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RESEARCH ARTICLE

Variations in salinity tolerance in wild pepper (*Capsicum annuum* L. var. *glabriusculum*) populations

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ABSTRACT

The wild pepper (*Capsicum annuum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill) is a valuable genetic resource for agriculture and food. Around the world salinity is a significant environmental stress that limit and affect agriculture productivity. This work estimates the variation in salinity tolerance in six populations of wild pepper populations of the Northwest of Mexico at three salinity levels (without NaCl, 25 and 50 mM NaCl). The measured traits were height, stem development, foliar area, relative content of chlorophyll, dry weight of plant, root, stem, and leaves. Salinity tolerance was estimated with a stress tolerance index (STI) obtained by comparing values of traits between control treatment (without NaCl) and salinity treatments. Data were subjected to univariate and multivariate variance analysis of principal components. All measured traits were negatively and significantly affected by salinity. Univariate variance analysis and of principal components clearly differentiated the studied populations. At 50 mM NaCl, height, stem diameter, foliar area, stem and leaves dry weight correlated positively with electrical conductivity, and foliar area, relative content of chlorophyll, stem and leaves dry weight correlated with soil Na at the site of origin of the populations. Presa Oviachic showed a higher salinity tolerance in both NaCl treatments (1.17 and 0.99), followed by two more populations (Lo de Vega and Yecorato), each with each salinity treatment. Presa Oviachic presented the highest average STI in both treatments, 37.6% and 40.4% higher than Cósala and Mazocahui respectively. Root dry weight (0.427), stem diameter (0.419), leaf area (0.412), stem dry weight (0.407) and plant dry weight (0.345) were the most important traits in that order and Presa Oviachic was significantly superior to the rest of populations in STI at 50 mM NaCl. Plants of these populations could be a source of salinity resistance. The variation pattern observed in these traits suggests adaptation to the local edaphic conditions.

Key words: *Capsicum annuum* var. *glabriusculum*, NaCl, northwestern Mexico, salinity stress, stress tolerance index.

INTRODUCTION

At the worldwide level, the increasing scarcity of water and land for agriculture and food production has become a critical concern because a large part of the agricultural production comes from irrigated lands. One of the main abiotic factors that limits growth and productivity of plants around the world is soil salinity (Munns and Tester, 2008), which affects negatively more than 20% of the agricultural surface under irrigation (Henderson et al., 2020). Salinity refers to the concentration of soluble salts in the soil higher than 40 mM NaCl or an electrical conductivity above 4 dS m^{-1} (Henderson et al., 2020).

Mexico is one of the countries with the highest vegetal diversity of pepper (*Capsicum* spp.) and one of the main centers of plants domestication in the world. In particular, pepper was one of the first plants domesticated in the American continent. The genus *Capsicum* (Solanaceae) is constituted by around 43 species distributed from the South of the USA until the North of Argentina (Carrizo et al., 2016). From the *Capsicum* genus, the following species *C. annuum*, *C. chinense*, *C. frutescens*, *C. baccatum*, and *C. pubescens* have been domesticated (Barboza et al., 2022). Of the domesticated species, *C. annuum* is the one of highest economic relevance and presents the highest variability in fruits size, shape, and color. The peppers “de árbol” or “cola de rata”, “anchos”, “serranos”, “jalapeños” and “bell-pepper”, among others, belong to this species. It is considered that *C. annuum* has been domesticated in Mexico.

The wild relatives of cultivated plants are an important genetic resource that constitutes a primary genes repertory of resistance or tolerance to biotic and abiotic factors; knowing them could contribute to improve the current agricultural production (Hernández-Verdugo et al., 1998). Previous studies with isoenzymes, RAPDs molecular markers, microsatellites, and quantitative traits indicate that populations of wild pepper of the Northwest of Mexico retain high levels of genetic variation among and within their populations (Oyama et al., 2006). These populations also vary significantly in the resistance against the *Pepper huasteco yellow vein virus* (Hernández-Verdugo et al., 2001; Retes-Manjarrez et al., 2018). However, it is not known whether these populations present variations in their response to abiotic stress, like salt tolerance. This study analyzed six populations of wild *C. annuum* of the Northwest of Mexico under nursery conditions aimed at estimating variation in tolerance, identifying the source of tolerance to this factor, as well as the adaptive nature of this variation. The working hypothesis was that the wild populations of *C. annuum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill of northwestern Mexico will show variation in salt tolerance in response to three levels of salinity under nursery conditions.

MATERIALS AND METHODS

Fruit collection sites

Mature fruits were sampled from *Capsicum annuum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill. Plants were located in their wild habitat, surrounding vegetation corresponds to thorny scrubland of piedmont and low deciduous forest native from northwestern Mexico. The sampling sites (Figure 1) were chosen to represent a wide geographical distribution and different habitats in which the wild populations of this species are found in northwestern Mexico (Hernández-Verdugo et al., 2012; Díaz-Sánchez et al., 2021). The geographical, climate, and soil data of the sampling sites are given on Table 1.

Plant description

Wild *C. annuum* var. *glabriusculum* reproduction is exclusively through seeds, although these are produced mainly by selfing. The plants were perennial, erect or 1-4 m tall shrubs; showed intermediate, erect or climbing growth habit and spontaneous breeding state. Its fruits at mature stage were pungent, small, red, almost round and erect that encouraging consumption by frugivorous birds favoring their wide dispersal (IPGRI, AVRDC and CATIE, 1995; Votava et al., 2002; Barboza et al., 2022).

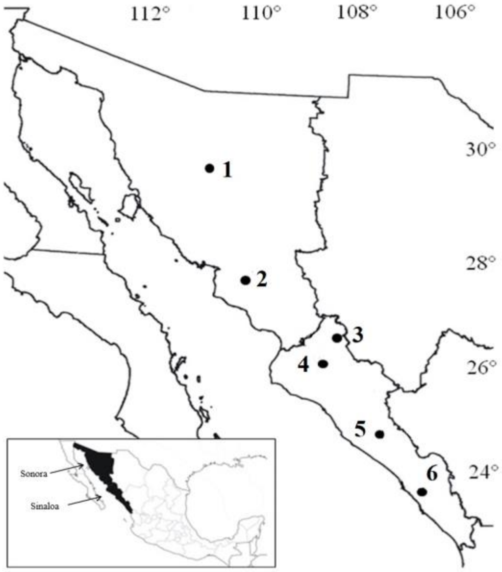


Figure 1. Geographical localization of the six wild populations of *Capsicum annuum* collected in the states of Sonora and Sinaloa, Mexico. 1: Mazocahui; 2: Presa Oviachic; 3: Yecorato; 4: Lo de Vega; 5: Cosalá; 6: El Roble.

Table 1. Geographical, climatic, and edaphic data of the six wild populations of *Capsicum annuum* of northwestern Mexico. MaxT: Maximum annual temperature; MedT: mean annual temperature; MinT: minimum annual temperature; PP: mean annual rainfall; EC: electrical conductivity Na^+ and Cl^-.

ID	Populations	N lat	W long	MaxT	MedT	MinT	PP	EC	pH	Na^+	Cl^-
				°C			mm	$dS \cdot m^{-1}$		mM	
1	Mazocahui	29°31’	110°05’	31.6	21.3	10.8	534	0.7	6.6	0.3	4.0
2	Presa Oviachic	27°46’	109°54’	33.9	24.7	15.6	410	1.0	7.8	1.2	3.5
3	Yecorato	26°26’	108°12’	34.8	24.1	13.5	818	1.0	6.8	1.4	3.1
4	Lo de Vega	26°08’	108°32’	33.2	23.6	14.2	628	0.8	7.6	0.7	3.2
5	Cosalá	24°24’	106°36’	33.7	24.9	16.2	1098	0.8	7.5	0.4	3.4
6	El Roble	23°25’	106°17’	29.2	23.5	17.3	587	0.8	7.8	0.9	2.5

Experimental design

Seeds from collected fruits were soaked in 1000 $mg \cdot L^{-1}$ gibberellic acid for 24 h, and germinated in 60-well polystyrene (individual cavity = 230 cm^3) plates filled with organic substrate of peat moss, under greenhouse conditions. A low germination response of wild *C. annuum* was observed (data were overlooked in this research process) since it is highly dependent on the growth environment of the mother plants (Hernández-Verdugo et al., 2010). After germinated, plantlets with two to five real leaves were transplanted to new 60-well polystyrene plates with organic peat moss substrate (each plantlet occupied one cavity). The final number of individuals in the populations were: Mazocahui 36, Presa Oviachic 99, Yecorato 153, Lo de Vega 63, Cosalá 144 and El Roble 180 plants. In each population, the plants were divided into three equal groups to balance the experiment of three NaCl treatments.

Three treatments: 0 (control), 25 and 50 mM NaCl were applicated to germinated plantlet from six populations. The nutrient solution based on modifications of the Steiner universal solution (Steiner, 1984) and using distilled water for their preparation. Treatment started at 30 d after transplantation and was continued for 42 d more. Studies on salt tolerance in the plantlet stage are of great relevance in the search of genotypes tolerant to salinity in different species of cultivated plants, because this stage is one of the most sensitive in the growth and development of a plant (Efisue and Igoma, 2019; Dong et al., 2019).

The experiment consisted of one factor (NaCl) with three levels of variation (0, 25 and 50 mM). For each population we applied three experimental conditions of NaCl. The experiment consisted of divided plots (three polystyrene plates) for each treatment of each population. The number of individuals (replicates) per treatment (within polystyrene plates) in each population varied depended of the number of plantlets obtained (Mazocahui 12, Presa Oviachic 33, Yecorato 51, Lo de Vega 21, Cosalá 48 and El Roble 60 plants), trying to place the same number of individuals per treatment to balance the experiment. The polystyrene plates were moved within the experimental space to avoid microenvironmental bias due to the effect of light. Each seedling was considered a replicate.

Evaluated traits

At 42 d after the start of salinity treatments, in each plant the following traits were measured: (1) Plant height (cm); (2) stem diameter (cm); (3) foliar area (cm^2) (measured with the foliar area meter Li-Cor3100C, LI-COR Biosciences, Lincoln, Nebraska, USA); (4) relative chlorophyll content as SPAD index (Soil Plant Analysis Development 502, Konica Minolta Sensing, Tokyo, Japan); (5) plant dry weight (g) (plantlets were dried at 60-70 °C for 72 h in an oven); this last trait was divided in (6) root, (7) stem, and (8) leaves dry weight (g).

Stress tolerance index

The stress tolerance index (STI) has been used successfully to identify genotypes with the best response under salinity stress conditions (Henderson et al., 2020). The STI was estimated (Negrão et al., 2017; Henderson et al., 2020) for all analyzed characteristics:

$$\text{STI} = (Y_{\text{control}}/Y_{\text{average of control}})\ (Y_{\text{salinity}}/Y_{\text{average of control}})$$

where Y_{control} and Y_{salinity} are the values of the evaluated traits in each plant in the control and salinity treatments; while $Y_{\text{average of control}}$ is the average value of the traits in the population evaluated in non-salinity conditions. A higher STI in a population indicates a higher tolerance to salinity.

Statistical analysis

Effects of treatments on the evaluated traits were analyzed with a one-way ANOVA, and when differences were significant ($P \leq 0.05$) the multiple comparison of means Tukey's test ($P \leq 0.05$) was performed.

A one-way ANOVA was performed for the net values (0 mM) obtained and another one-way ANOVA for the STIs of the 25 and 50 mM NaCl treatments of the different populations.

The STI values of the measured traits for 25 and 50 mM NaCl in the different populations were subjected to a principal components analysis (PCA). The PCA allows identifying the most important characteristics contributing to salinity tolerance in the studied genotypes and detecting the trends in the differentiation of populations (Negrão et al., 2017).

In addition, the adaptive nature of the differentiation in salinity tolerance was estimated among the populations by means of linear regression analysis among the means of the STI of the populations for each trait and edaphic variables of the sites of origin. All analyses were made with the JMP 13 statistical software (SAS Institute, Cary, North Carolina, USA).

RESULTS AND DISCUSSION

Effect of treatments

All traits were negatively and significantly affected at the 25 and 50 mM NaCl. The reduction was higher with the higher dose (Figure 2). These results coincide with those reported by other authors, who have shown that salinity reduces growth and production of several vegetal species exposed to salinity (Talei et al., 2013; Tiwari et al., 2013; Dong et al., 2019; Liu et al., 2020). Talei et al. (2013) and Tiwari et al. (2013) reported a significant reduction in height and dry weight of the plant, dry weight of the root and stem in

Andrographis paniculata plantlets and of a crossbreed of *Gossypium hirsutum* × *G. barbadense*, exposed to different NaCl concentrations. Dong et al. (2019) reported a reduction in the plant height and biomass in *Vigna unguiculata* plantlets, whereas Liu et al. (2020) found a significant reduction in the foliar area, height and dry weight of *Cornus alba* plantlets. The foliar area generally decreases under salinity conditions, especially in the plantlet stage, as well as its photosynthesis capacity (Munns and Tester, 2008).

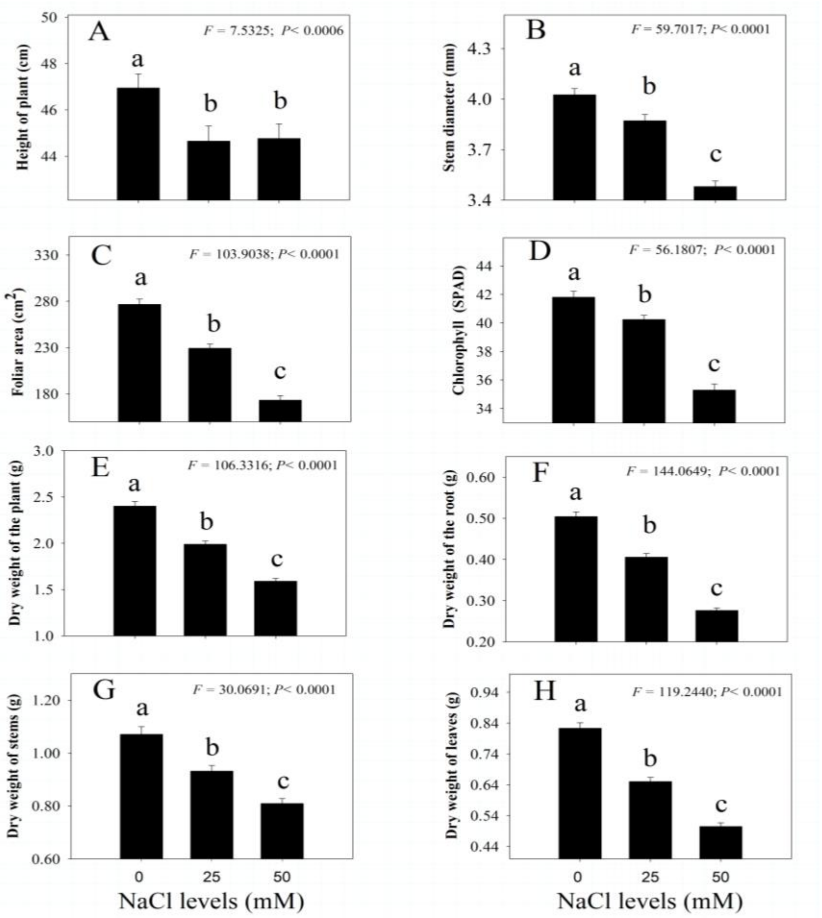


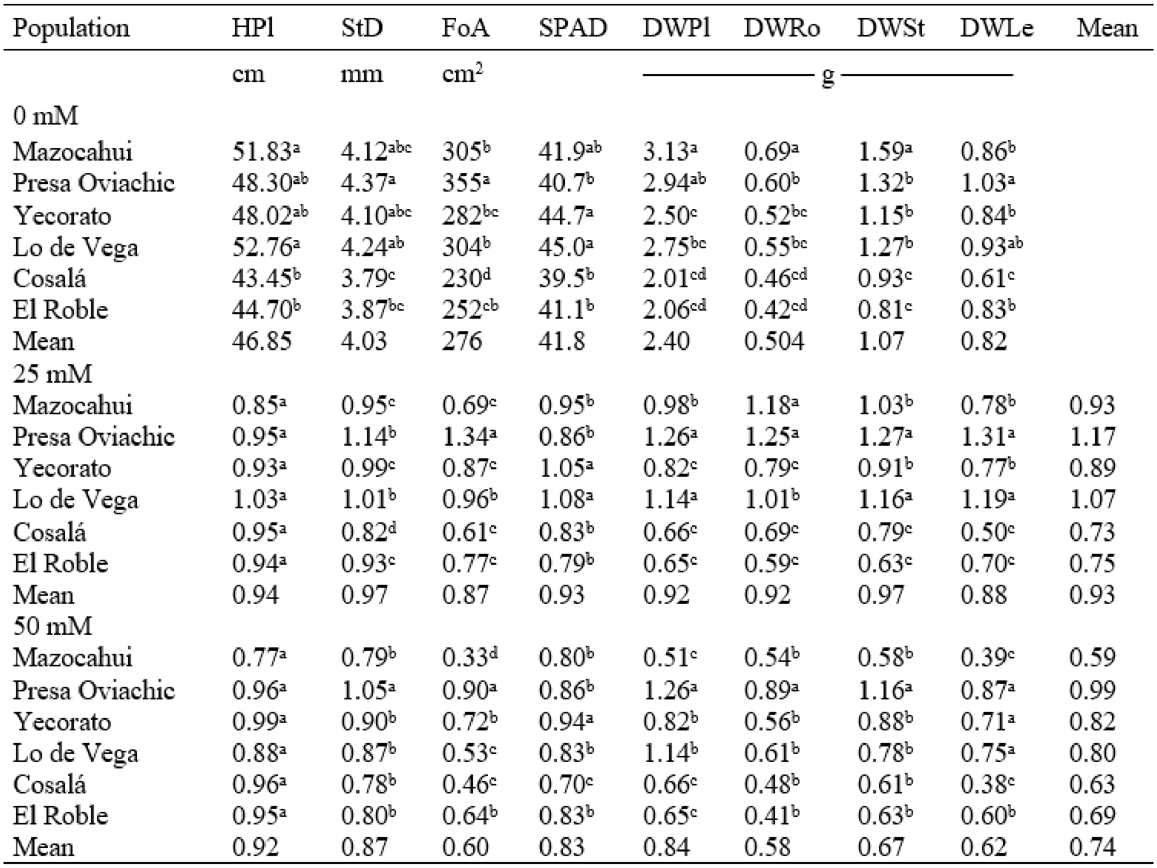
Figure 2. Mean (± 1 standard error) of the traits of height of plant, stem diameter, foliar area, chlorophyll content (SPAD), dry weight of plant, dry weight of root, dry weight of stem, and dry weight of leaves at the three salinity levels. Means with the same letters are not significantly different (Tukey, 0.05).

The salinity increase in agricultural soils affects negatively the function and development of plants through osmotic and ionic effects (Munns and Tester, 2008). Salinity hinders water absorption by the roots of the plants, even when the soil has enough moisture because of the highly negative osmotic potential of the soil compared with the less negative osmotic potential of the plant. This imbalance hinders the extraction of water by the roots of the plants, similarly to drought conditions (Munns and Tester, 2008). In response to the osmotic stress, the plant reduces its growth rate in the stem, leaves, and roots, increases the closure of the stoma and diminishes photosynthesis (Munns and Tester, 2008; Henderson et al., 2020). The Na^+ and Cl^- ions enter the plant and accumulate at toxic levels in the cytoplasm and avoid the absorption and distribution of K^+, an essential ion for the basic biological functions, such as opening of the stomas, enzymatic activity, or cell metabolism (Munns and Tester, 2008).

Variation among population and the STIs

The studied populations showed significant difference in the STIs in all measured traits, except in plant height with both salt treatments (Table 2). At 25 mM NaCl, the populations Presa Oviachic and Lo de Vega presented the highest average salinity indices of all populations (Table 2A). In this treatment, the Presa Oviachic population presented the highest STIs in all the traits, except in the relative content of chlorophyll (SPAD), in which Lo de Vega and Yecorato populations presented the highest STI (Table 2A). In the 50 mM NaCl treatment, Presa Oviachic population presented the highest average STIs, followed by Yecorato and Lo de Vega populations (Table 2B). In this treatment, again the Presa Oviachic population showed the highest STIs in all traits, except in chlorophyll content (SPAD), in which the Yecorato population had the highest STI (Table 2B).

Table 2. Salinity stress tolerance indices at 0, 25, and 50 mM NaCl on evaluated traits height of plant (HPl), stem diameter (StD), foliar area (FoA), relative content of chlorophyll (SPAD), dry weight of the plant (DWPl), dry weight of the root (DWRo), dry weight of stems (DWSt), and dry weight of leaves (DWLe) of the six wild *Capsicum annuum* populations of northwestern Mexico. Means with different letters within the same column in each salinity level indicate significant differences (Tukey, $P \leq 0.05$).



Population	HPl	StD	FoA	SPAD	DWPl	DWRo	DWSt	DWLe	Mean
	cm	mm	cm^2		g				
0 mM									
Mazocahui	51.83^{a}	4.12^{abc}	305^{b}	41.9^{ab}	3.13^{a}	0.69^{a}	1.59^{a}	0.86^{b}	
Presa Oviachic	48.30^{ab}	4.37^{a}	355^{a}	40.7^{b}	2.94^{ab}	0.60^{b}	1.32^{b}	1.03^{a}	
Yecorato	48.02^{ab}	4.10^{abc}	282^{bc}	44.7^{a}	2.50^{c}	0.52^{bc}	1.15^{b}	0.84^{b}	
Lo de Vega	52.76^{a}	4.24^{ab}	304^{b}	45.0^{a}	2.75^{bc}	0.55^{bc}	1.27^{b}	0.93^{ab}	
Cosalá	43.45^{b}	3.79^{c}	230^{d}	39.5^{b}	2.01^{cd}	0.46^{cd}	0.93^{c}	0.61^{c}	
El Roble	44.70^{b}	3.87^{bc}	252^{cb}	41.1^{b}	2.06^{cd}	0.42^{cd}	0.81^{c}	0.83^{b}	
Mean	46.85	4.03	276	41.8	2.40	0.504	1.07	0.82	
25 mM									
Mazocahui	0.85^{a}	0.95^{c}	0.69^{c}	0.95^{b}	0.98^{b}	1.18^{a}	1.03^{b}	0.78^{b}	0.93
Presa Oviachic	0.95^{a}	1.14^{b}	1.34^{a}	0.86^{b}	1.26^{a}	1.25^{a}	1.27^{a}	1.31^{a}	1.17
Yecorato	0.93^{a}	0.99^{c}	0.87^{c}	1.05^{a}	0.82^{c}	0.79^{c}	0.91^{b}	0.77^{b}	0.89
Lo de Vega	1.03^{a}	1.01^{b}	0.96^{b}	1.08^{a}	1.14^{a}	1.01^{b}	1.16^{a}	1.19^{a}	1.07
Cosalá	0.95^{a}	0.82^{d}	0.61^{c}	0.83^{b}	0.66^{c}	0.69^{c}	0.79^{c}	0.50^{c}	0.73
El Roble	0.94^{a}	0.93^{c}	0.77^{c}	0.79^{b}	0.65^{c}	0.59^{c}	0.63^{c}	0.70^{c}	0.75
Mean	0.94	0.97	0.87	0.93	0.92	0.92	0.97	0.88	0.93
50 mM									
Mazocahui	0.77^{a}	0.79^{b}	0.33^{d}	0.80^{b}	0.51^{c}	0.54^{b}	0.58^{b}	0.39^{c}	0.59
Presa Oviachic	0.96^{a}	1.05^{a}	0.90^{a}	0.86^{b}	1.26^{a}	0.89^{a}	1.16^{a}	0.87^{a}	0.99
Yecorato	0.99^{a}	0.90^{b}	0.72^{b}	0.94^{a}	0.82^{b}	0.56^{b}	0.88^{b}	0.71^{a}	0.82
Lo de Vega	0.88^{a}	0.87^{b}	0.53^{c}	0.83^{b}	1.14^{b}	0.61^{b}	0.78^{b}	0.75^{a}	0.80
Cosalá	0.96^{a}	0.78^{b}	0.46^{c}	0.70^{c}	0.66^{c}	0.48^{b}	0.61^{b}	0.38^{c}	0.63
El Roble	0.95^{a}	0.80^{b}	0.64^{b}	0.83^{b}	0.65^{c}	0.41^{b}	0.63^{b}	0.60^{b}	0.69
Mean	0.92	0.87	0.60	0.83	0.84	0.58	0.67	0.62	0.74

The multivariate PCA revealed that wild populations of *C. annuum* of the Northwest of Mexico retain high levels of variation in STI. The PCA of 25 mM NaCl treatment showed that the two first principal components explained 82.94% of the variation (Table 3). The first principal component explained 67.67% of the variation. All traits showed a positive sign and relatively high values in this first principal component, except for plant height and leaves dry weight (Table 3). The second principal component explained 15.27% of the variance and was determined by the STIs of the traits of plant height of positive sign and dry weight of the plant with negative sign. In the 50 mM NaCl treatment, the first principal component explained 64.80% of the variance. All traits had a positive sign and relatively high values, except for height of the plant and SPAD (Table 3). The second principal component explained 19.32% of the variation and was determined mainly for the SPAD and plant height of positive sign and dry weight of plant of negative sign (Table 3).

Table 3. Result from principal components analyses of the stress tolerance index (STIs) of the analyzed traits in six wild *Capsicum annuum* populations subjected to 25 and 50 mM salinity. Variables with the highest weight are in bold. PC1: Principal component 1; PC2: principal component 2.

Traits	25 mM		50 mM	
	PC1	PC2	PC1	PC2
Height of plant	0.124	**0.841**	0.242	**0.363**
Stem diameter	**0.396**	-0.038	**0.419**	-0.223
Foliar area	**0.379**	0.098	**0.412**	0.050
SPAD	**0.423**	-0.080	0.169	**0.674**
Dry weight of plant	**0.363**	**-0.428**	**0.345**	**-0.446**
Dry weight of root	**0.409**	-0.099	**0.427**	-0.162
Dry weight of stem	**0.417**	0.140	**0.407**	-0.054
Dry weight of leaves	0.181	0.249	**0.316**	**0.365**
Explained variance, %	67.67	15.27	64.80	19.32
Accumulated variance, %	67.67	82.94	64.80	84.12

Populations were clearly different in the two-dimensional space of the 1 and 2 principal components in both treatments (Figure 3). In the 25 mM NaCl treatment, principal component 1 distinguished the Presa Oviachic and Lo de Vega populations in the region of plants with higher STIs in all measured traits, whereas Cosalá and El Roble populations occupied the opposite region. The Mazocahui and Yecorato populations occupied the intermediate region (Figure 3A, Table 3). The principal component 2 separated Lo de Vega population in the region of the highest plant height and dry weight of leaves, but less dry weight of the plant (Figure 3A, Table 3), whereas Mazocahui population occupied the opposite region. The remainder populations were distributed in the intermediate region (Figure 3, Table 3).

In the 50 mM NaCl treatment, the principal component 1 distinguished the Presa Oviachic and Yecorato populations in the region of plants with the highest STIs in all measured characteristics, whereas the Mazocahui and Cosalá populations occupied the opposite region, and El Roble and Lo de Vega populations occupied the intermediate region (Figure 3B, Table 3). The principal component 2 separated the Yecorato population in the region of the highest chlorophyll content, dry weight of leaves, and plant height, but less dry weight of the plant (Figure 3B), whereas the Presa Oviachic population occupied the opposite region. The remainder populations were distributed in the intermediate region (Figure 3B, Table 3). Because plants were grown in a uniform environment, it is considered that the observed variation has a genetic basis.

Salt tolerance of plants is generally associated with the capacity to restrict absorption and/or transport of saline ions from the roots to the leaves (Acosta-Motos et al., 2017). Long exposure to NaCl results in growth inhibition, changes in development, sequestering or exclusion of ions, metabolic reductions, reductions of biomass, stomatal conductance, and chlorophyll content (Negrão et al., 2017; Van Zelm et al., 2020; Parra-Terraza et al., 2022). Chlorophyll plays a fundamental role in regulating the photosynthetic capacity of plants, it helps leaves to perform photosynthesis and attach enough C to sustain the general growth of the plant and, especially, to continue with new growth (Henderson et al., 2020; Javed et al., 2022).

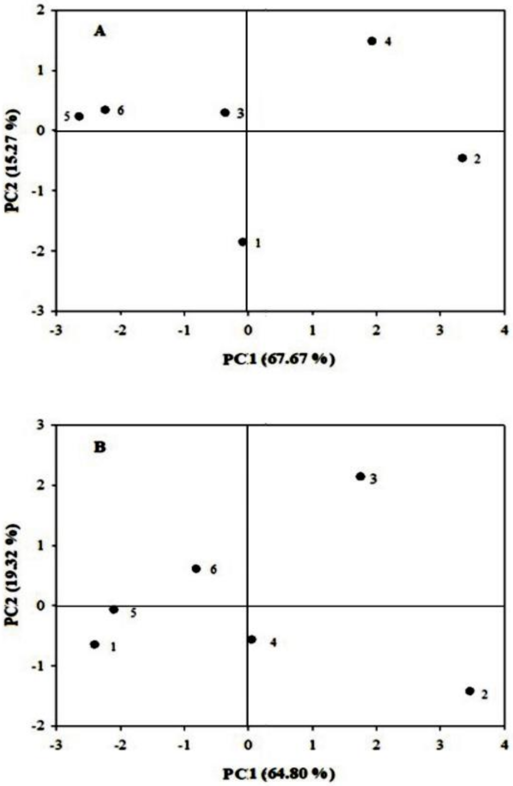


Figure 3. Differentiation of the six wild *Capsicum annuum* populations according to the principal components 1 and 2 obtained with stress tolerance index (STIs) in treatments 25 (A) and 50 mM (B). 1: Mazocahui; 2: Presa Oviachic; 3: Yecorato; 4: Lo de Vega; 5: Cosalá; 6: El Roble.

Relation among stress tolerance indices and characteristics of soils

A positive and significant relation was observed between the STIs and root dry weight with Cl concentration of the soil of origin of populations treated with 25 mM NaCl (Figure 4).

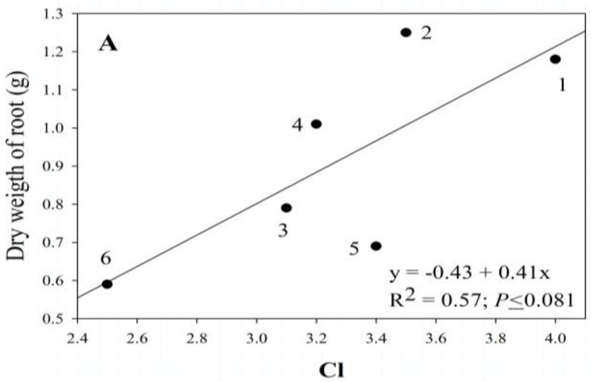


Figure 4. Relation between the stress tolerance index (STIs) of dry weight of root with 25 mM NaCl treatment and Cl concentration (in mM) in the soil at the sites of origin. 1: Mazocahui; 2: Presa Oviachic; 3: Yecorato; 4: Lo de Vega; 5: Cosalá; 6: El Roble.

In the 50 mM NaCl treatment, SITs, plant height, stem diameter, foliar area, dry weight of stem and leaves correlated positively and significantly with soil electrical conductivity of the sites of origin of populations (Figures 5A, 5B, 5C, 5D, and 5E). The STIs of the foliar area, relative content of chlorophyll, dry weight of stem and leaves correlated positively and significantly with Na of soil of the sites of origin of populations (Figures 5F, 5G, 5H, and 5I).

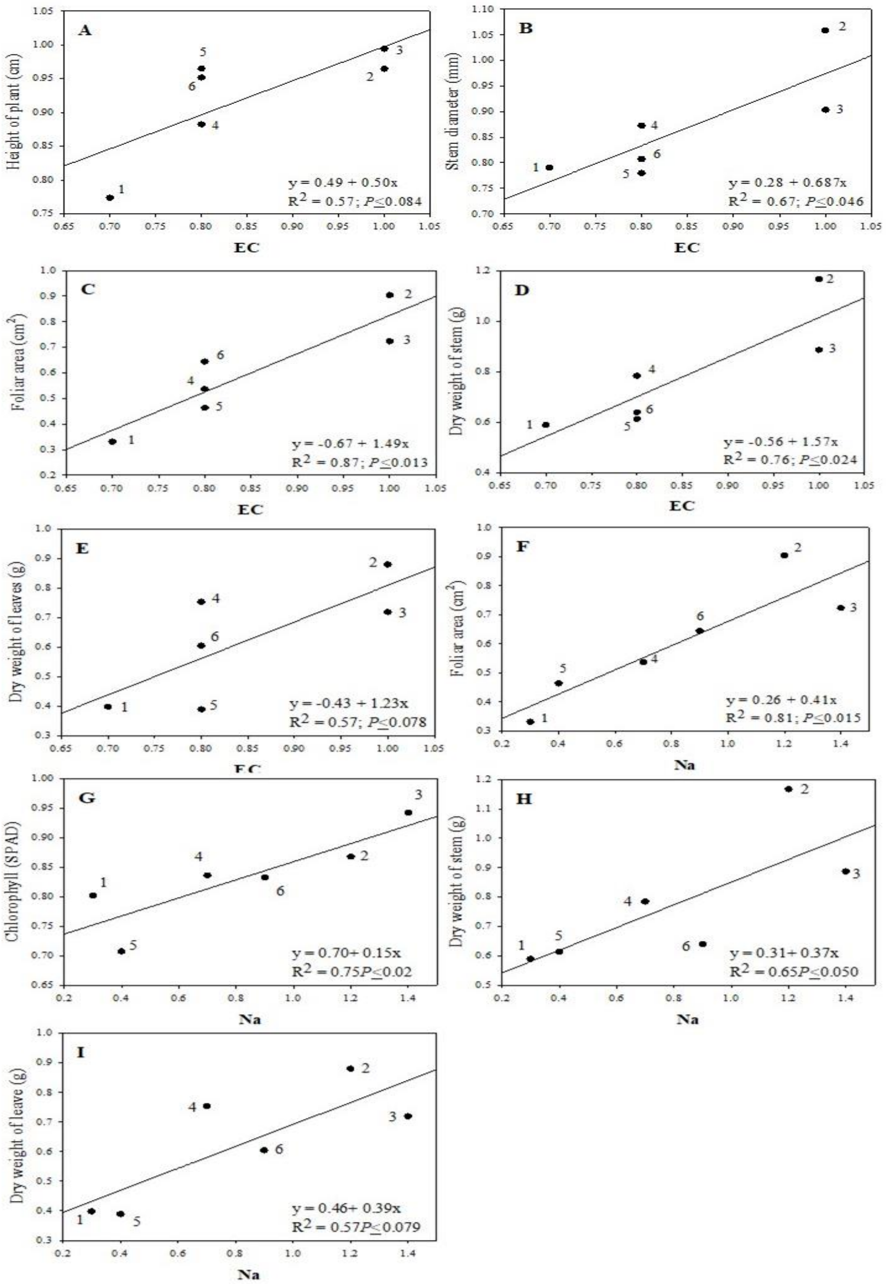


Figure 5. Relation between stress-tolerance index (STIs) in 50 mM NaCl treatment and some characteristics of the soil at the sites of origin: Height of plant (A), stem diameter (B), foliar area (C), dry weight of stem (D), and dry weight of leaves (E) with electrical conductivity (EC), foliar area (F), chlorophyll content (G), dry weight of stem (H), and dry weight of leaves (I) with Na. 1: Mazocahui; 2: Presa Oviachic; 3: Yecorato; 4: Lo de Vega; 5: Cosalá; 6: El Roble.

Variation in the salinity tolerance levels of the studied population could be attributed to the fact that they have been under continuous selection of salinity during long exposure periods, which has led these plants to develop tolerance to salinity and adapt to the different eco-geographical conditions of northwestern Mexico. Other authors have proposed that the phenotypical differences among plant populations of the same species that grow in a uniform environment and show differentiation patterns related to soil salinity levels are due to the natural selection acting along environmental gradients (De Frenne et al., 2013). Plant adaptation varies according to the salinity level, species, duration of the exposure, and development stage of the crop. This variation has been documented by Wu et al. (2011), who point out that there is a useful natural variation in diverse lines of wild Tibetan barley in the levels of salt tolerance in terms of biomass accumulation. Hence, research with the germplasm of wild relatives of crops of agronomical interest has a great potential to improve their salt tolerance. Exploring the genetic background of the wild relatives of modern crops has served to generate Na-tolerant genotypes (Munns et al., 2000).

The univariate and multivariate analyses revealed that the Presa Oviachic population was the most tolerant to both NaCl levels (25 and 50 mM), whereas Lo de Vega population was the second most tolerant in 25 mM NaCl treatment, and that of Yecorato was the second most tolerant in 50 mM NaCl. Results show that these three populations are promising sources of genes with salinity tolerance that could be incorporated in future crop improvement programs.

CONCLUSIONS

The wild *Capsicum annuum* var. *glabriusculum* populations of northwestern Mexico retain a high variation in their salinity tolerance in terms of the measured phenotypical traits. Because plants were grown in a uniform nursery environment, it can be considered that the observed differences have a genetic base. Additionally, three population showed high levels of salt tolerance, indicating that this species is a valuable genetic asset that must be studied to improve its use and conservation. Several of the measured traits correlated positively and significantly with the salinity of the soils of origin of the studied populations, indicating that these traits are the product of adaptations to the local edaphic conditions during the growth of the *C. annuum* plants in their natural environment.

Author contributions

Methodology: S.E-V., J.M.O-R., S.P-T. Formal analysis: S.E-V., J.M.O-R., C.E.R-H. Investigation: J.M.O-R., S.H-V. Data curation: J.M.O-R., C.E.R-H. Writing-original draft: J.M.O-R., S.E-V. Writing-review & editing: J.M.O-R., S.E-V., T.O-E. Supervision: S.H-V., A.P-O. Funding acquisition: S.E-V., A.P-O. All authors reviewed the final version and approved the manuscript before submission.

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