns	10.8
Total number of flowers†	12555.2**	704.8**	314.95*	117.9ns	21.0
Total number of fruits†	8612.1**	471.9**	180.4*	29.4ns	17.0
Average weight of fruit	18184**	4283.7**	123.18ns	178.5ns	26.8
Total weight of fruits per plant†	6901444**	4439179**	718958ns	204807ns	17.1

nsNot significant ($p > 0.05$); *significant at $p \leq 0.05$; **significant at $p \leq 0.01$; †variables evaluated at fifth floral and fruit branches; ††effect of genotypes nested in genetic groups of tomato and plants nested in repetitions; CV = coefficient of variation.

21.1°C exterior temperature, Oaxaca, Mexico). Before transplanting, the soil was removed to incorporate sawdust, cattle manure, lime and water, and at transplant, soils were treated with Captan®. During the cultivation, pruning, tutoring and staking of plants were the common practices, together with drip-fertilization using commercial formulas of 15-30-15, 18-18-18, and 13-6-40 (N-P-K) and calcium nitrate. Additionally, a preventive program of pest and disease management was implemented by applying preventive chemical products and vegetable extracts.

The agronomic behavior of the genotypes was evaluated throughout the study with physiological, morphological and agronomic variables. For example, in the experimental plots, the precocity was assessed with counts of days after transplant to reach flowering, fruit set and maturing fruit stages in 50% or more of plants at the level of the fifth floral branch. To determine growth habits, plant growth was evaluated with measurements of plant height at 60 and 90 days after transplanting. The primary traits associated with yield were total number of flowers and fruits per plant at the fifth floral branch, polar and equatorial fruit diameters, average fruit weight and yield per plant.

Statistical analyses

Different analyses of variance were performed on the database per experimental plot and genotype using a linear model of completely randomized blocks with nesting of tomato genotypes or populations into genetic groups of evaluation and for some response variables, nesting of number of evaluated plants in a genotype. All analyses of variance evaluated the differences among and within genetic groups, with the analyses complemented with multiple Tukey's tests ($p \leq 0.05$). Additionally, for the average per genotype for each variable, later standardized, two principal component analysis were conducted using a variance-covariance matrix to describe and assess the variables of high descriptive value in the agronomic behavior of the evaluated genotypes and its relationships with plant yield. All analyses were conducted in the SAS statistical software package (SAS, 1999).

RESULTS

Significant differences ($p \leq 0.05$) were detected among and within genetic groups of tomato for all variables, except in days to fruit ripening at the fifth floral branch (Table 1). The results showed different responses among genetic groups under greenhouse conditions, and in such responses, the genetic variability contained in the genetic groups was clearly a buffer mechanism or for resilience.

In the comparison of means among genetic groups, the advanced lines presented high homogeneity in days to flowering and fruit setting, compared with the non-conventional hybrids and landraces (Table 2). Particularly, the hybrids showed precocity in reaching flowering, fruit setting and ripening. The commercial maturation of fruits from the fifth branch approached 108 days after transplanting. Consequently, the first harvests were performed between 32 and 42 days after transplanting, which included the first floral branches. Therefore, before the harvest of the fifth branch, two or three harvests with high quality fruit have been conducted.

In advanced lines, the number of flower and fruits per branch was higher than that in hybrids and farmer landraces. Additionally, in the tomato landraces, the fruit setting was lower than that in hybrids and advanced lines, and only one-third of the total of flowers produced fruits. Nevertheless, these fruits were large in size and weighed approximately 200 g or more per fruit, which is a characteristic that is very attractive to small-scale farmers. The advanced lines averaged 3 kg of fruit per plant, which was higher than that in hybrids and landraces (Table 2), because such lines were in a selection process for eight cycles with selection by the bulk population method (Acqaah, 2012). Into each genetic group, all agromorphological traits were highly variable. For example, among population hybrids, the flowering of the fifth floral branch occurred between 49 and 59 days after transplant (dat), plant height varied from 1.9 to 3.0 m at 90 dat and fruits shapes were round,

Table 2. Comparisons of physiological and agronomic behaviors among three gene pools of tomato.

Traits	Non-conventional hybrids	Landraces	Advanced lines
Days of transplant to flowering of the 5th floral branch	53.3±2.4[c*]	55.4±2.2[b]	57.1±1.6[a]
Days of transplant to setting of fruits in the 5th branch	61.6±2.4[b]	65.7±1.6[a]	65.4±1.6[a]
Days of transplant to ripening of the 5th fruit branches	107.7±4.6[a]	108.1±3.1[a]	109.3±3.5[a]
Plant height at 60 days after transplanting (cm)	179.2±19.6[a]	162.8±12.0[b]	159.0±27.7[b]
Plant height at 90 days after transplanting (cm)	237.0±26.2[a]	224.3±18.1[b]	212.3±35.8[c]
Polar diameter (length) of fruit† (mm)	56.5±12.5[b]	45.6±5.7[c]	61.0±9.6[a]
Equatorial diameter (width) of fruit† (mm)	54.8±5.1[b]	67.8±10.5[a]	49.7±4.2[c]
Total number of flowers†	39.6±5.6[b]	53.2±10.7[a]	38.0±4.3[b]
Total number of fruits†	23.4±6.0[b]	13.1±6.3[c]	27.9±7.5[a]
Average weight of fruit (g)	73.0±21.4[b]	83.9±37.9[a]	73.5±12.8[b]
Total weight of fruits per plant† (g)	1703.8±622.5[b]	1053.5±600.7[c]	2114.5±791.6[a]

*In row, means with same letter are not significantly different (Tukey's test, $p \leq 0.05$).

pyriform, saladette-type, round-flattened with shoulders and other shapes. The hybrids H-06, H-06a, H-22a, H-67, H-68 and H-72 had fruit set of more than 70%, measured by the relation fruits/flowers on the fifth floral branch. Seven non-conventional hybrids produced between 2.03 and 3.0 kg per plant (Table 3).

In the regional landraces, fructifying of the fifth branch occurred from 63 to 68 dat, plant height was from 1.9 to 2.4 m at 90 dat and the growth, which never stopped during the entire experiment, was considered indeterminate. These landraces had regularly round-flattened fruits with shoulders and the fruit set rate (fruits/flower) was low at 50%; only in the genotype I-25, fruit set reached 57.4%. Therefore, although these genotypes were highly variable in traits of plants and fruit shapes, variability in fruit setting was low. For landraces from Oaxaca, Mexico, the resulting lower yields were compensated with flavor, aroma and texture of fruit. In these cases, the yield varied from 0.27 to 2.06 kg per plant with an average weight from 52.0 to 192.6 g per fruit (Table 3).

The fruit of all advanced lines was saladette-type, and consequently, the length was major than equatorial diameter of fruit, except in the genotype LA-113a, which had a round shape. In these genotypes, the fruit setting rates (fruits/flowers) were from 75.5 to 88.7%, except in LA-106, with a rate less than 42%. A group of five lines presented high fruit weights (39.4 to 84.5 g) and uniformity in fruit shape of the commercial-type. Specifically, line LA-108 presented pyriform-enlarged fruits (7.7 cm in length) and line LA-113a had round-heart fruits, with yields up to 2.8 kg per plant for both lines (Table 3).

In the principal component analysis by morphological and physiological traits, the first principal component described 94.9% of total phenotypic variation, with eigenvalues of 0.58 and 0.81 for the variables plant height at 60 and 90 days after transplanting, respectively, and the physiological traits of flowering, fruit set and ripening of fruits with significant descriptive value (Figure 1). Based on yield traits, a second principal component (PC) analysis was performed, and in this case, the first component (PC1) described 71.5% of the total phenotypic variation, which was considered a discriminant index (PC1) of genotypic productivity. In this analysis, the variables of primary descriptive value for the total variability were polar (0.11 eigenvector) and equatorial (0.29 eigenvector) diameters and average weight of fruit (0.94 eigenvector). The relationships between yield per plant and first principal component or yield component index are shown in Figure 2. The landraces I-07, I-18 and I-31 had the highest values of equatorial diameter of fruit and high yield per plant. Similarly, the advanced lines LA-113 and LA-108 and the non-conventional hybrids H-06, H-06a and H-01 were outstanding within their heterogeneous genetic group.

DISCUSSION

Table 1 shows significant differences among genotype groups mainly due to high variability in each group, it was notorious that the advanced lines showed less variability than non-conventional hybrids and landraces. For plant height, the hybrids grew taller than the landraces (Table 2). Therefore, although the hybrids were non-conventional (crossing of lines x landraces or populations), the plants exhibited a hybrid vigor as result of the heterotic effect caused by genetic divergences among crossed parents. Mendoza-de Jesús et al. (2010) and Pinacho-Hernández et al. (2011) also observed heterotic effects in inter-population and inter-varietal crosses, respectively. These findings suggest that it is not only possible to exploit the hybrid vigor of the crossing of inbred lines but also that of crossing among populations or landraces-x-advanced lines, such as in this study. For both cases, lines or genetic populations without recent matching are the principle.

Table 3. Means comparison among populations within each tomato gene pool (ID, genotype H = non-conventional hybrids; X, I or COMP = landraces; LA = advanced lines).

Genotypes	DFL[1]	DFR	DMF	AP60	AP90	DPF	DEF	NFL	NFR	PMFR	RPP
H-01	54.0	63.7	107.7	172.9	223.3	54.6	58.5	32.5	14.5	104.5	1564.2
H-06	50.0	58.7	108.3	199.9	262.9	80.9	68.0	35.8	26.3	117.9	3003.8
H-06a	51.7	61.3	100.7	208.7	252.5	91.3	52.6	26.2	21.2	127.9	2596.0
H-12	56.3	64.3	110.0	165.2	229.6	55.0	55.6	35.4	22.7	73.8	1684.4
H-12a	56.3	64.3	107.3	179.4	235.0	51.2	55.8	38.7	27.7	72.3	1976.7
H-19	54.0	63.0	104.7	217.6	301.7	62.0	51.3	54.7	24.5	88.9	2042.4
H-22	51.0	61.3	103.7	163.7	218.3	45.5	50.6	41.9	23.9	62.1	1486.9
H-22a	54.0	60.3	110.0	154.7	216.2	46.4	53.0	40.8	26.7	63.6	1712.8
H-60	51.3	62.0	114.7	162.4	223.3	45.6	54.3	50.1	26.7	51.3	1365.0
H-61	57.7	66.3	116.3	145.3	193.7	54.5	46.2	40.8	11.6	47.1	581.3
H-62	56.0	66.3	114.3	140.6	195.4	54.1	48.5	39.7	19.5	52.3	1029.2
H-63	55.0	62.0	110.0	161.5	223.7	41.1	46.6	37.4	15.2	44.7	691.8
H-64	53.7	59.7	110.0	167.5	225.8	74.4	53.3	38.6	27.8	71.9	2025.2
H-65	53.0	61.7	111.7	183.2	256.2	56.9	58.5	37.4	15.7	49.8	780.3
H-66	58.7	65.3	114.0	165.4	236.7	49.9	52.0	44.3	11.4	66.2	709.8
H-67	52.3	59.0	109.0	176.3	251.7	56.1	55.7	38.6	29.5	86.2	2466.8
H-68	52.0	59.0	104.7	164.0	237.1	60.3	65.3	39.8	31.4	77.6	2437.8
H-69	49.3	59.0	100.0	195.2	268.6	43.6	57.3	45.7	26.5	82.4	2146.3
H-70	51.7	59.7	102.0	164.0	221.2	49.6	50.5	37.0	33.2	53.5	1769.8
H-71	52.0	62.0	103.3	150.5	212.5	74.1	57.0	39.9	24.5	68.3	1686.4
H-72	52.7	59.3	104.7	190.2	265.8	51.6	54.5	37.5	27.2	65.2	1776.5
H-73	53.3	61.0	108.3	159.0	208.7	53.6	58.9	34.8	22.7	89.4	1905.1
H-74	51.0	59.7	108.0	179.2	257.1	53.1	55.3	40.0	25.0	67.6	1682.0
H-75	51.7	58.7	101.0	191.3	270.0	49.9	55.3	41.8	26.6	67.8	1770.9
COMP5	55.7	66.7	110.7	168.7	232.9	41.2	73.5	57.2	13.3	86.7	1135.5
I-18	57.7	64.7	111.0	174.6	230.4	54.7	78.7	45.2	12.4	157.5	1880.6
I-07	59.0	65.7	113.3	132.2	187.8	52.3	97.1	38.0	9.7	192.6	1772.3
I-25	54.3	65.3	105.0	156.2	214.6	52.6	63.0	45.1	25.9	73.1	1520.8
I-31	57.3	63.7	111.0	152.3	197.9	45.6	70.8	44.9	17.5	119.6	2059.8
I-35	50.0	64.7	103.0	175.2	235.4	49.8	58.3	47.8	25.2	69.3	1639.3
I-38	56.3	64.7	110.0	164.3	203.3	52.3	63.4	43.5	20.1	82.8	1619.8
I-42	55.7	63.0	110.3	148.6	201.7	49.8	55.9	40.0	14.7	91.6	1131.9
I-51	55.0	65.3	107.7	150.0	207.9	45.0	61.0	40.0	18.1	72.7	1267.4
X-04	54.7	68.0	111.7	170.4	240.8	42.8	57.7	63.0	8.4	61.4	474.0
X-05	56.3	68.0	108.3	168.7	235.2	37.1	61.3	52.7	5.5	52.0	265.7
X-07	52.3	65.0	105.3	164.4	227.9	40.1	67.8	58.5	8.7	66.9	567.1
X-08	56.3	68.3	105.3	162.1	229.6	41.2	59.9	64.1	6.4	67.3	404.8
X-09	54.3	65.0	105.7	169.7	241.7	43.2	67.2	73.3	10.2	64.6	693.8
X-12	53.7	64.7	103.7	177.5	252.9	38.3	64.5	59.2	10.1	55.4	511.0
X-13	58.3	68.0	108.0	171.2	234.6	49.9	81.6	64.2	8.6	79.9	705.3
X-15	54.7	66.7	109.0	153.2	228.7	40.0	63.7	63.3	7.0	57.5	375.0
LA-106	59.7	68.0	115.0	117.7	152.9	56.2	46.0	35.2	14.5	49.9	734.6
LA-107	58.3	66.0	112.3	149.3	201.7	77.2	46.3	34.9	26.7	69.4	1816.2
LA-108	56.7	65.7	106.7	165.7	232.9	52.8	51.4	38.0	33.7	84.5	2828.5
LA-110	56.0	63.3	107.7	145.4	198.7	61.2	52.0	33.5	25.7	79.1	2065.4
LA-113a	56.0	64.0	106.7	180.0	234.2	52.0	56.3	42.1	34.7	83.0	2860.5
LA-113b	55.7	65.3	107.3	195.9	253.3	66.4	46.2	44.3	31.8	75.1	2381.8
DSH-Tukey	*7.9*	*7.9*	*13.1*	*28.7*	*37.1*	*9.8*	*16.1*	*16.8*	*11.2*	*44.5*	*915.0*

[1]DFL, days of transplant to flowering of the 5th branch; DFR, days of transplant to setting of fruits in the 5th branch; DMF, days of transplant to ripening of the 5th fruit branches; AP60, plant height at 60 days after transplanting (cm); AP90, plant height at 90 days after transplanting (cm); DPF, polar diameter (length) of fruit (mm); DEF, equatorial diameter (width) of fruit (mm), NFR, total number of flowers; NFR, total number of fruits; PMF, average weight per fruit; RPP, total weight of fruits per plant.

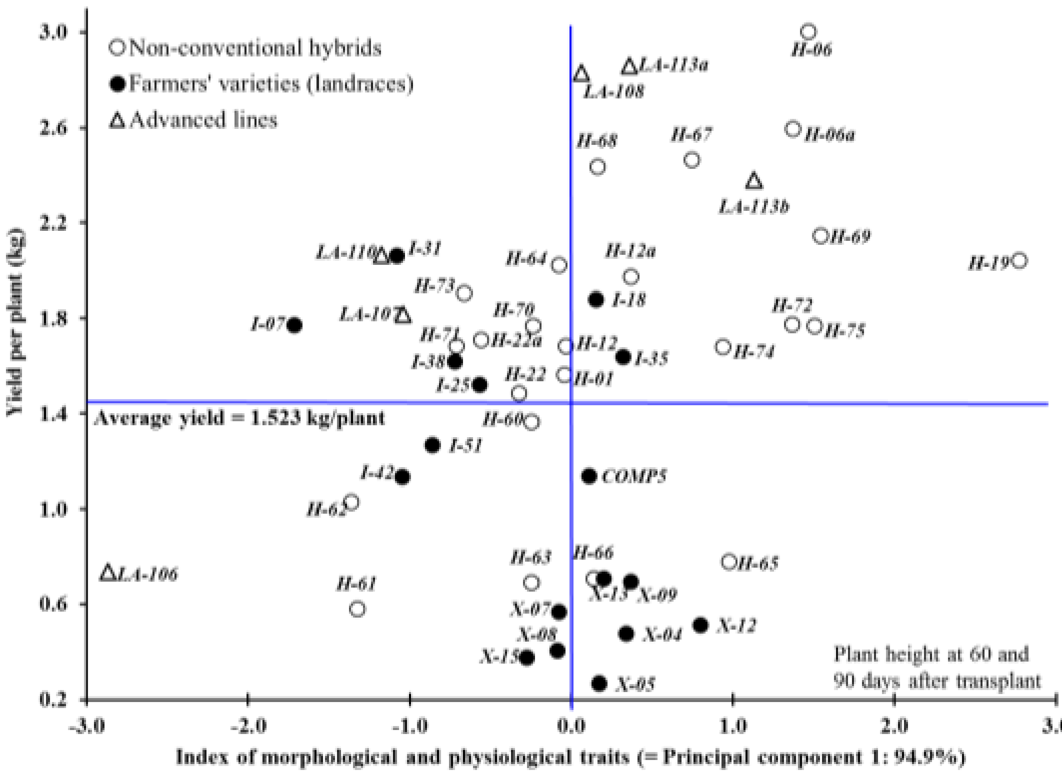

Figure 1. Relationship between plant yield and first principal component (index), based on morphological and physiological traits of plants.

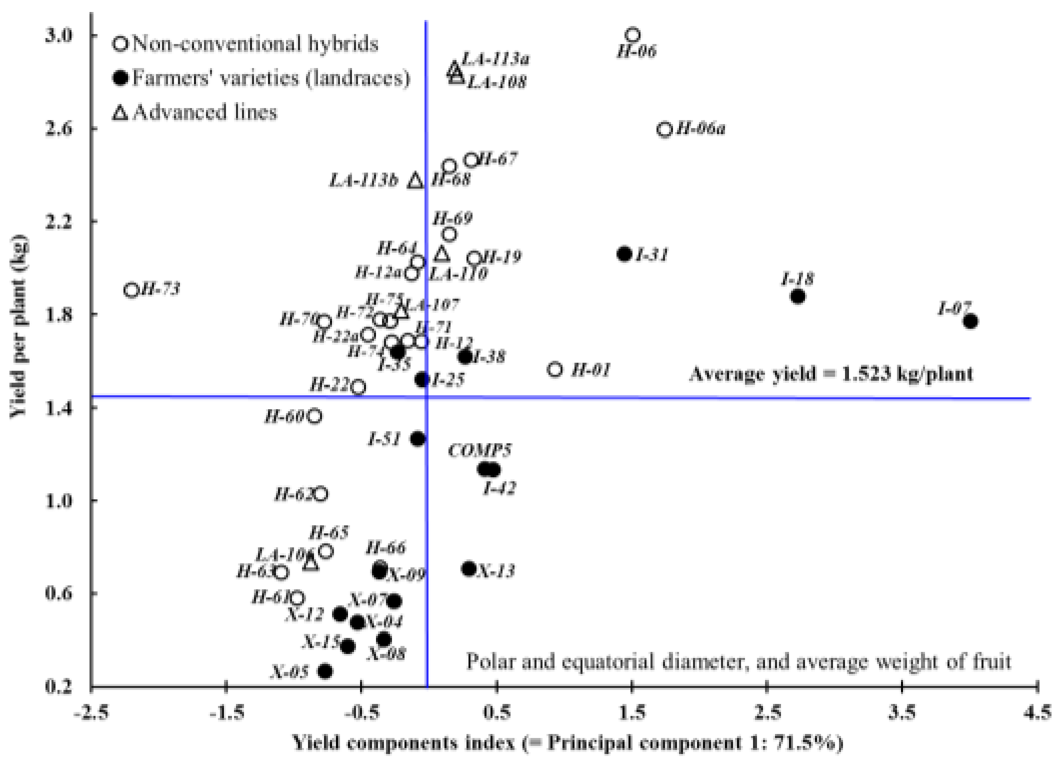

Figure 2. Pattern of relationships between yield per plant and first principal component (index), based on characters of yield.

In the size, shape and dimensions of fruit, the genetic groups showed phenotypic divergences in agronomic traits. For example, the fruits of advanced lines were oblong-elongated and lengthy; those of landraces were commonly rounded-flattened, lightly flattened or similarly shaped with shoulders and with a wide equatorial diameter; and those of non-conventional hybrids showed more variability of shape from rounded, saladette-type or round-flattened and high variation in size (Table 2). Phenotypic variation of these genetic groups offers opportunities for small-scale producers of tomato because of the necessity to diversify their production systems, which includes the production of fruit types for local or regional markets (specialties) and fruit shapes for the national market. Although the characteristics of plants and fruits may satisfy the requirements of a producer, in different local production systems, the shelf life and agronomic behavior must also be evaluated. In these cases, the hybrids with better performance had fruit shapes that were close to those of their parent populations from an irregular aspect and produced exceptional commercial-type fruits such as round enlarged (saladette type) or heart-shaped and other commercial types.

In reference to average weight per fruit in this study (52.0 to 192.6 g) was similar to that reported by Mazzucato et al. (2010) in populations of ‘A pera Abruzzese’ from Italy, ranging from 150 to 366 g, and by Cebolla-Cornejo et al. (2013) with landraces ‘Valenciano’, ‘Muchamiel’, ‘Penjar’ and ‘Pimiento’, ranging from 113.7 to 302.9 g. In the specific case of ‘Muchamiel,’ the authors reported that three populations presented yields surpassing 4 kg per plant. The results presented here indicated that is plausible start a participatory breeding program with regional landraces supported by farmers in their own cultivated parcels and principally, with those populations of high yield and fruit quality. Such a proposal is supported by previous experiences such as: Ríos-Osorio et al. (2014), with similar genetic material, landraces from Oaxaca, Mexico, obtained yields up to 8.2 kg per plant in a more intensive production system.

The group of advanced lines presented high weights and uniformity in fruit shape and yields similar to commercial types (2.8 kg per plant). Therefore, these advanced lines are an option for small farmers, which can be used in a combination of alternate parcels or as a varietal rotation with landraces. Thus, farmers could cultivate landraces and advanced lines to diversify crop varieties and as opportunities in regional, national or international markets. In the study region, small and medium farmers are promoting agroecological and organic cultivation; and in these systems, these genotypes are a plausible option and also farmers can produce their own seed.

Hybrids, varieties or advanced lines are commonly evaluated in the practice of the plant breeding of tomato. In this work, we propose a strategy to start participative selection on-farm and in the agroecological conditions of the small-scale farmer when new hybrids or varieties show a decrease in agronomic performance. The advanced lines can compete with new materials because of the approximately 84 g average weight per fruit and more than 30 fruits at the fifth floral branch. Hernández-Leal et al. (2013) found that varieties SUN-7705, Moctezuma and Reserva produced from 99.3 to 117.0 g per fruit and from 1.03 to 1.06 kg of fruit per plant. Riahi et al. (2008) evaluated the varieties and hybrids Rio Grande, Pefectpeel, Hypeel 108 and Firenze and obtained from 56 to 90 g per fruit. Therefore, the agronomic performance of the advanced lines and landraces evaluated in this work is convenient for small tomato producers.

In this work, the first principal component was considered a discrimination index to differentiate genotypes with high performance based on plant growth and physiological traits. A scatterplot of genotypes represented on the two axes is shown in Figure 1; yield per plant and first principal component as the discriminant index. Under these considerations, high fruit yield was associated with taller plants, principally in hybrids H-19, H-06, H-06a and H-69, lines LA-65, LA-113a, LA-113 and LA-108, and two landraces, I-18 and I-35. This result showed that the genotypes of plants with indeterminate growth presented outstanding yields per plant. Later, a second principal component analysis was performed using characters associated to yield (Figure 2), in such case the discrimination among genotypes groups similar to first one, and also it was confirmed that heterogeneous genetic groups were outstanding. Therefore, heterogeneous genotypes (landraces or hybrids) can be an option for small-scale farmers.

Phenotypic homogeneity and uniformity in tomato cultivation are common because of the use of improved varieties or commercial hybrids, which are selected as the goal of a strategy regularly used in plant breeding programs to increase the productivity (Grandillo et al., 1999; Barrios-Masias and Jackson, 2014). With this cultivation approach, the objective is national or international markets for which the quality of fruit is less relevant. However, in recent years, the nutraceutical quality of the tomato fruit has gained major commercial importance, and currently, the quality of fruit is an indispensable character in plant breeding strategies (Grandillo et al., 2011). Moreover, small producers of tomato require varieties or new materials not necessarily with high productivity but with high consumption value associated with flavor, aroma and texture of fruit. Until now, farmers developed or selected new varieties or local varieties from the old varieties, new genetic crossings among commercial varieties and local genotypes or by induced crossing among landraces in which the advanced genotype is highly variable in plant and fruit traits (Mazzucato et al., 2010; Cebolla-Cornejo et al., 2013; Rocchi et al., 2016). Therefore, the results suggest that it is feasible to select landraces (I-07, I-18 and I-31) or generate non-conventional F_1 hybrids (H-06, H-06a, H-19, H-64, H-67, H-68 and H-69) with high productivity and healthy plants with similar performance to that of advanced lines such as (LA-108 and LA-113a). In the southeast of Mexico, the small-scale tomato producers commonly have a high level of acceptance for highly variable genotypes, and the proposal developed here can be useful for this type of farmer.

All the results in this study were from a greenhouse experiment, as a continuation of previous works developed by Gaspar-Peralta et al. (2012) and Rios-Osorio et al. (2014) using same genotypes at same greenhouse. Therefore, we state that landraces and advanced lines selected in this study as outstanding were also outstanding in previous evaluations, which indicated stability in productivity and fruit size. Consequently, based on the analyses in this study, we can recommend heterogeneous genotypes for selection by small-scale farmers, and when the farmer prefers advanced lines, suggestions can also be provided.

Conclusions

In relevance to producers, breeders, and germplasm curators, we remark that the evaluation of three genetic groups showed significant differences ($p \leq 0.5$) among and within the heterogeneous groups of landraces and non-conventional hybrids and the homogenous group of advanced lines for all evaluated variables, except days after transplant to fruit ripening on the fifth branch. In this study, many outstanding genotypes corresponded to the non-conventional hybrids H-06, H-06a, H-19, H-64, H-67, H-68 and H-69, later landraces I-07, I-18 and I-31 and two advanced lines LA-108 and LA-113a. For the hybrids and landraces, the genotypes had high phenotypic variability in plant and fruit traits.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Acqaah G (2012). Principles of Plant Genetics and Breeding. John Wiley & Sons, Chichester, UK.

Asgedom S, Vosman B, Esselink D, Struik PC (2011). Diversity between and within farmers' varieties of tomato from Eritrea. African Journal of Biotechnology 10:2193-2200.

Barrios-MASIAS FH, Jackson LE (2014). California processing tomatoes: Morphological, physiological and phenological traits associated with crop improvement during the last 80 years. European Journal of Agronomy 53:45-55.

Bonilla-Barrientos O, Lobato-Ortiz R, García-Zavala J, Cruz-Izquierdo S, Reyes-López D, Hernández-Leal E, Hernández-Bautista A (2014). Agronomic and morphological diversity of local kidney and bell pepper-shaped tomatoes from Puebla and Oaxaca, Mexico. Revista Fitotecnia Mexicana 37:129-139.

Cebolla-Cornejo J, Rosello S, Valcárcel M, Serrano E, Beltrán J, Nuez F (2011). Evaluation of genotype and environment effects on taste and aroma flavor components of Spanish tomato varieties. Journal of Agricultural Food Chemistry 59:2440-2450.

Cebolla-Cornejo J, Rosello S, Nuez F (2013). Phenotypic and genetic diversity of Spanish tomato landraces. Scientia Horticulturae 162:150-164.

Chávez-Servia JL, Carrillo-Rodríguez JC, Vera-Guzmán AM, Rodríguez-GUZMÁN E, Lobato-Ortiz R (2011). Utilización actual y potencial del jitomate silvestre mexicano [Current and potential utilization of Mexican wild tomato]. Subsistema Nacional de Recursos Fitogenéticos para la Alimentación y la Agricultura (SINAREFI), Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, CIIDIR-Unidad Oaxaca del Instituto Politécnico Nacional e Instituto Tecnológico del Valle de Oaxaca. Oaxaca, México.

FAOSTAT (2014). Yearbook of crop statistics 2013. Food and Agriculture organization of the United Nations (FAO), Rome, Italy. Available online at: http://www.fao.org/faostat/en/#data/QC

Gaspar-Peralta P, Carrillo-Rodríguez JC, Chávez-Servia JL, Vera-Guzmán AM, Pérez-León I (2012). Variation in agronomic traits and lycopene in advanced tomato (*Solanum lycopersicum* L.) cultivars. Phyton, International Journal of Experimental Botany 81:15-22.

Grandillo S, Zamir D, Tanksley SD (1999). Genetic improvement of processing tomatoes: A 20 years perspective. Euphytica 110:85-97.

Grandillo S, Chetelat R, Knapp S, Spooner D, Peralta I, Cammareri M, Perez O, Termolino P, Tripodi P, Chiusano ML, Ercolano MR, Frusciante L, Monti L, Pignone D (2011). *Solanum* sect. *Lycopersicon*. *In*: Wild Crop Relatives: Genomic and Breeding Resources, Vegetable. C. Kole (ed.). Springer-Verlag Berlin Heidelberg, NY, USA. pp 129-215.

Hernández-Leal E, Lobato-Ortiz R, García-ZavalA J, Reyes-López D, Méndez-López A, Bonilla-Barrientos O, Hernández-Bautista A (2013). Agronomic performance of F_2 populations from tomato hybrids (*Solanum lycopersicum* L.). Revista Fitotecnia Mexicana 36:209-215.

Koutsika-Sotiriou M., Mylonasa I, Tsivelikas A, Traka-Mavrona E (2016). Compensation studies on the tomato landrace 'Tomataki Santorinis'. Scientia Horticulturae 198:78-85.

Lammert van Bueren ET, Jones SS, Tamm L, Murphy KM, Myers JR, Leifert C, Messmer MM (2011). The need to breed crop varieties suitable for organic farming, using wheat, tomato and broccoli as examples: A review. NJAS-Wag. Journal of Life Science 58:193-205.

Mazzucato A, Ficcadenti N, Caioni M, Mosconi P, Piccinini E, Sanampudi VR, Sestili S, Ferrari V (2010). Genetic diversity and distinctiveness in tomato (*Solanum lycopersicum* L.) landraces: The Italian case study of 'A pera Abruzzese' 2010. Scientia Horticulturae 25:55-62.

Mendoza-de Jesús V, Sahagún-Castellanos J, Rodríguez-P$ JE, Legaria-Solano JP, Peña-Lomelí A, Pérez-G$ M (2010). Intervarietal heterosis in indeterminate saladette tomato. Revista Chapingo Serie Horticultura 16(1):57-66.

Parisi M, Aversano R, Graziani G, Ruggieri V, Senape V, Sigillo L, Barone A (2016). Phenotypic and molecular diversity in a collection of 'Pomodoro di Sorrento' Italian tomato landrace. Scientia Horticulturae 203:143-151.

Pinacho-Hernández A, José-José E, Carrillo-Rodríguez JC, Villegas-AParicio Y, Chávez-Servia JL, Vera-Guzmán A (2011). Heterosis interpoblacional de híbridos F_2 de tomate (*Solanum lycopersicum* L.) nativo de Oaxaca, México [Inter-population heterosis of F2 hybrids of native tomato (*Solanum lycopersicum* L.) from Oaxaca, Mexico]. Journal of the Interamerican Society for Tropical Horticulture 55:74-77.

Riahi A, Hdider C, Sanaa M, Tarchoun N, Kheder MB, Guezal I (2009). Effect of the conventional and organic production systems on the yield and quality of field tomato cultivars grown in Tunisia. Journal of the Science of Food and Agriculture 89:2275-2282.

Ríos-Osorio O, Carrillo-Rodríguez JC, Chávez-Servia JL, Vera-Guzmán AM (2014). Agromorphological variation and postharvest biophysical changes in fruits of tomato (*Solanum lycopersicum* L.). Revista de la Facultad de Ciencias Agrarias 46:29-44.

Rocchi L, Paolotti L, Cortina C, Boggia A (2016). Conservation of landrace: the key role of the value for agrobiodiversity conservation. An application on ancient tomatoes varieties. Agriculture and Agricultural Science Procedia 8:307-316.

Sanjuan F, Ramírez P, Sánchez P, Livera M, Sandoval M, Carrillo JC, Perales C (2014). Variation in characteristics of agricultural interest within a native tomato (*Solanum lycopersicum* L.) population. Revista Fitotecnia Mexicana 37:159-164.

SAS (1999). Procedures Guide, Version 8. SAS Institute Inc. Cary, NC, USA, P 1643.

Vargas TO, Alves EP, Abboud CS, Leal AA, Carmo GF (2015). Genetic diversity in heirloom tomato genotypes. Horticultura Brasileira 33:174-180.