

Diversity of Mexican wild tomatoes (*Solanum lycopersicum* var. *cerasi-forme*) produced in a greenhouse

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ABSTRACT

Objective: To characterize and evaluate the agronomic diversity of 31 native tomato populations from Mexico, cultivated under greenhouse conditions in Sinaloa.

Design/Methodology/Approach: The biological material was collected from eight Mexican states and transplanted into soil beds in 2022. The experimental design consisted of plots arranged in rows with three replications, where the experimental unit comprised the three central rows, totaling 279 plants. Agronomic traits and fruit quality variables were measured and analyzed using the SAS 9 statistical package.

Results: Significant differences ($p \leq 0.05$) were observed across the evaluated variables. Mean comparisons highlighted key traits: number of fruits per plant reached 89 (Hidalgo), fruit weight was 46.6 g (Oaxaca 7), yield was 2.5 kg per plant (Veracruz 3), number of locules reached 9 (Veracruz 1), and total soluble solids were 9.2 °Brix (Oaxaca 5).

Limitations/Implications: Genotypes with small fruits (~2 g) require intensive labor due to their high shoot production, representing a challenge for large-scale cultivation.

Findings/Conclusions: The evaluated genotypes exhibit strong potential for hybrid vigor, particularly in agronomic performance (Veracruz 4), yield (Veracruz 3), and fruit quality (Oaxaca 5). These findings are valuable for future hybridization efforts in tomato breeding programs.

Keywords: Native tomato, greenhouse, yield, number of loculus and total soluble solids

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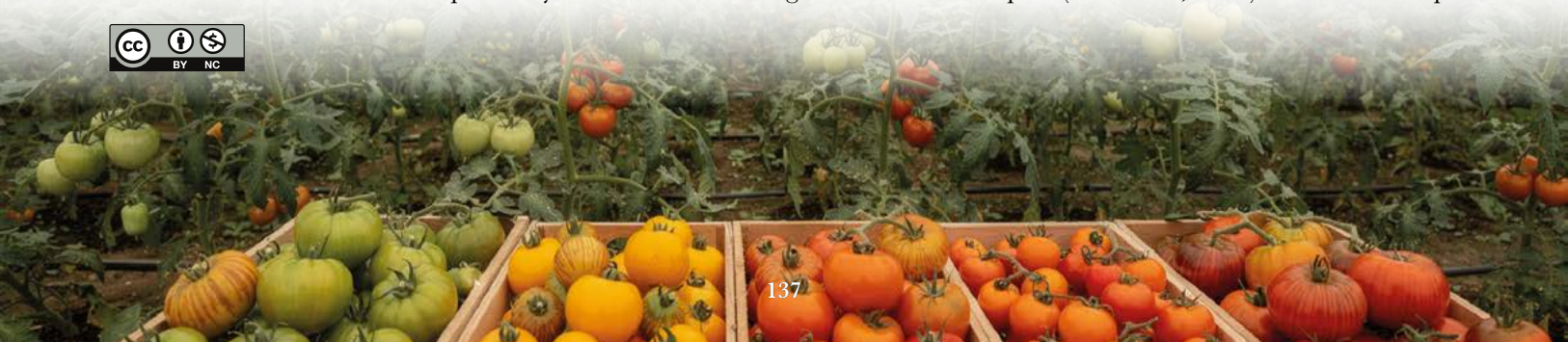
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INTRODUCTION

Agriculture is currently facing one of the greatest challenges in human history due to the projected growth of the global population (Egea *et al.*, 2022). This scenario demands increased food production and enhanced nutritional quality to meet the needs of a rapidly expanding population (Bhardwaj *et al.*, 2024; Jiang *et al.*, 2022). Ensuring food security requires the development of crops geared toward sustainable agriculture systems that optimize yield while minimizing environmental impact (Tian *et al.*, 2022). To achieve crops



with greater tolerance to abiotic stress and enhanced nutritional value, it is essential to deepen our understanding of the mechanisms underlying species resilience (Lazaridi *et al.*, 2024). Modern cultivars are genetically homogeneous and widely cultivated across large geographic areas (Khoury *et al.*, 2022). Tomato (*Solanum lycopersicum* L.) is the most widely consumed and most produced vegetable globally (FAO, 2023). In Mexico, tomato production systems predominantly rely on improved, imported varieties, leading to a high degree of dependence on foreign germplasm (Salgado-Meraz *et al.*, 2018). This genetic uniformity renders tomato crops vulnerable to biotic and abiotic stresses, posing significant threats to food production in conventional agricultural systems (Nesbitt & Tanksley, 2002; Lazaridi *et al.*, 2024). The limited genetic diversity of cultivated crops weakens agricultural systems, making them more susceptible to pests and diseases and compromising long-term genetic sustainability (Hamilton *et al.*, 2020; Singh *et al.*, 2023). In contrast, native populations exhibit higher genetic diversity than modern cultivars (Khoury *et al.*, 2022). Since the late 19th century, local varieties and their wild relatives have been recognized by scientists as valuable resources for plant breeding, contributing to improved yield and resistance to biotic and abiotic factors (Michels *et al.*, 2019; Nankar *et al.*, 2020). However, the loss of diversity due to the lack of conservation of local varieties and wild relatives remains a major issue, particularly in the absence of broad initiatives for germplasm bank preservation. For decades, farmers have selected local varieties based on fruit quality, adaptability for subsistence, and resistance to diverse environmental conditions (Asprelli *et al.*, 2017). Native tomatoes are known for their unique flavor, shape, and size; many growers cultivate them to preserve the “taste of the past” (Terzopoulos & Bebeli, 2008; Nankar *et al.*, 2020). The genus *Solanum* exhibits considerable variability in fruit color intensity, shape, size, growth habit, and leaf morphology (Flores-Hernández *et al.*, 2017a; Hernández-Valladares *et al.*, 2021). Given that flavor driven by soluble solids content and aroma is a key determinant of tomato quality, the variety *cerasiforme* holds outstanding genetic potential for improving internal fruit quality (Galiana-Balaguer *et al.*, 2018; Salgado-Meraz *et al.*, 2018). This study was conducted to characterize and evaluate the agronomic diversity of 31 native tomato populations from Mexico, cultivated under greenhouse conditions in Sinaloa.

MATERIALS AND METHODS

The experiment was conducted in a polyethylene greenhouse located at the experimental field of the Instituto Tecnológico Superior de Guasave, Sinaloa (25° 31' 33" N, 108° 22' 45" W), at an elevation of 15 meters above sea level, in a clay-textured soil. The study was carried out during the 2023 fall-winter growing cycle under drip irrigation conditions, in a clay loam soil with a moderate organic matter content (1.95%), an alkaline pH of 8.1, and moderate salinity, with an electrical conductivity of 2.69 dS m⁻¹. A total of 31 tomato genotypes (*Solanum lycopersicum* var. *cerasiforme*) were evaluated, collected from various states of Mexico: Chiapas (1 genotype), State of Mexico (2 genotypes), Guerrero (1), Hidalgo (1), Puebla (8), Oaxaca (7), Sinaloa (2), and Veracruz (9). These populations were cultivated under controlled greenhouse conditions in Sinaloa.

Experimental design

The genotypes were arranged in the field following a randomized complete block design with three replications. The experimental plot consisted of five beds, each 30 meters long and spaced 1.2 meters apart. The useful plot was defined as the three central beds, each 18 meters in length, with a plant spacing of 30 cm. Each row included three plants per genotype, and each treatment had three replications, resulting in a total of nine plants per genotype and 279 plants across the entire experiment. Seeds were sown on September 23, 2022, in 200-cell polystyrene germination trays filled with peat as substrate. After 40 days, the seedlings were transplanted into the previously prepared beds. A drip irrigation system was installed to deliver both water and a 25% Steiner nutrient solution, applied weekly and gradually increased according to plant age, as was the irrigation frequency.

Agronomic management

Once the plants were established in the soil, they were trained to a single stem using raffia as support. Constant monitoring was carried out to detect the main pests and diseases associated with the crop. For prevention and control, both chemical and biological products were applied. The most common pests observed were whitefly (*Bemisia tabaci*), leaf miner (*Liriomyza* spp.), red spider mite (*Tetranychus urticae*), and thrips (*Frankliniella occidentalis*), as reported by Castellanos (2009). These pests were managed using Muralla Max[®] and Agrimec[®] at a dosage of 1 mL L⁻¹. For diseases such as powdery mildew (*Leveillula taurica*) and early blight (*Alternaria* spp.), Ridomil Gold[®] was applied at the same dosage to reduce incidence. Pollination was performed manually by gently tapping the plant support wires to facilitate pollen release.

Evaluated variables

The response variables evaluated during the crop cycle included plant height, which was measured from the base to the apex using a tape measure; number of leaves, obtained by counting the total leaves per plant; and number of fruits, determined by the total number of fruits harvested per plant. Fruit weight was recorded using an Ohaus[®] CS 5000 scale (China) with a maximum capacity of 5,000 g and a precision of 0.1 g.

Fruit yield per plant was obtained by summing the weights recorded across five harvests. Fruit size was measured by determining the polar and equatorial diameters on a sample of fruits using a Truper[®] digital caliper, model CALDI-6MP (Mexico). Pericarp thickness was measured using the same caliper on a sample of four halved fruits, which were also used to count the number of locules. Total soluble solids were determined using a portable VRW[®] refractometer (0-32 °Brix) by placing a drop of juice from the same fruits on the device.

Statistical analysis

An analysis of variance (ANOVA) was performed, and mean separation was conducted using Tukey's test at a significance level of $p \leq 0.05$, using SAS statistical software, version 9.0.

RESULTS AND DISCUSSION

According to the analysis of variance, significant differences ($p \leq 0.05$) were detected for all evaluated variables. These results are consistent with those reported by Flores-Hernández *et al.* (2018b), who evaluated native materials from the Andean region (Peru); Bonilla-Barrientos *et al.* (2014), who worked with native genotypes from the state of Puebla; and Carrillo and Chávez (2010), who studied native genotypes from Oaxaca. All these studies confirm the existence of broad morphological and genetic variation among the evaluated materials.

The statistical parameters showed variation in standard deviation and least significant difference, with fruit number and fruit weight exhibiting the highest values. Yield and fruit weight also presented the highest coefficients of variation at 26.7% and 24.3%, respectively. These results reveal considerable diversity among the evaluated wild tomato populations and indicate genetic variation in agronomic traits, which reflects broad potential for selection based on plant size, yield, and fruit quality, in line with findings by Bonilla-Barrientos *et al.* (2014), Carrillo and Chávez (2010), Flores-Hernández *et al.* (2018b), Juárez-López *et al.* (2009), and Sánchez-Peña *et al.* (2006).

Agronomic variables

Plant height ranged from 1.7 to 4.3 meters, observed in the accessions from Veracruz 4 and Hidalgo, respectively (Table 2). This trait is of interest in breeding programs aiming to develop compact plant architectures. Thus, it is crucial to continue exploring new germplasm sources to identify novel genes that could significantly contribute to developing new varieties with improved resistance or tolerance to adverse conditions, as well as enhanced quality, through the utilization of wild tomato genetic diversity (Hernández-Bautista *et al.*, 2014).

The genotypes with the highest and lowest number of leaves were Veracruz 3 with 47 leaves and Veracruz 10 with 33, resulting in a 14-leaf difference across all evaluated

Table 1. Agronomic variables measured in wild tomato genotypes cultivated under greenhouse conditions.

Variable	Mean	Range (Min-Max)	Standard Deviation	Coefficient of Variation (%)	Least Significant Difference (LSD)
Plant height (m)	3.2**	1.2-4.5	0.54	5.1	0.31
Number of leaves	38.6**	30-58	3.91	6.6	4.88
Number of fruits	56.9**	14-100	17.70	16.3	17.76
Fruit weight (g)	18.1**	2.0-65.0	14.39	24.3	8.41
Yield (kg plant ⁻¹)	0.9**	0.1-3.3	0.69	26.7	0.47
Polar diameter (mm)	26.5**	13.4-53.7	8.12	6.5	3.28
Equatorial diameter (mm)	30.9**	3.5-62.0	11.98	12.1	7.16
Number of locules	3.2**	2.0-11.0	2.11	20.7	1.26
Pericarp thickness (mm)	2.6**	0.5-7.0	1.24	20.7	1.01
Total soluble solids (%)	6.7**	3.2-10.5	1.33	9.6	1.23

Table 2. Mean comparison of agronomic variables in native tomato plants cultivated under greenhouse conditions in Guasave, Sinaloa.

Number	Morphotype	Plant height (m)	Number of leaves	Number of fruits	Fruit weight (g)	Yield (kg plant ⁻¹)
1	Chiapas	3.3 efgh	40 bcde	77 abc	5.0 lmn	0.3 hij
2	Estado de México 1	3.7 bc	39 bcde	70 bcde	22.0 fgh	1.5 bcd
3	Estado de México 2	3.4 defg	41 bc	75 abc	26.3 efg	1.9 b
4	Guerrero	2.5 n	37 cdef	75 abc	26.3 efg	1.9 b
5	Hidalgo	4.3 a	39 bcde	89 a	7.6 jklmn	0.6 ghi
6	Oaxaca 1	3.0 ijk	42 ab	85 ab	20.3 fg	1.7 bc
7	Oaxaca 2	2.9 jkl	35 ef	53 efhij	19.5 ghi	1.0 edf
8	Oaxaca 3	2.5 n	39 bcde	50 hij	3.0 n	0.1 j
9	Oaxaca 4	2.5 n	37 cdef	70 bcde	10.8 jklm	0.7 gh
10	Oaxaca 5	3.4 defg	36 def	44 hij	13.2 ijkl	0.5 ghij
11	Oaxaca 6	3.2 fghij	37 cdef	50 hij	2.6 n	0.1 j
12	Oaxaca 7	3.7 bcd	38 bcde	40 ij	49.1 a	1.9 bc
13	Puebla 1	2.9 kl	36 def	42 hij	6.2l mn	0.7 gh
14	Puebla 2	3.6 cde	39 bcde	51 fhij	3.2 n	1.4 cde
15	Puebla 3	3.8 bc	41 bc	69 bcde	5.2 lmn	1.2 def
16	Puebla 4	2.6 mn	35 ef	40 ijk	39.7 bce	1.0 edf
17	Puebla 5	2.6 mn	36 def	48 hij	15.8 hijk	0.2 ij
18	Puebla 6	2.9 klm	38 bcde	44 hij	34.3 de	0.1 j
19	Puebla 7	3.0 hijk	40 bcd	45 hij	28.1 ef	0.3 hij
20	Puebla 8	2.6 lmn	39 bcde	43 hij	24.1 fgh	1.5 bcd
21	Sinaloa 1	3.5 cdef	43 ab	66 cdef	3.5 n	0.2 ij
22	Sinaloa 2	3.3 efgh	33 f	47 hij	20.6 fghi	0.7 ghi
23	Veracruz 1	2.7 lmn	35 def	59 cdefh	43.1 abc	1.0 edf
24	Veracruz 2	3.4 defg	34 f	22 k	34.7 cde	1.6 bcd
25	Veracruz 3	3.2 efghi	47 a	73 abcd	4.2 mn	0.9 fg
26	Veracruz 4	1.7 o	43 ab	65 cdef	5.6 lmn	2.5 a
27	Veracruz 5	3.7 bcd	37 cdef	59 cdefh	6.7 lmn	0.7 gh
28	Veracruz 6	3.4 defg	39 bcde	67 cdef	4.8 lmn	0.3 hij
29	Veracruz 7	3.9 b	34 f	57 defhi	12.3 ijklm	0.3 hij
30	Veracruz 8	3.3 efgh	35 ef	55 efhi	18.6 ghij	0.4 hij
31	Veracruz 9	3.2 ghijk	37 cdef	37 jk	44.7 ab	0.3 hij

Means with different letters indicate significant differences ($p \leq 0.05$).

genotypes. According to Dong *et al.* (2024), leaves and stems are the primary sources of assimilates for fruit development, and are therefore considered key traits in tomato breeding programs, as also supported by Flores-Hernández *et al.* (2018b). The genotype with the highest fruit number was Hidalgo with 89 fruits per plant, while Veracruz 2 recorded the lowest with 22. According to Urrieta-Velázquez *et al.* (2012), high fruit number is often associated with racemose inflorescences, which are indeterminate reproductive structures that may exhibit helicoid, scorpioid, or raceme shapes. This trait depends on the genotype's capacity to set and develop fruit clusters, as noted by Dalpra *et*

al. (2021). In this study, the fruit number per plant was higher compared to the range of 51 to 79 fruits reported by Cordoba *et al.* (2018) in three cherry tomato varieties. In terms of fruit weight, there was a difference of 44 g between the heaviest and lightest fruits, ranging from 46.6 g in Oaxaca 7 to 2.6 g in Oaxaca 6. This variation reflects significant differences in fruit size, consistent with findings by Lin *et al.* (2014), who noted that tomatoes have undergone a dramatic increase in fruit size during domestication, with some modern cultivars producing fruits up to a thousand times larger than their wild counterparts. Raya *et al.* (2024) further explained that cultural practices such as irrigation, fertilization, planting density, leaf pruning, fruit thinning, and stem number management are key strategies for improving yield. Similarly, Luitel *et al.* (2012) emphasized that fruit number and weight are critical traits for enhancing tomato productivity, making them important indirect criteria in selection for high-yielding genotypes in breeding programs. The genotype with the highest yield was Veracruz 4, reaching 2.5 kg per plant, whereas the lowest was Oaxaca 6 with only 0.1 kg per plant. These results underscore the wide variability among the 31 morphotypes evaluated. Comparable ranges were reported by Cordoba *et al.* (2018) in cherry tomato varieties, with yields from 0.19 to 0.75 kg per plant. Other authors highlight that yield is a variable trait largely influenced by the genetic material used (Monge-Pérez, 2015), as well as environmental conditions, pest and disease incidence, and management practices such as planting density (Maboko and Du Plooy, 2018). Nevertheless, wild tomato materials exhibit far greater genetic variation compared to cultivated tomatoes, which possess only 4.48% of the total genetic diversity (Bai and Lindhout, 2007; Miller and Tanksley, 1990).

Fruit quality variables

To evaluate fruit quality, tomatoes were harvested at physiological maturity. The morphotype Oaxaca 7 exhibited the largest polar and equatorial diameters, measuring 46 mm and 57 mm, respectively, while Oaxaca 3 had the smallest diameters at 14 mm and 16 mm (Table 3). In this study, the fruits obtained were larger compared to those reported by Córdoba *et al.* (2018), who found fruit diameters ranging from 11 to 23 mm. According to the classification by Maboko and Du Plooy (2018), the fruits in this study were categorized as 10% extra-large, 29% large, 29% small, and 32% extra-small, indicating wide diversity in fruit size among wild tomatoes. Nevertheless, Nuez (2001) described cherry tomatoes as producing small, variable fruits ranging from 10 to 30 mm in diameter. Therefore, the morphotypes evaluated in this study showed greater variability, with average sizes exceeding those commonly reported, suggesting that fruit size is highly influenced by morphotype and production conditions. The number of locules in wild tomato fruits varied from 2 to 9. Morphotypes from Puebla averaged seven locules, while those from Veracruz typically had only one. These findings align with Medina and Lobo (2001), who reported tomatoes with 2 to 8 locules in 82 evaluated accessions. Barrero and Tanksley (2004) noted that wild tomatoes often have flowers with five to six sepals, petals, and stamens, producing bilocular fruits. However, they also explained that a mutation known as fasciation can lead to flowers with up to eight petals and an increased number of locules, resulting in elongated and multi-segmented fruits. According to Bai and Lindhout (2007), multilocular fruits have

Table 3. Comparison of means of quality variables of native Mexican tomato fruits grown in greenhouses in Guasave, Sinaloa.

Number	Morphotype	Polar Diameter (mm)	Equatorial Diameter (mm)	Number of Locules	Pericarp Thickness (mm)	Total Soluble Solids (%)
1	Campeche	18.6ijkl	20.5hij	2.4cde	1.39lm	8.61ab
2	Estado de México 1	31.6def	33.7cde	2.0e	3.31bcdef	6.5defghi
3	Estado de México 2	32.5cbe	37.6cd	8.0a	2.05hijkl	5.44hijk
4	Guerrero	30.8ef	36.7cd	3.9b	3.96bc	5.63ghijk
5	Hidalgo	20.3hij	23.5ghij	2.0e	1.72ijklm	8.61ab
6	Oaxaca 1	29.5ef	33.5cde	2.0e	2.71efghi	6.23efghij
7	Oaxaca 2	41.5b	29.0efg	2.1de	4.09b	5.66ghijk
8	Oaxaca 3	14.4m	16.7j	2.0e	1.30lm	6.98def
9	Oaxaca 4	30.1ef	24.8ghi	2.0e	2.63efghij	6.21efghijk
10	Oaxaca 5	31.4def	25.9egh	2.0e	3.26bcdef	9.20a
11	Oaxaca 6	15.5lm	16.3j	2.0e	0.79m	8.98a
12	Oaxaca 7	46.7a	57.2a	3.4bcd	6.04a	6.3efghij
13	Puebla 1	23.5gh	33.7cde	3.6bc	2.87defgh	6.3efghij
14	Puebla 2	34.3cd	39.8c	3.1bcde	4.03bc	5.63ghijk
15	Puebla 3	32.5cde	35.2cde	3.5bc	3.35bcde	5.73ghijk
16	Puebla 4	35.6cd	34.5cde	3.1bcde	3.79bcd	5.84fghijk
17	Puebla 5	17.8ijkl	22.0ghij	3.1bcde	1.33lm	7.26cde
18	Puebla 6	17.2jklm	17.8ij	2.0e	2.16ghijkl	6.6defgh
19	Puebla 7	19.1ijk	21.3hij	2.0e	1.46lm	7.31bcd
20	Puebla 8	28.5f	49.2b	2.0e	2.66efghi	4.99k
21	Sinaloa 1	17.5ijklm	18.7hij	2.4cde	1.43lm	7.59bcd
22	Sinaloa 2	30.6ef	31.6 def	3.4bcd	3.07cdefg	6.75defg
23	Veracruz 1	29.7ef	52.4ab	9.0a	2.52fghijk	5.78fghijk
24	Veracruz 2	31.0def	35.5cde	2.8bcde	3.19bcdef	5.36ijk
25	Veracruz 3	31.7def	49.0b	7.8a	3.64bcde	6.19efghijk
26	Veracruz 4	28.5f	50.4ab	8.4a	2.55fghijk	5.21jk
27	Veracruz 5	17.9ijkl	19.2hij	2.0e	1.38lm	8.25abc
28	Veracruz 6	20.0ij	19.8hij	2.0e	1.64ijklm	6.5defghi
29	Veracruz 7	20.5hi	22.8ghij	2.0e	1.60klm	7.41bcde
30	Veracruz 8	16.6klm	18.2ij	2.0e	1.36lm	8.84a
31	Veracruz 9	24.7g	28.6efg	2.0e	1.94hijkl	6.2efghij

Means with different letters indicate significant differences ($p \leq 0.05$).

been selectively bred during domestication, although only a small proportion of modern tomato cultivars are multilocular, as stated by Barrero and Tanksley (2004). Other studies have reported that native tomatoes exhibit between 2 and 10 locules, depending on the shape of the fruit (Roohanitaziani, 2019; Salinas-Vargas *et al.*, 2020). Pericarp thickness ranged from 0.8 to 6 mm in morphotypes Oaxaca 7 and Oaxaca 6, respectively, indicating variability in this trait. This is similar to results obtained by Medina and Lobo (2001), who found an average pericarp thickness of 3.3 mm in cherry tomatoes. Total soluble solids

content in tomato fruits ranged from 4.9 to 9.2 °Brix, with Puebla 8 showing the lowest and Oaxaca 5 the highest values. These results are comparable to those reported by Juárez-López *et al.* (2009), who found total soluble solids ranging from 5.8 to 8.0 °Brix. The values observed in this study are higher than those reported by Bonilla-Barrientos *et al.* (2014), who recorded 4.44 °Brix in cherry-type accessions and 3.88 and 3.99 °Brix for kidney- and saladette-type fruits, respectively. They are also greater than those reported by Maboko and Du Plooy (2018) in the cherry tomato variety Josefina, which averaged 7.2 °Brix. According to Costa *et al.* (2020) and Fukudome *et al.* (2022), total soluble solids are among the most important quality criteria for tomatoes, as they reflect sugar content in solution. Nuez (2001) emphasized that higher soluble solids content translates into superior flavor for fresh consumption. In addition, elevated levels of antioxidants associated with high soluble solids contribute to the prevention of cancer and cardiovascular diseases (Luna & Delgado, 2014) and play a significant role in combating oxidative stress (Bergougnoux, 2014). In this

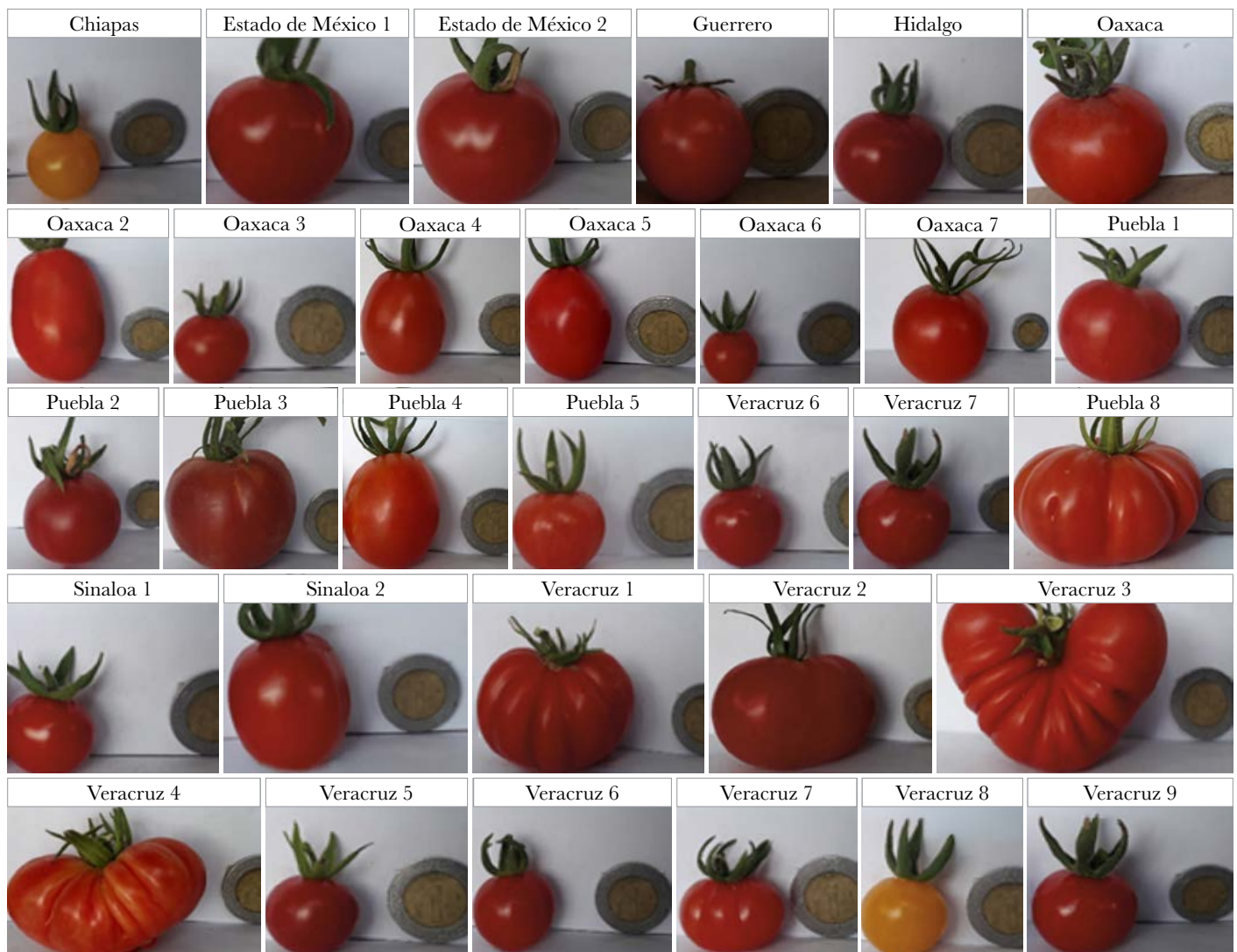


Figure 1. Fruits of 31 wild tomato morphotypes cultivated under greenhouse conditions in Guasave, Sinaloa.

study, the smallest fruits, such as those from Oaxaca 6, exhibited the highest soluble solids content, making them suitable for local use or as valuable germplasm sources.

In the Figure 1 shows images of the fruits from the 31 morphotypes cultivated in the Guasave region of Sinaloa. Several researchers have highlighted that wild tomatoes represent the most important source of genetic diversity, which can be used in the improvement of commercial tomato varieties, as it would broaden their currently narrow genetic base (Bai and Lindhout, 2007; Bergougnoux, 2014; Miller and Tanksley, 1990).

The studied germplasm represents a valuable resource for tomato breeding programs due to potentially useful traits such as fruit number, size, yield, and total soluble solids content.

CONCLUSIONS

Several of the evaluated morphotypes demonstrated considerable potential for developing strong hybrid vigor in terms of agronomic traits (Veracruz 4), yield (Veracruz 3), and quality (Oaxaca 5). These findings support their suitability for future hybridization efforts within tomato breeding programs.

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