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Morphological characterization of *Capsicum annuum* L. accessions from southern Mexico and their response to the *Bemisia tabaci-Begomovirus* complex

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The high diversity of chili pepper (*Capsicum annuum* L.) in Mexico offers an excellent alternative to search for wild and semi-domesticated genotypes as sources of resistance to the complex *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae)-*Begomovirus*, which has caused enormous losses in commercial production of various horticultural crops. The goal of the present work was to characterize *ex situ* 18 genotypes of *C. annuum* from southern Mexico through 47 morphological descriptors, and to evaluate its response to the *B. tabaci-Begomovirus* complex. Morphological characterization showed the variables calyx annular constriction (CAC), number of branch bifurcation (NBB), and calyx pigmentation (CP) had the highest variation. Principal components analysis (PCA) of 47 morphological characteristics showed that 12 components were selected as meaningful factors. These components explained 94% of the variation. Cluster analysis showed three major clusters and seven sub-clusters. On the other hand, evaluation of the response to *B. tabaci-Begomovirus* showed that the genotypes have differential susceptibility to this vector-pathogen complex. Genotypes 'Chawa', 'Blanco', 'Maax' and 'X´catic' were into the low susceptibility to *B. tabaci* and low severity of viral symptoms. Surprisingly, the genotype 'Simojovel' showed high susceptibility to whitefly, but was grouped into genotypes with low symptom severity. This study shows the potential of native germplasm of pepper to explore sources of resistance to the *B. tabaci-Begomovirus* complex.

Key words: Plant resistance, semi-cultivated peppers, whitefly.

INTRODUCTION

Chili pepper (*Capsicum annuum* L.) is a widely cultivated species that has been used since ancient times as food flavoring and for human health (Milla, 2006). Mexico, as center of domestication and genetic diversity of *C. annuum*, has the cultivated species *C. annuum* L. var. *annuum* and the wild *C. annuum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill (Loaiza-Figueroa et al., 1989). In southern Mexico chili pepper is cultivated in backyard gardens as well as in extensive areas as highly managed crop in Southern Mexico (Pérez-Castañeda et al., 2008). The first attempts to characterize the pepper germplasm in Southern Mexico showed a great genetic diversity of three species: *Capsicum frutescens* L., *C. annuum*, and *C. chinense* Jacq. (Castañón-Nájera et al., 2008; Pérez-Castañeda et al., 2008; Prado, 2008).

Commercial production of *C. annuum* faces various constraints, particularly those related to phytophagous insects. In this context, the whitefly *Bemisia tabaci* (Genn.) (Hemiptera: Aleyrodidae) is the most dangerous pest in tropical and neotropical regions (Brown and Bird, 1992). *Bemisia tabaci* induces losses in pepper crops by direct feeding and transmission of a wide variety of *Begomoviruses* (Oliveira et al., 2001). Management of the complex *B. tabaci-Begomovirus* has been typically carried out by chemical insecticides to control vector populations. This action has selected *B. tabaci* populations with high level of resistance (Elbert and Nauen, 2000). To cope with the potential risk associated to the use of chemical insecticides, host plant resistance to insects is an effective, economical, and environmentally friendly method for pest control. This alternative uses wild and semi-domesticated relatives of cultivated species as sources of pest resistance genes and in turn as an effective tool to minimize losses due to phytophagous insects or vector-borne virus diseases (Sharma and Ortiz, 2002).

Studies of plant resistance to the vector *B. tabaci* have found that this phytophagous is affected mainly by the external/physical characteristics of the leaf surface, such as hairiness, glandular trichomes, leaf shape and cuticle thickness (Berlinger, 1986; Boiça et al., 2007; Oriani and Vendramim, 2010; Oriani et al., 2011). Resistance to *B. tabaci* and its relation to plant morphological traits has been well documented in other crops, such as tomato, cotton, and cassava (Bellotti and Arias, 2001; Boiça et al., 2007; Oriani and Vendramim, 2010). Physical barriers,

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such as the cuticle thickness of leaf may prevent the insect stylet from reaching the phloem (Janssen et al., 1989), while the presence of high density of glandular trichomes may cause high mortality of whitefly as compounds act as a glued trap for adult whiteflies, in addition, the acylsugars produced by such trichomes deters settling and probing of *B. tabaci* (Heinz and Zalom, 1995; Liedl et al., 1995; Rodríguez-López et al., 2012). The internal characteristics of the leaves, such as chemical composition of leaf sap, nutritional value of leaves, and activity of plant defense-related enzymes has been also implicated but less studied in host resistance to *B. tabaci*. Particularly, the increased activity of plant defense-related enzymes can induce synthesis of toxic metabolites in leaves, which in turn can affect negatively the survivorship, growth and reproduction of herbivore insects (Bowles, 1990; McKenzie et al., 2002).

In field, severe population outbreaks of *B. tabaci* are usually accompanied by a high incidence of *Begomovirus*. This group of viruses is exclusively transmitted by *B. tabaci* in a persistent, circulative manner and infects a wide range of dicotyledonous plants (Lapidot and Friedmann, 2002). Studies on host plant resistance to *Begomovirus* have been carried out in various crops, such as tomato, bean, and cassava. The outcomes of such studies have been difficult to widely adopt due to the variation in occurrence of virus strains in certain geographic areas (Borah and Dasgupta, 2012).

The exploration of wild and semi-cultivated land-race genotypes of chili peppers offers an excellent opportunity to identify possible sources of resistance to the *B. tabaci-Begomovirus* complex. Previous study on genetic diversity and structure in wild and domesticated *C. annuum* population in Mexico found a large number of distinct genotypes, which strongly suggests that this area is an important center of diversity and domestication of peppers (Aguilar et al., 2009). As part of a long-term project to potentiate the local germplasm of *C. annuum*, the present study was carried out to characterize the morphological diversity of *C. annuum* from southern Mexico (Chiapas, Tabasco, and the Yucatan Peninsula) and to evaluate the response of such genotypes to the *B. tabaci-Begomovirus* complex.

MATERIAL AND METHODS

Genotypes collection and seedling establishment

Wild and semi-cultivated genotypes of *C. annuum* were collected in home gardens and rural markets in the states of Tabasco, Chiapas, and Yucatan (Table 1). Two commercial genotypes ('Jalapeño' and 'Pimiento') were also included in the collection as standard controls for susceptibility to the *B. tabaci-Begomovirus* complex. To homogenize germination, seeds obtained from dried fruits were immersed in 250 mL water containing 250 mg L^{-1} gibberellic acid (Plant Health Care, México DF., México) for 48 h. Seeds were kept in constant oxygenation using an aquarium air pump (Hagen Elite 803, Montreal, Quebec, Canada). Seeds were sown in polystyrene trays using Cosmopeat® (Cosmocel, Canada) as substrate. Seedling was maintained with 60% of moisture in the substrate and fertilized twice a week with 2 g L^{-1} of Triple 17® (FLUGSA, Mexico DF., Mexico) dissolved in the irrigation water.

Table 1. Origin of *Capsicum annuum* genotypes evaluated in this study.

Genotype	Origin site	Collected from	State
Xcat´ik	Conkal	Rural market	Yucatán
Chawa	Conkal	Home garden	Yucatán
Maax	Tizimín	Home garden	Yucatán
Güero	Macuspana	Rural market	Tabasco
Pico paloma	Tizimín	Home garden	Yucatán
Simojovel	Simojovel	Rural market	Chiapas
Amaxito	Villahermosa	Rural market	Tabasco
Pozol	Tuxtla Gtz	Rural market	Chiapas
Blanco	Villaflores	Home garden	Chiapas
Bolita	Suchiapa	Home garden	Chiapas
Jalapeño	Comercial	--	--
Pimiento	Comercial	--	--
Miraparriba	Tuxtla Gtz	Rural market	Chiapas
Dulce	Conkal	Rural market	Yucatán
Crespo	Comitán	Rural market	Chiapas
Sucurre	Yaxcabá	Home garden	Yucatán
Pijadegato	Suchiapa	Home garden	Chiapas
Verde	Chontalpa	Home garden	Tabasco

Establishment of pepper genotypes in field

The experiment was carried out at the Instituto Tecnológico de Conkal, located in Conkal (21°06' N, 89°31' W, 10 m a.s.l.), Yucatan, Mexico. Köppen climate classification is AWo"(X'),(i') g, tropical wet and dry, the average annual high temperatures range from 28 to 36 °C, and the low temperatures range between 18 to 23 °C. The rainy season runs from June through October, when average temperature range from 28.5 to 26.8 °C. The year rainfall is in average 1036.9 mm. The soil type is litosol/rendzina, usually stony, highly alkaline, and with low content of organic matter (Cabadas et al., 2010).

The pepper plantation was established in a randomized block design with three replicates. Forty-day-old seedlings of all genotypes were individually transplanted in small plots (4 m × 2 m) that contained 16 plants. Plants were fertilized with the formula 250-200-150, supplied in the dripping irrigation system. No application of insecticide was carried out to allow successful infestation of *B. tabaci*.

Morphological characterization of pepper genotypes

Morphological characteristics were taken from *Capsicum* descriptors documented by IPGRI, AVRDC and CATIE (1995). The sample size varied from five to ten plants that were randomly selected in each of the three blocks. For leaf, flower and fruit traits, three to ten samples were taken per selected plant. Forty seven morphological

characteristics were measured; 17 for plant: Plant height (PH, cm), number of branch bifurcation (NBB), stem shape (SS), stem pubescence (SP), plant growth habit (PGH), plant canopy width (PCW, cm), stem length (SL, cm), stem diameter (SD, cm), branching habit (BH), tillering (T), leaf density (LD), leaf color (LC), leaf shape (LS), lamina margin (LM), leaf pubescence (LP), mature leaf length (MLL, cm), and mature leaf width (MLW, cm); 14 for flower: Days to flowering (DF), number of flowers per axil (NFA), flower position (FP), corolla color (CC), corolla shape (CS), anther color (AC), filament color (FC), calyx pigmentation (CP), calyx margin (CM), calyx annular constriction (CAC), corolla length (CL, cm), anther length (AL, mm), filament length (FiL, mm), and pistil length (PiL, mm); and 16 for fruits: Fruit length (FL, cm), pedicel length (PeL, cm), fruit color at intermediate stage (FCIS), fruit shape (FS), fruit shape at pedicel attachment (FSPA), fruit shape at blossom end (FSBE), neck at base of fruit (NBF), fruit blossom end appendage (FBEA), type of fruit surface (TFS), number of locules (NL), fruit diameter (FD, cm), fruit wall (FW), placenta length (PL, cm), pedicel with fruit (PF), pedicel with stem (PS), and fruit cross-sectional corrugation (FCSC).

Evaluation of whitefly population in pepper leaves

Population densities of whitefly adults, eggs and nymphs (first to fourth instar) in pepper leaves were evaluated in five sampling times. Sampling time 1 was carried out 30 d after transplant and the four subsequent samples were taken at 15 d intervals. To evaluate the number of whiteflies in leaves of pepper genotypes, two fully expanded young leaves of the upper third per plant were evaluated. Number of adults in the leaves was directly counted in the field by carefully observing abaxial side of selected leaves. Leaves then were detached and taken to the laboratory, where they were individually observed, and eggs and nymphs were counted in a stereomicroscope (BME L13395H11, Leica, Wetzlar, Germany). Leaf area was measured in a leaf area meter (LI-3100C, Li-Cor, Lincoln, Nebraska, USA). Results were expressed as number of nymphs per squared centimeter.

Evaluation of viral incidence and severity

Incidence and severity of viral symptoms were evaluated weekly. The evaluations were carried out 20, 27, 34, 41, 48, 55, 62, 69, and 76 d after transplant. For viral incidence, percent of plants with symptoms was determined based on the total number of plants in each plot replicate. For viral severity, a scale of five levels was modified from Anaya-López et al. (2003): Level 1, asymptomatic; level 2, slight crumpling and presence of yellow spots on apical leaves; level 3, groups of yellow spots coalesced forming a network on the base of apical leaves and protuberances observable in the middle zone of apical leaves; level 4, network clearly visible and slight leaf curling; level 5, severe yellowing/distortion of leaves.

Data analyses

The morphological characterization was analyzed with descriptive statistics. Principal Component Analysis (PCA) was carried out with the statistics mean and modes of each variable, which allow for the identification of the most important variables in the description of the observed variance of germplasm. Hierarchical Cluster Analysis (CA) was carried out with the most valued variables from the PCA. Cluster Analysis was determined by Unweighted Pair Group Method with Arithmetic Mean (UPGMA), where the differences among elements were calculated using the Euclidian Distance as a Similarity Metric. ANOVA and mean comparison for whitefly population and intensity of viral symptoms were performed by Scott-Knott test (Scott and Knott, 1974). Incidence and severity of viral symptoms were transformed to area under the disease progress curve as described by Campbell and Madden (1990). Comparisons of means were considered significantly different if $P < 0.05$. Prior to run, data in percent were transformed to $y = \arcsin(\sqrt{(x/100)})$. The rate of apparent incidence and severity over time were estimated following the logistic model as the regression coefficient of the *logit x* on time in days (van der Plank, 1963). All data were analyzed in the statistical software InfoStat (Di Rienzo et al., 2008). The relationships among the 17 morphological characteristics of 18 pepper genotypes, and the complex *B. tabaci* (nymphs and adults abundance only)-*Begomovirus* (severity and incidence) was assessed using Redundancy Analysis (RDA; Legendre and Legendre, 1998), which was selected over Canonical Correspondence Analysis because of reduced length of gradient of our variables (Ter Braak and Smilauer, 2002). The length of gradients was calculated by detrended correspondence analysis (Hill, 1979). The significance of each indicator of severity and incidence, as well as the first axis, was tested within the forward selection procedure using a Monte Carlo random permutation test (499 permutation, $P \leq 0.05$). The analysis was performed using Canoco 4.5 (Ter Braak and Smilauer, 2002).

RESULTS AND DISCUSSION

Variation in morphologic characteristics of the pepper genotypes

All the *C. annuum* genotypes displayed variation for all the morphological characteristics evaluated in the present work (Table 2). Days to flowering (DF) and fruit color at intermediate stage (FCIS) were the variable with minor variation (coefficient of variation CV 8.07 and 13.17, respectively). In other studies, low variation in DF has been also observed. For example, Sharma et al. (2010) found 8.18% CV in DF in a collection of accessions of sweet pepper *C. annuum*. Although we observed low CV for FCIS, other studies have reported the opposite, like that of Sudré et al. (2010), who showed high CV in fruit

Table 2. Central tendency and dispersion values obtained with 47 morphological characteristics in 18 *Capsicum annuum* genotypes from Southern Mexico.

Morphological characteristic	nr	Mean ± SE	Value		Coefficient of variation (%)
			Min.	Max.	
Plant height	326	44.21 ± 0.91	0.0	86	37.26
Number of branch bifurcation	327	1.74 ± 0.12	0.0	101	287.06
Stem shape	327	1.30 ± 0.03	1.0	2	35.28
Stem pubescence	324	3.68 ± 0.05	3.0	5	25.78
Plant growth habit	327	6.27 ± 0.08	3.0	7	22.03
Plant canopy width	322	28.81 ± 0.64	4.0	63	39.88
Stem length	316	6.25 ± 0.44	0.0	88	125.54
Stem diameter	315	1.02 ± 0.04	0.0	9	75.44
Branching habit	327	5.02 ± 0.07	3.0	7	23.87
Tillering	325	5.61 ± 0.07	3.0	7	23.83
Leaf density	327	5.86 ± 0.07	3.0	7	20.55
Leaf color	328	3.97 ± 0.05	3.0	5	24.46
Leaf shape	328	2.43 ± 0.04	1.0	3	28.66
Lamina margin	329	1.16 ± 0.02	1.0	2	31.54
Leaf pubescence	329	3.36 ± 0.04	3.0	5	22.87
Mature leaf length	323	7.22 ± 0.17	2.0	17	42.03
Mature leaf width	319	4.04 ± 0.11	0.9	11	49.50
Days to flowering	233	56.12 ± 0.30	50.0	62	8.07
Number of flowers per axil	239	2.42 ± 0.04	1.0	3	23.69
Flower position	239	5.89 ± 0.10	3.0	7	25.58
Corolla color	239	1.83 ± 0.09	1.0	4	73.50
Corolla shape	239	1.31 ± 0.03	1.0	2	35.35
Anther color	239	3.68 ± 0.06	2.0	5	25.43
Filament color	239	1.59 ± 0.08	1.0	6	79.01
Calyx pigmentation	239	0.22 ± 0.03	0.0	1	190.03
Calyx margin	239	5.16 ± 0.10	3.0	7	30.51
Calyx annular constriction	239	0.03 ± 0.01	0.0	1	576.90
Corolla length	239	1.77 ± 0.03	1.0	3	30.02
Anther length	239	2.49 ± 0.04	1.0	4	24.38
Filament length	239	2.61 ± 0.05	1.0	4	27.06
Pistil length	239	5.27 ± 0.06	3.0	8	16.91
Fruit length	360	5 ± 0.17	0.5	16	62.94
Pedicel length	360	3.09 ± 0.06	0.7	7	34.64
Fruit color at intermediate stage	360	2.83 ± 0.02	2.0	3	13.17
Fruit shape	360	2.06 ± 0.07	1.0	5	65.90
Fruit shape at pedicel attachment	360	2.33 ± 0.06	1.0	5	49.55
Fruit shape at blossom end	360	1.78 ± 0.04	1.0	3	40.07
Neck at base of fruit	360	0.39 ± 0.03	0.0	1	125.53
Fruit blossom end appendage	360	0.39 ± 0.03	0.0	1	125.53
Type of fruit surface	360	1.56 ± 0.03	1.0	2	31.98
Number of locules	360	2.33 ± 0.04	2.0	4	28.61
Fruit diameter	360	2.20 ± 0.08	0.7	7	72.93
Fruit wall	360	1.96 ± 0.05	1.0	4	48.05
Placenta length	360	2.56 ± 0.03	2.0	3	19.47
Pedicel with fruit	360	5.67 ± 0.07	3.0	7	23.56
Pedicel with stem	360	4.22 ± 0.06	3.0	7	28.01
Fruit cross-sectional corrugation	360	3.33 ± 0.05	3.0	7	30.04

color when assessing the morphological and agronomic characteristics of *Capsicum* species.

On the other hand, the highest CV of our pepper collection were observed in calyx annular constriction (CAC), number of branch bifurcation (NBB) and calyx pigmentation (CP), which showed CV values of 576.9, 287.06, and 190.03, respectively (Table 2). Due to its wide variation, CAC has been established as a descriptor of great importance in pepper, even to distinguish among pepper species (Sudré et al., 2010). The high variation in CAC in our study supports the idea of a high intra-genotypes variation in *C. annuum* (Castañón-Nájera et al., 2008). Other authors have also documented various characteristics with high variation in *C. annuum* genotypes, for example, fruit yield per plant (Ukkund et al., 2007), number of fruits per plant (Sreelathakumary and Rajamony, 2002), and plant height (Ibrahim et al., 2001).

Principal components analysis of morphologic characteristics of pepper genotypes

Principal components analysis (PCA) was performed using 47 morphological characteristics. Twelve components were selected as meaningful factors with eigenvalues > 1. These components explained 94% of the variation. The first principal component (PC 1) explained 22% of total variation in original data, second component (PC 2) explained 15%, and third principal component (PC 3) explained 11% of variation. The other principal components (PC 4-PC 12) explained an additional 46% of the variation (a total 94% of explained variation, Table 3). The percentages of variance explained by the 12 components and the correlation between the PC and the original morphological characteristics of the pepper genotypes are shown in Table 3. The 94% total variability obtained in PCA indicated an adequate percentage of variation, as indicated by Pla (1986), who suggests at least an 80% total variability. Likewise, the number of PC formed indicates high variation in *C. annuum* genotypes as reported by Matthew et al. (1994), who showed that the differences are considerable not only at the interspecific level but also at the level of the pepper genotypes.

The PC 1 was contributed by positive loading of CL, FiL, PiL, FL, FD, FW, and PF, followed by negative and minor loading of T, LD, and FC. The PC 2 was strongly contributed by positive loading of MLL and MLW, followed by negative and minor loading of NBB, NFA, CS, FS, and FSBE. The PC 3 was contributed by positive loading for FCSC, followed by negative and minor loading of BH, AL and NBF (Table 3; Figure 1). As for the PC1, only FD, FCSC, and FL have been previously reported as important contributors to the main principal component in morphological characterization of *C. annuum* (Latournerie et al., 2002; Castañón-Nájera et al., 2008). Notably, fruit morphological characteristics were the principal contributors in this case, which is in agreement with the studies mentioned above. This is the result of the major variation in fruit shape of *C. annuum* complexes (Pardey et al., 2006; Moscone et al., 2007; Castañón-Nájera et al., 2010).

Hierarchical clustering of pepper genotypes

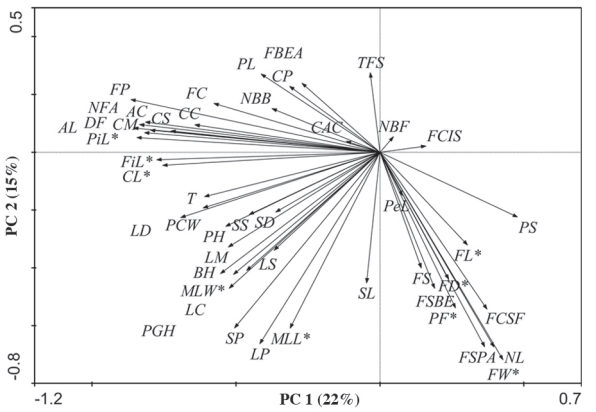
In the hierarchical clustering analysis, three major clusters of pepper genotypes and seven sub-clusters were observed (Figure 2). The subgroup 1 included genotypes: 'Pijadegato', 'Chawa', 'Miraparriba', and 'Blanco' (Euclidean distance between 10 and 12.5); subgroup 2: 'Pimiento' and 'Jalapeño' (Euclidean distance to ~10);

Table 3. Variance explained by twelve principal components derived from 47 morphological characteristics of *Capsicum annuum* genotypes, and the weights of the original variables in each component.

	Principal component axis											
	1	2	3	4	5	6	7	8	9	10	11	12
Eigenvalues	10.27	7.08	5.22	4.37	3.76	3.13	2.85	1.99	1.71	1.62	1.46	1.11
Explained proportion of variation, %	22	15	11	9	8	7	6	4	4	3	3	2
Cumulative proportion of variation, %	22	37	48	57	65	72	78	82	86	89	92	94
	Correlations with original variable											
PH	-0.34	0.41	0.27	0.48	0.20	0.31	-0.40	0.08	0.19	0.01	-0.05	-0.14
NBB	-0.49	-0.67	-0.02	0.14	-0.09	0.08	0.20	0.22	0.23	-0.25	-0.22	-0.03
SS	-0.32	0.22	0.04	0.16	-0.32	0.76	0.07	-0.23	0.21	-0.03	0.07	-0.04
SP	0.11	0.27	0.36	0.36	0.35	-0.26	0.32	-0.27	-0.02	0.18	-0.33	0.12
PGH	-0.34	0.36	0.63	0.28	-0.04	0.13	-0.21	-0.12	-0.01	0.13	0.07	0.39
PCW	-0.37	-0.41	0.02	0.65	-0.03	-0.31	-0.26	0.05	0.11	-0.07	0.04	-0.08
SL	0.36	0.38	-0.05	-0.36	-0.45	-0.33	-0.04	-0.02	0.21	-0.39	-0.24	-0.01
SD	0.22	-0.16	0.14	-0.22	0.77	0.03	-0.00	0.01	0.38	0.10	0.09	0.10
BH	0.43	-0.38	-0.55	0.07	0.39	-0.03	0.00	0.12	0.15	0.13	-0.04	0.16
T	-0.66	-0.46	-0.20	-0.06	0.03	0.27	0.04	-0.10	-0.20	0.25	-0.09	-0.02
LD	-0.57	-0.04	-0.21	0.06	0.61	0.22	0.14	-0.11	0.15	0.30	-0.07	-0.04
LC	-0.16	0.27	-0.30	0.09	-0.46	-0.29	0.21	0.43	-0.29	0.27	-0.23	-0.05
LS	0.12	-0.42	0.09	-0.45	0.21	0.34	-0.49	0.03	0.07	-0.34	-0.24	-0.02
LM	0.09	0.07	-0.06	-0.13	-0.45	-0.64	-0.18	-0.06	0.31	0.39	-0.04	0.25
LP	0.16	0.53	0.06	0.14	0.48	-0.21	0.27	-0.02	-0.21	-0.31	-0.18	0.37
MLL	0.36	0.80	0.29	-0.05	-0.17	-0.15	0.06	0.03	-0.05	-0.12	0.11	-0.19
MLW	0.23	0.89	0.10	0.07	-0.02	-0.00	0.22	0.14	0.12	-0.00	0.13	0.00
DF	-0.39	0.56	0.12	-0.52	0.15	-0.18	-0.17	-0.02	-0.07	0.05	0.25	-0.06
NFA	0.22	-0.62	0.06	0.56	-0.27	-0.16	-0.26	-0.16	-0.11	-0.08	0.06	-0.02
FP	-0.48	0.07	-0.41	-0.25	0.04	-0.01	0.53	-0.24	-0.08	-0.19	-0.07	-0.23
CC	-0.48	0.50	0.24	-0.03	-0.00	-0.11	0.48	0.15	0.24	0.21	0.01	-0.10
CS	0.24	-0.62	0.14	0.23	-0.12	-0.02	0.12	0.21	-0.14	0.07	0.52	0.29
AC	-0.34	0.05	0.33	-0.11	-0.60	0.37	0.25	-0.06	0.04	0.26	-0.23	0.19
FC	-0.61	0.02	0.34	-0.41	0.06	0.08	0.21	-0.17	0.15	-0.11	0.08	0.01
CP	-0.27	-0.22	-0.26	0.11	-0.01	0.13	0.23	0.73	0.15	-0.16	0.27	0.05
CM	0.38	-0.22	-0.44	0.62	0.08	0.10	0.23	-0.18	-0.00	-0.19	-0.24	0.10
CAC	-0.06	0.24	-0.20	0.58	-0.21	0.08	-0.28	0.10	0.58	0.07	-0.05	-0.13
CL	0.90	0.04	-0.05	0.30	-0.08	0.06	-0.15	-0.00	-0.02	-0.11	-0.08	-0.08
AL	0.63	0.12	-0.59	-0.01	0.10	-0.04	0.30	-0.13	0.23	-0.07	0.24	0.00
FiL	0.89	-0.01	0.08	0.19	0.10	-0.18	0.14	0.13	0.08	0.05	0.10	-0.19
PiL	0.72	-0.13	-0.41	-0.16	0.01	-0.21	0.14	-0.00	0.24	-0.07	-0.08	0.09
FL	0.74	0.29	-0.18	-0.21	0.13	0.39	-0.09	-0.02	-0.00	0.19	0.05	-0.01
PeL	0.34	0.62	-0.02	0.42	-0.06	0.24	0.19	0.38	-0.00	0.13	-0.05	-0.19
FCIS	-0.07	-0.33	-0.05	-0.57	0.10	-0.05	-0.29	0.53	0.10	0.26	-0.30	0.10
FS	-0.11	-0.50	0.55	0.03	0.17	-0.22	0.45	0.21	-0.19	-0.07	-0.11	-0.20
FSPA	0.57	-0.13	0.63	0.24	-0.01	0.27	0.24	-0.04	-0.05	-0.10	0.25	0.02
FSBE	0.30	-0.61	0.20	-0.41	0.13	-0.06	0.15	-0.10	0.09	0.11	0.11	-0.37
NBF	0.33	0.13	-0.50	-0.14	0.04	0.66	0.28	0.18	-0.09	0.05	0.04	0.21
FBEA	0.05	-0.33	-0.59	0.28	-0.11	-0.14	0.13	-0.39	-0.10	0.45	0.14	-0.15
TFS	0.05	0.55	-0.32	0.24	0.33	0.14	-0.43	0.05	-0.26	0.07	-0.19	-0.21
NL	0.59	-0.36	0.60	0.08	-0.26	0.07	0.13	-0.08	0.17	-0.02	-0.09	0.01
FD	0.74	-0.18	0.51	-0.05	0.10	0.19	0.10	0.04	0.02	0.19	-0.19	-0.02
FW	0.78	0.06	0.05	-0.42	-0.18	0.02	-0.01	-0.22	0.28	0.13	0.02	-0.03
PL	-0.55	-0.22	-0.24	-0.03	-0.59	0.22	0.25	-0.08	0.21	-0.13	-0.10	0.01
PF	0.85	-0.01	-0.21	-0.07	-0.18	0.22	0.14	-0.04	-0.16	0.04	-0.28	0.09
PS	0.56	-0.09	-0.01	-0.35	-0.44	0.27	-0.27	0.06	-0.33	0.06	0.12	-0.07
FCSC	0.42	-0.38	0.70	0.12	0.11	0.07	0.11	0.14	0.00	0.19	-0.20	-0.14

PH: plant height; NBB: number of branch bifurcation; SS: stem shape; SP: stem pubescence; PGH: plant growth habit; PCW: plant canopy width; SL: stem length; SD: stem diameter; BH: branching habit; T: tillering; LD: leaf density; LC: leaf color; LS: leaf shape; LM: lamina margin; LP: leaf pubescence; MLL: mature leaf length; MLW: mature leaf width; DF: days to flowering; NFA: number of flowers per axil; FP: flower position; CC: corolla color; CS: corolla shape; AC: anther color; FC: filament color; CP: calyx pigmentation; CM: calyx margin; CAC: calyx annular constriction; CL: corolla length; AL: anther length; FiL: filament length; PiL: pistil length. FL: fruit length; PeL: pedicel length; FCIS: fruit color at intermediate stage; FS: fruit shape; FSPA: fruit shape at pedicel attachment; FSBE: fruit shape at blossom end; NBF: neck at base of fruit; FBEA: fruit blossom end appendage; TFS: type of fruit surface; NL: number of locules; FD: fruit diameter; FW: fruit wall; PL: placenta length; PF: pedicel with fruit; PS: pedicel with stem; FCSC: fruit cross-sectional corrugation.

subgroup 3: 'X'catic' and 'Güero' (Euclidean distance to ~12); subgroup 4: 'Pozol'; subgroup 5: 'Verde', 'Simojovel', 'Picopaloma', 'Dulce', and 'Crespo' (Euclidean distance between 10 and 12.5); group 6: 'Sucurre'; and group 7: 'Maax', 'Bolita', and 'Amaxito' (Euclidean distance between 10 and 12). The first major cluster included only subgroup 1. The second major cluster included groups 2 and 3, and the third major cluster included groups 4, 5, 6, and 7. The clustering showed a clear distinction between some pepper genotypes.



PH: plant height; NBB: number of branch bifurcation; SS: stem shape; SP: stem pubescence; PGH: plant growth habit; PCW: plant canopy width; SL: stem length; SD: stem diameter; BH: branching habit; T: tillering; LD: leaf density; LC: leaf color; LS: leaf shape; LM: lamina margin; LP: leaf pubescence; MLL: mature leaf length; MLW: mature leaf width; DF: days to flowering; NFA: number of flowers per axil; FP: flower position; CC: corolla color; CS: corolla shape; AC: anther color; FC: filament color; CP: calyx pigmentation; CM: calyx margin; CAC: calyx annular constriction; CL: corolla length; AL: anther length; FiL: filament length; PiL: pistil length. FL: fruit length; PeL: pedicel length; FCIS: fruit color at intermediate stage; FS: fruit shape; FSPA: fruit shape at pedicel attachment; FSBE: fruit shape at blossom end; NBF: neck at base of fruit; FBEA: fruit blossom end appendage; TFS: type of fruit surface; NL: number of locules; FD: fruit diameter; FW: fruit wall; PL: placenta length; PF: pedicel with fruit; PS: pedicel with stem; FCSC: fruit cross-sectional corrugation.

Figure 1. Biplot graph of 18 genotypes of *Capsicum annuum* based on 47 morphological traits. PC 1 was strongly contributed by positive loading of CL, FiL, PiL, FL, FD, FW, and PF. PC 2 was strongly contributed by positive loading of MLL and MLW. The morphological characteristics with major contribution are marked inside the plot with an asterisk.

For example, commercial genotypes were noticeable in subgroup 2. These results match those found by Chávez and Castillo (1999) working with accessions of *C. pubescens*, and Castañón-Nájera et al. (2008) working with *C. annuum* genotypes. These authors found that commercial peppers have an oblique fruit position, in contrast to erect fruit position of wild peppers. Similarly, Hernández et al. (2006) showed the same pattern when separating wild from commercials genotypes. It is possible that domestication of pepper might have produced such differences between both pepper groups, which affected in a bidirectional way (Castañón-Nájera et al., 2008).

Response of peppers to the *Bemisia tabaci-Begomovirus* complex

Pepper genotypes showed distinct levels of susceptibility to *B. tabaci*. Adult population in leaves varied significantly among pepper genotypes at 45 and 60 d after transplant (dat); in both recording times the genotype "Simojovel" showed the highest number of adult in leaves (mean ± standard error SE: ranking 0.05 ± 0.2 to 0.06 ± 0.02). In the evaluation at 45 dat genotypes 'Bolita', 'Amaxito', 'Crespo', 'Maax' and 'Verde' showed also higher number of adults (ranking 0.04 ± 0.0 to 0.04 ± 0.01) in leaves than that by the rest of the genotypes (Table 4). Egg population of whitefly in leaves showed no difference among pepper

Table 4. Mean (± SE) number of adults per cm² of *Bemisia tabaci* in leaves of *Capsicum annuum* at different days after transplant (dat).

Genotype	30 dat	45 dat	60 dat	75 dat	100 dat
Güero	0.03 ± 0.02a	0.03 ± 0.02c	0.01 ± 0.00b	0.01 ± 0.00a	0.02 ± 0.01a
Pozol	0.02 ± 0.00a	0.01 ± 0.01c	0.01 ± 0.01b	0.01 ± 0.01a	0.01 ± 0.00a
Simojovel	0.01 ± 0.00a	0.06 ± 0.02a	0.05 ± 0.02a	0.00 ± 0.00a	0.02 ± 0.01a
Chawa	0.02 ± 0.00a	0.03 ± 0.01c	0.00 ± 0.00b	0.01 ± 0.01a	0.02 ± 0.01a
Bolita	0.03 ± 0.01a	0.04 ± 0.01b	0.02 ± 0.01b	0.01 ± 0.00a	0.01 ± 0.00a
Amaxito	0.02 ± 0.01a	0.04 ± 0.01b	0.02 ± 0.01b	0.01 ± 0.00a	0.01 ± 0.01a
Pimiento	0.00 ± 0.00a	0.02 ± 0.01c	0.00 ± 0.00b	0.01 ± 0.01a	0.01 ± 0.01a
Miraparriba	0.01 ± 0.00a	0.02 ± 0.00c	0.01 ± 0.01b	0.01 ± 0.01a	0.02 ± 0.01a
Picopaloma	0.02 ± 0.00a	0.03 ± 0.01c	0.01 ± 0.01b	0.01 ± 0.01a	0.01 ± 0.01a
Jalapeño	0.02 ± 0.01a	0.02 ± 0.01c	0.01 ± 0.01b	0.01 ± 0.01a	0.01 ± 0.00a
Dulce	0.01 ± 0.01a	0.01 ± 0.00c	0.01 ± 0.00b	0.00 ± 0.00a	0.01 ± 0.00a
Blanco	0.02 ± 0.00a	0.01 ± 0.01c	0.00 ± 0.00b	0.01 ± 0.01a	0.01 ± 0.01a
Crespo	0.01 ± 0.00a	0.04 ± 0.01b	0.01 ± 0.00b	0.02 ± 0.01a	0.02 ± 0.01a
Sucurre	0.01 ± 0.01a	0.02 ± 0.01c	0.00 ± 0.00b	0.01 ± 0.00a	0.01 ± 0.00a
Pijadegato	0.01 ± 0.01a	0.01 ± 0.00c	0.00 ± 0.00b	0.00 ± 0.00a	0.01 ± 0.00a
Maax	0.02 ± 0.01a	0.04 ± 0.01b	0.02 ± 0.01b	0.01 ± 0.00a	0.01 ± 0.01a
X´catic	0.00 ± 0.00a	0.01 ± 0.00c	0.01 ± 0.01b	0.02 ± 0.01a	0.01 ± 0.01a
Verde	0.02 ± 0.01a	0.04 ± 0.01b	0.03 ± 0.02b	0.01 ± 0.00a	0.02 ± 0.01a

Values are means ± standard error of adults/cm² in leaves of *Capsicum annuum* genotypes.
Values with the same letter within a column are not significantly different according to Scott-Knott cluster analysis (P ≤ 0.05).

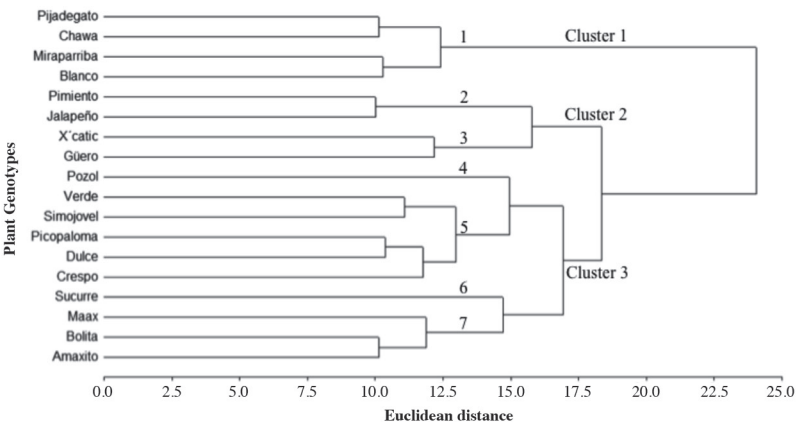


Figure 2. Cluster analysis of 18 genotypes of *Capsicum annuum* based on Euclidean distance using 47 plant, flower and fruit traits. Numbers 1 to 7 are subgroups formed inside each major cluster.

genotypes (Table 5). Nymphal population in leaves varied significantly among pepper genotypes at 45, 60, and 75 dat, while no difference was observed at 30 and 90 dat (Table 6). In general, 'Chawa', 'Pimiento', 'Dulce', 'Blanco', 'Sucurre', 'Pijadegato', 'Maax', 'X´catic' and 'Verde' showed lower number of nymphs (ranking 0.00 ± 0.0 to 0.03 ± 0.02) on leaves when compared to the rest of the genotypes. In contrast, higher numbers of nymphs on leaves were observed in the genotypes 'Simojovel' and 'Crespo' (ranking 0.08 ± 0.02 to 0.12 ± 0.03).

The intensity of the viral symptoms was evaluated by recording the incidence and severity of plant symptoms. Interestingly, no difference (Scott-Knott P > 0.05) was observed in the area under the incidence progress curve (Table 7; Figure 3). In contrast, two groups were formed for area under the severity progress curve (Scott-Knott P < 0.05), where the low severity group was formed by 'Dulce', 'Verde', 'X´catic', 'Chawa', 'Blanco', 'Amaxito', 'Miraparriba', 'Maax', and 'Simojovel' (ranking 7.75 ± 4.51 to 84.62 ± 16.64). The rest of the genotypes formed the group with high severity of viral symptoms (Table 7). The latter genotypes showed values (mean ± SE) that ranged from 97.87 ± 10.24 to 131.87 ± 10.16 for area under the severity progress curve.

Possible relationships among morphological characteristics of the genotypes and susceptibility to

Table 5. Mean (± SE) number eggs *Bemisia tabaci* cm^{-2} in leaves of *Capsicum annuum* at different days after transplant (dat).

Genotype	30 dat	45 dat	60 dat	75 dat	100 dat
Güero	0.03 ± 0.02a	0.02 ± 0.01a	0.02 ± 0.01a	0.01 ± 0.01a	0.01 ± 0.00a
Pozol	0.01 ± 0.00a	0.03 ± 0.02a	0.02 ± 0.01a	0.02 ± 0.01a	0.02 ± 0.01a
Simojovel	0.02 ± 0.01a	0.04 ± 0.02a	0.03 ± 0.02a	0.01 ± 0.01a	0.01 ± 0.01a
Chawa	0.02 ± 0.01a	0.03 ± 0.01a	0.03 ± 0.01a	0.00 ± 0.00a	0.01 ± 0.00a
Bolita	0.03 ± 0.01a	0.01 ± 0.01a	0.01 ± 0.01a	0.00 ± 0.00a	0.01 ± 0.01a
Amaxito	0.00 ± 0.00a	0.02 ± 0.01a	0.01 ± 0.01a	0.00 ± 0.00a	0.01 ± 0.00a
Pimiento	0.01 ± 0.01a	0.01 ± 0.01a	0.01 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a
Miraparriba	0.02 ± 0.02a	0.00 ± 0.00a	0.04 ± 0.02a	0.00 ± 0.00a	0.02 ± 0.01a
Picopaloma	0.01 ± 0.00a	0.01 ± 0.01a	0.01 ± 0.01a	0.00 ± 0.00a	0.00 ± 0.00a
Jalapeño	0.04 ± 0.01a	0.02 ± 0.01a	0.03 ± 0.02a	0.01 ± 0.01a	0.01 ± 0.00a
Dulce	0.00 ± 0.00a	0.01 ± 0.00a	0.01 ± 0.01a	0.00 ± 0.00a	0.02 ± 0.01a
Blanco	0.00 ± 0.00a	0.04 ± 0.02a	0.00 ± 0.00a	0.00 ± 0.00a	0.01 ± 0.00a
Crespo	0.02 ± 0.00a	0.04 ± 0.02a	0.02 ± 0.01a	0.01 ± 0.00a	0.01 ± 0.01a
Sucurre	0.00 ± 0.00a	0.02 ± 0.01a	0.01 ± 0.01a	0.00 ± 0.00a	0.01 ± 0.00a
Pijadegato	0.01 ± 0.01a	0.00 ± 0.00a	0.00 ± 0.00a	0.00 ± 0.00a	0.01 ± 0.00a
Maax	0.02 ± 0.01a	0.03 ± 0.01a	0.03 ± 0.02a	0.00 ± 0.00a	0.01 ± 0.01a
X´catic	0.00 ± 0.00a	0.01 ± 0.00a	0.01 ± 0.01a	0.01 ± 0.01a	0.01 ± 0.00a
Verde	0.00 ± 0.00a	0.01 ± 0.01a	0.02 ± 0.01a	0.01 ± 0.00a	0.01 ± 0.01a

Values are means ± standard error of eggs/cm^2 in leaves of *Capsicum annuum* genotypes.
Values with the same letter within a column are not significantly different according to Scott-Knott cluster analysis (P ≤ 0.05).

Table 6. Mean (± SE) number *Bemisia tabaci* nymphs cm^{-2} in leaves of *Capsicum annuum* at different days after transplant (dat).

Genotype	30 dat	45 dat	60 dat	75 dat	100 dat
Güero	0.06 ± 0.02a	0.04 ± 0.02b	0.06 ± 0.02b	0.05 ± 0.03b	0.02 ± 0.02a
Pozol	0.04 ± 0.00a	0.05 ± 0.02b	0.01 ± 0.01c	0.01 ± 0.01c	0.01 ± 0.01a
Simojovel	0.04 ± 0.01a	0.08 ± 0.02a	0.04 ± 0.02c	0.12 ± 0.03a	0.03 ± 0.01a
Chawa	0.03 ± 0.03a	0.01 ± 0.01c	0.02 ± 0.01c	0.02 ± 0.01c	0.02 ± 0.01a
Bolita	0.03 ± 0.01a	0.05 ± 0.01b	0.04 ± 0.01c	0.06 ± 0.01b	0.01 ± 0.01a
Amaxito	0.02 ± 0.01a	0.04 ± 0.01b	0.01 ± 0.01c	0.00 ± 0.00c	0.02 ± 0.01a
Pimiento	0.02 ± 0.01a	0.02 ± 0.01c	0.00 ± 0.00c	0.03 ± 0.01c	0.01 ± 0.01a
Miraparriba	0.02 ± 0.02a	0.00 ± 0.00c	0.05 ± 0.01b	0.01 ± 0.01c	0.02 ± 0.01a
Picopaloma	0.02 ± 0.00a	0.02 ± 0.01c	0.05 ± 0.01b	0.03 ± 0.01c	0.01 ± 0.01a
Jalapeño	0.02 ± 0.01a	0.03 ± 0.02c	0.02 ± 0.01c	0.06 ± 0.01b	0.01 ± 0.01a
Dulce	0.01 ± 0.01a	0.00 ± 0.00c	0.03 ± 0.01c	0.00 ± 0.00c	0.02 ± 0.01a
Blanco	0.01 ± 0.00a	0.01 ± 0.01c	0.01 ± 0.01c	0.02 ± 0.01c	0.01 ± 0.01a
Crespo	0.01 ± 0.00a	0.01 ± 0.01c	0.09 ± 0.03a	0.08 ± 0.03b	0.02 ± 0.01a
Sucurre	0.00 ± 0.00a	0.02 ± 0.01c	0.03 ± 0.01c	0.02 ± 0.01c	0.01 ± 0.01a
Pijadegato	0.00 ± 0.00a	0.00 ± 0.00c	0.02 ± 0.00c	0.02 ± 0.01c	0.01 ± 0.00a
Maax	0.00 ± 0.00a	0.01 ± 0.01c	0.03 ± 0.02c	0.01 ± 0.01c	0.03 ± 0.01a
X´catic	0.00 ± 0.00a	0.01 ± 0.00c	0.01 ± 0.01c	0.03 ± 0.01c	0.01 ± 0.01a
Verde	0.00 ± 0.00a	0.01 ± 0.01c	0.02 ± 0.02c	0.01 ± 0.01c	0.01 ± 0.01a

Values with the same letter within a column are not significantly different according to Scott-Knott cluster analysis (P ≤ 0.05).

Table 7. Incidence and severity of viral symptoms in the genotypes of *Capsicum annuum*.

Genotype	Area under the incidence progress curve	Maximum incidence (%)	Rate of apparent infection	R^2	Area under the severity progress curve	Maximum severity (%)	Rate of apparent infection	R^2
Pimiento	2055.5 ± 657.1a	58.7	0.055	0.83	131.8 ± 10.1a	3	0.030	0.69
Dulce	1725.7 ± 400.1a	58.0	0.050	0.91	63.5 ± 19.2b	3	0.049	0.91
Picopaloma	1673.3 ± 384.3a	58.5	0.134	0.77	118.5 ± 12.9a	4	0.067	0.75
Güero	1388.2 ± 366.4a	54.0	0.067	0.92	103.3 ± 22.8a	4	0.040	0.84
Crespo	1365.2 ± 323.3a	44.7	0.045	0.94	97.8 ± 10.2a	4	0.030	0.96
Verde	1328.1 ± 306.7a	68.7	0.136	0.85	53.7 ± 22.4b	3	0.065	0.92
X´catic	1287.7 ± 275.8a	39.2	0.042	0.90	84.6 ± 16.6b	3	0.030	0.96
Pozol	1227.3 ± 273.7a	52.2	0.104	0.82	107.5 ± 27.8a	4	0.060	0.82
Jalapeño	1174.6 ± 247.3a	30.2	0.027	0.90	128.6 ± 43.7a	4	0.029	0.55
Chawa	1144.8 ± 247.0a	35.7	0.051	0.89	56.2 ± 16.1	2	0.045	0.91
Bolita	1133.2 ± 238.2a	34.2	0.032	0.95	126.6 ± 3.7a	3	0.024	0.80
Blanco	1121.8 ± 218.3a	43.2	0.119	0.75	80 ± 13.2b	4	0.068	0.89
Amaxito	1089.2 ± 214.9a	64.0	0.148	0.84	75.8 ± 26.6b	3	0.071	0.80
Miraparriba	1028.8 ± 187.1a	35.0	0.115	0.75	80 ± 12.1b	3	0.067	0.88
Pijadegato	1026.5 ± 137.0a	30.2	0.082	0.64	103.5 ± 7.3a	3	0.055	0.75
Sucurrre	1000.7 ± 130.5a	27.2	0.035	0.91	109.2 ± 22.4a	3	0.034	0.83
Maax	634.6 ± 102.0a	33.7	0.114	0.86	83.7 ± 29.6b	4	0.073	0.85
Simojovel	92.75 ± 57.6a	13.0	0.090	0.70	7.75 ± 4.5b	1	0.035	0.60

Values are means ± standard error of incidence and severity of virus symptoms in *Capsicum annuum* genotypes. Area under the curve was calculated as indicated in material and methods.
Values with the same letter within a column are not significantly different according to Scott-Knott cluster analysis (P ≤ 0.05).

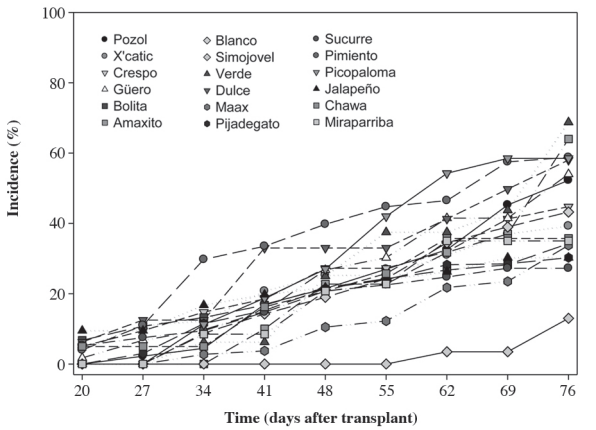


Figure 3. Progress of the viral incidence (%) in 18 pepper genotypes from Southern Mexico.

B. tabaci-Begomovirus complex were analyzed. The RDA triplot showed a reduced separation of the pepper genotypes on the axes, and Monte Carlo permutation test was not significant for the first axis (Table 8). However, axis 1 was closely related to severity (r = 0.86). Severity was, indeed, the only variable with marginal effects in the model (F ratio = 3.27, P = 0.06), where a strong negative relationships among disease severity and various morphological characteristics were observed; among these were stem diameter (SD), leaf density (LD), leaf shape (LS), number of branch bifurcation (NBB), tillering (T) and plant canopy width (PCW). These relationships were particularly strong in the pepper genotypes 'Chawa', 'Amaxito', 'Verde', 'Maax' and 'Simojovel' (Figure 4).

Resistance to either *B. tabaci* or *Begomovirus* has been previously studied in various groups of horticultural crops, such as tomato, pepper, bean, cotton, soybean, and cassava. In horticultural crops, enormous losses caused by this biotic constraint have been widely recognized (Berlinger, 1986; Lapidot and Friedmann, 2002; Morales, 2011; Borah and Dasgupta, 2012). Literature available have documented that in pepper, host resistance to *B. tabaci* is mainly mediated by morphological traits of plants, such as leaf trichomes and leaf thickness (Firdaus et al., 2011). On the other hand, *Begomovirus* resistance has been suggested to be due to constraints in viral movement, which in turn leads to no symptoms, delayed symptoms, and symptom remission (Anaya-López et al., 2003). For the best of our knowledge, no studies have

Table 8. Eigenvalues and Monte Carlo results for Redundancy Analysis (RDA) of pepper genotypes in the complex *Bemisia tabaci-Begomovirus*.

Axes	1	2	3	4
Eigenvalues	0.233	0.051	0.017	0.002
Species-environment correlations	0.602	0.541	0.452	0.406
Cumulative % variance				
Species data	23.3	28.4	30.1	30.3
Species-environment relation	76.8	93.7	99.3	100.0

Test of significance of first canonical axis: F ratio = 3.95 P value = 0.31

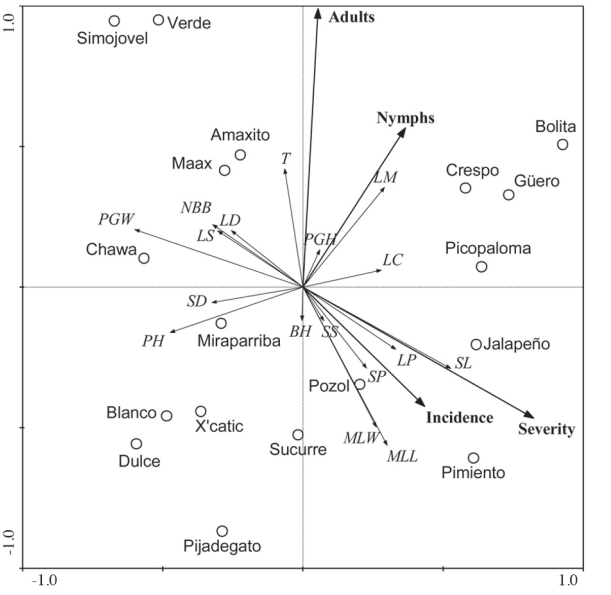


Figure 4. Redundancy Analysis (RDA) scatterplot illustrating the relationship between 17 morphological characteristics of 18 pepper genotypes with four variables of complex *Bemisia tabaci* (nymphs and adults abundance)-*Begomovirus* (severity and incidence). Dots represent pepper genotypes. Bold arrows Nymphs, Adults, Severity and Incidence refer to complex *B. tabaci-Begomovirus*. Thin arrows refer to 17 morphological characteristics of pepper genotypes.

been carried out on pepper resistance to both *B. tabaci* and *Begomovirus*. This type of studies might have bigger significance as in field *B. tabaci-Begomovirus* complex occurs concomitantly. In the present work, we observed that *B. tabaci* was able to colonize all genotypes. Moreover, viral symptoms appeared in all genotypes as well. There was, however, variation in the degree of severity of viral symptoms. In general, genotypes 'Chawa', 'Blanco', and 'X´catic' were grouped into the genotypes that showed low adult and nymphal population in leaves and low severity of viral symptoms. Surprisingly, the genotype 'Simojovel' showed high susceptibility to whitefly, but was grouped into genotypes with low symptom severity. A plausible explanation in this case would be that while the morphological or biochemical traits of the plant would favor the colonization of *B. tabaci*, viral infection would not succeed in such genotype due to resistance to *Begomovirus* infection. In practical terms, farmers would tend to prefer genotypes that are not susceptible to *Geminivirus* infection compared to those that show only resistant to *B. tabaci*.

CONCLUSIONS

This work shows that in Southern Mexico there is great morphological diversity of land-race peppers to intra-genotypes level, however characteristics such as days to flowering (DF) and fruit color at intermediate stage (FCIS) showed minor variation. Twelve principal components

were selected as meaningful factors explaining 94% of the total variation of morphological characteristics, and the contribution of each morphological characteristic to PC was differential, underlining the influence of fruit morphological characteristics. Among morphological characteristics of the genotypes, only "Tillering" and "Plant Canopy Width" showed strong negative relationship with disease severity, while no relationship was observed for disease incidence and density of *B. tabaci* population. Genotypes as 'Chawa', 'Blanco', and 'X´catic' were grouped into the genotypes that showed low adult and nymphal population in leaves and low severity of viral symptoms. Notably, genotype 'Simojovel' showed high susceptibility to whitefly, but was grouped into genotypes with low symptom severity. This data highlight the potential of native pepper germplasm to explore sources of resistance to this pest complex. In a long-term scenario, resistance to the *B. tabaci-Begomovirus* complex might be used in breeding programs related to pest management.

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