In Situ Characterization of Fruits and Seeds of a Number of White Sapote (Casimiroa edulis Llave & Lex.) Accessions in Mexico

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Abstract. Fifty-six accessions of white sapote (Casimiroa edulis Llave & Lex.) grown in situ in 11 municipalities in the state of Michoacán, Mexico, were characterized using 14 morphometric variables (six of fruit and eight of seed). There was a high CV for fruit weight (0.50), the number of developed seeds (NDS) (0.48), and total seed weight (0.45). Principal component analysis (PCA) showed that the main differences among the C. edulis accessions were fruit weight, seed projected area, Feret diameter (FD), the length of polar and equatorial axes of the fruit, the number of undeveloped seeds (NUS), the NDS, hardness of the skin (HS), and total soluble solids content of the fruits. Three groups of accessions were determined by cluster analysis (CA). The first group was made up of 53 accessions with intermediate values of fruit size and seed size. The second group, comprising two accessions, had the lowest values of fruit size. The third group showed an outstanding individual with the highest values for fruit size/weight, seed weight, and total soluble solids. Through an in-depth examination of the genotypes of the first group, four genotypes were identified for their positive characteristics. The results indicate an extremely high variability in the fruit and seed characteristics produced by different trees/genotypes of white sapote in Mexico. Hence, an initial, preliminary individuation/selection of five genotypes could be considered for the development of new cultivars for establishing white sapote orchards in Mexico.

The genus Casimiroa (Rutaceae) is a native of the subtropical regions of Mesoamerica. Ten species have been recognized, nine of which are present in Mexico and Central America (Chiang, 1989; Henry and Vera-Calleti, 2010). Because of the sweet flavor and medicinal properties of the fruit, C. edulis is the best known species and is cultivated around the world. White sapote (C. edulis), or “zapote blanco” in Spanish, or “uruhuta urapiti” in the Purhepecha language in Michoacán, Mexico, is distributed throughout the subtropical frost-free areas of Mexico at altitudes of 1500–2500 m. In particular, it is found in the states of Michoacán, Guanajuato, Jalisco, Colima, Hidalgo, State of Mexico, Veracruz, Chiapas, Puebla, Taxcala, and México City, in areas with rainfall between 900 and 1300 mm/year. White sapote is common in backyards, semicultivated areas, and wild areas (Andrés-Aguinstit, 1996; Martínez, 1951; Popeone, 1920). In Mexico, the fruit is available from April to July. White sapote is propagated by seed and this leads to a wide variability among trees in Mexico. The fruit of C. edulis is harvested for fresh consumption and is frequently sold in local markets (Andrés-Aguinstit, 1996). The leaves and seeds of this species are used in traditional medicine as a sedative (Khaelel, 2002) and as antihypertensive (Vidal-López et al., 2017) and anticonvulsant (Satheesh, 2015) agents.

The origin of domestication of white sapote was in the Basin of Mexico, which started between 6800 and 2500 BC and is similar to other fruits such as avocado (Persea americana) and black sapote (Diospyros digyna) (García, 2007; González, 2001). White sapote was used by the Aztecs who named this fruit species “Cochitzapotli” (cochī = sleep and tzapotli = fleshy and sweet fruit) due to its sleep-inducing properties (Sahagún, 1990). During the colonial conquest, white sapote, along with other native fruit species, was displaced by the introduction of European fruit species (González, 2001; Martínez et al., 2013).

Trees of white sapote are 3–5 m high. The fruit is climacteric (Lozano-Grande et al., 2006) and can be round, oval, or ovoid. It can be 6.25–11.25 cm wide and up to 12 cm long. Its skin is greenish-yellow in color (Fig. 1). The pulp is edible and creamy-white or yellow with tiny yellow oil glands. Its flavor is sweet with a hint of bitterness. The fruit may have one to six white seeds 2.5–5 cm long and 1.25–2.5 cm wide, but often some seeds are underdeveloped and very thin (Morton, 1987).

Currently, white sapote is cultivated in subtropical areas throughout the world and in regions with a Mediterranean, tropical, or semiarid climate. The trees have been planted in the northern part of South America, the Caribbean region, Spain, Portugal, Southern France (Ahlawat et al., 2017), Italy (Rossini et al., 2002), Egypt (Abo-El-Ez et al., 2013), and Ethiopia (Satheesh, 2015). They are grown commercially on a small scale in New Zealand, Australia (Yamamoto et al., 2007), and South Africa. There are small plantings in California, Florida, Hawaii (Ahlawat et al., 2017), and experimental plantings in Israel (Nerd et al., 1990). White sapote has grown well in California since the early 1800s (Schneider, 1986) when it was introduced by Franciscan monks and produces well in San Francisco (Thompson, 1972).

There are few studies on white sapote. It was introduced into the Negev desert of Israel and its tolerance to salinity was studied by Nerd et al. (1992). Other studies on white sapote regard the analysis of varietal differences in floral and fruit morphology (Yonemoto et al., 2001), the definition of an index for establishing harvesting time for ‘Cuccio’ (Yonemoto et al., 2006), the genetic diversity of cultivars using SSR analysis (Yamamoto et al., 2007), and the selection in Egypt of trees/genotypes having outstanding yield and fruit quality (Abo-El-Ez et al., 2013). In addition, in Florida, cultivars of white sapote, such as ‘Dade’ and ‘Smathers’, have been developed and are cultivated in home gardens (Crane and Baledri, 2016).

Although white sapote is a native of Mexico, information regarding the characteristics of the trees/genotypes growing in
Mexico is very limited and no data are available in peer reviewed literature. In addition, there are no Mexican cultivars of white sapote registered and there are no commercial plantings of this species in Mexico. As white sapote is well adapted to the environmental conditions of large areas of Mexico, as demonstrated by the fact that it grows wild, and considering that the consumption of its fruit and the medicinal interest in its seeds is increasing, it could be important to give more attention to this species in Mexico. In particular, it could be useful to provide information for its cultivation. In this regard, a fundamental aspect is the individuation/selection of superior genotypes in terms of adaptability and fruit and seed characteristics, which are fundamental for establishing orchards.

The purpose of this study was to characterize, in situ, the fruit and seed characteristics of white sapote (Castimiro edulis Llave & Lex.) with outstanding characteristics and with the possibility of becoming registered cultivars. The domestication of white sapote began between 1861 and 2400 m altitude: Morelia, Tangancícuaro, Lagos de Moreno, Huaceua, Ziracuaretiro, Tzintzuntzan, Pátzcuaro, Lagunillas, Huirimba, Ziracuaretiro, Tangancicuaro, Purépero, Quiroga, Tzintzuntzan, and Los Reyes. For each accession, 10 fruits, at physiological maturity (Lozano-Zárate, 2006; Franco-Mora et al., 2008; López-Santiago et al., 2008). Standard errors of selected variables were determined with the InfoStat software version 2017 (Di Rienzo et al., 2017).

Materials and Methods

Fruits were collected from 56 white sapote trees (accessions) growing in ten municipalities of Michoacán, Mexico, located between 1861 and 2400 m altitude: Morelia, Pátzcuaro, Lagos de Moreno, Huaceua, Ziracuaretiro, Tangancicuaro, Purépero, Quiroga, Tzintzuntzan, and Los Reyes. For each accession, 10 fruits, at physiological maturity (Lozano-Grande et al., 2006), were collected from April to June of 2015. A digital scale (Ohaus Gram, 2017) and a hand refractometer ABBE® 117 digital (Leica Mark II) were used for measuring the total soluble solids (TSS) as °Brix and the fruit weight (FW). The equatorial and polar diameters of the fruit (cm) (EDF and PDF, respectively) were measured with a digital caliper (Mitutoyo CD-6”CSX). To evaluate the HS a McCormick fruit pressure tester [FT 0011 (0–11 lbs)] with a 11.2-mm plunger was used. Total soluble solids (TSS) as °Brix were determined with a hand refractometer ABBE® 117 digital (Leica Mark II). Skin and seeds were separated from the pulp and weighed (SW) (g). The NDS and NUS were recorded. A random sample of 15 seeds per accession was weighed (TSW) and scanned in digital photographs using Image Tool Ver. 3.00 (UTHSCSA, 2000) to determine the following parameters of the seeds: projected area (cm²) (SPA), the length of the equatorial diameter (cm) (LEA), the length of the polar axis (cm) (LPA), roundness index [(4·π·area)/perimeter²], and FD [(4·π·Area)/π]. The data were elaborated using PCA and CA and the data were standardized (Rhoff, 2000). For CA, the similarity matrix among specimens was calculated using the average taxonomic distance (Manly, 1986). The unweighted pair group method arithmetic average was used for clustering. Numerical analyses were carried out with the software package NTSYS-pc version 2.1 (Rhoff, 2000). Three different groups were defined with the CA (Table 4). The first group included 53 individuals characterized by intermediate values of fruit size, seed size, and HS. These trees had average values of FW = 100.56 ± 5.45 g, HS = 1.67 ± 0.60 kg·cm⁻2, PDF = 5.36 ± 0.12 cm, and TSW = 19.30 ± 1.10 g. The second group included two accessions (11 and 44) characterized by fruit and seeds of small size and weight. For example, they had average FW values = 26.76 ± 15.68 g, SW = 3.59 ± 0.21 g, PDF = 7.97 ± 0.09 cm, EDF = 6.59 ± 0.12 cm, and TSW = 7.97 ± 0.09 cm, EDF = 8.53 ± 1.0 cm, TSW = 23.60 ± 2.0 g, SPA = 7.69 ± 0.59 cm², LPA = 4.78 ± 0.77 cm, LEA = 2.14 ± 0.10 cm, and FD = 3.12 ± 0.04 values (Table 4).

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The domestication of white sapote began 6800–2500 BC in the Mesoamerican region at...
Table 1. Descriptive statistics of the 14 variables evaluated in 56 genotypes of white sapote (Casimiroa edulis Llave & Lex).

| Variable     | Mean     | sd       | cv (%)  | N     | Minimum | Maximum |
|--------------|----------|----------|---------|-------|---------|---------|
| FW           | 101.91   | 50.92    | 50.0    | 56    | 11.08   | 323.68  |
| HS           | 1.65     | 0.54     | 32.7    | 56    | 0.25    | 2.93    |
| TSS          | 18.70    | 3.39     | 18.1    | 56    | 11.20   | 26.83   |
| SW           | 9.80     | 3.43     | 35.0    | 56    | 2.62    | 20.41   |
| PDF          | 5.33     | 0.91     | 17.1    | 56    | 2.38    | 7.97    |
| EDF          | 5.56     | 1.09     | 19.6    | 56    | 2.41    | 8.52    |
| NUS          | 3.42     | 0.70     | 20.5    | 56    | 1.33    | 4.66    |
| NDS          | 1.38     | 0.67     | 48.6    | 56    | 0.00    | 3.00    |
| TSW          | 18.75    | 8.48     | 45.2    | 56    | 1.16    | 46.97   |
| SPA          | 4.44     | 1.16     | 26.1    | 56    | 0.78    | 7.69    |
| LPA          | 3.20     | 0.52     | 16.3    | 56    | 1.47    | 4.78    |
| LEA          | 1.78     | 0.27     | 15.2    | 56    | 0.70    | 2.24    |
| SRI          | 0.68     | 0.06     | 8.8     | 56    | 0.53    | 0.78    |
| EDN          | 2.34     | 0.34     | 14.5    | 56    | 0.99    | 3.12    |

FW = fruit fresh weight; HS = hardness of the skin; TSS = total soluble solids; SW = seed weight per fruit; PDF = polar diameter of the fruit; EDF = equatorial diameter of the fruit; NUS = number of undeveloped seeds; NDS = number of developed seeds; TSW = total seed weight per accession; SPA = surface projected area of the seed; LPA = length of the polar axis of the seed; LEA = length equatorial of the seed; SRI = seed roundness index; EDN = Feret diameter.

Table 2. Eigenvalues, percent, and cumulative variance of the first three principal components (PCs) on 14 variables measured on white sapote (Casimiroa edulis Llave & Lex) fruit and seeds.

| PC  | Eigenvalue | Percent | Cumulative (%) |
|-----|------------|---------|----------------|
| 1   | 7.4671     | 53.33   | 53.33          |
| 2   | 1.9322     | 13.80   | 67.13          |
| 3   | 1.3854     | 9.89    | 77.02          |

Table 3. Eigenvector values on the first three axes after principal component (PC) analysis of fruit and seed of white sapote (Casimiroa edulis Llave & Lex).

| Character | PC 1 | PC 2 | PC 3 |
|-----------|------|------|------|
| FW        | 0.8790 | 0.0688 | 0.1174 |
| HS        | 0.3783 | 0.1559 | -0.6398 |
| TSS       | 0.0824 | 0.0785 | -0.6161 |
| SW        | 0.7822 | 0.1946 | 0.3053 |
| PDF       | 0.9044 | 0.0903 | -0.0986 |
| EDF       | 0.9136 | 0.1166 | -0.0211 |
| NUS       | 0.3976 | -0.8235 | -0.2284 |
| NDS       | -0.2300 | 0.8653 | 0.2690 |
| TSW       | 0.8342 | -0.3134 | -0.0582 |
| SPA       | 0.9308 | 0.2193 | -0.0143 |
| LPA       | 0.9158 | 0.0651 | 0.1468 |
| LEA       | 0.8322 | 0.3250 | -0.2024 |
| SRI       | -0.3423 | 0.3260 | -0.5342 |
| EDN       | 0.9265 | 0.2194 | -0.0574 |

Values in each PC with important contribution are in bold.

Conclusions

This is the first report in peer-reviewed literature regarding fruit and seed characteristics of white sapote growing in Mexico, which is one of the centers of origin of this species. The results indicate that there is an extremely high variability in the fruit and seed characteristics produced by different trees. This allows an initial preliminary individuation/selection of genotypes (trees number 49, 17, 31, 41, and 48) to be made with the aim of developing new cultivars for the establishment of white sapote orchards in Mexico. Among them, tree number 49 is very interesting because all of the parameters of both fruits and seeds were excellent. For a full characterization of these genotypes, it would be important to propagate them to establish a comparative field (ex situ) which will allow the best genotypes to be selected for developing white sapote cultivation in Mexico. Moreover, the large variability indicates that it would also be useful to expand the study to include other promising trees not considered in this initial investigation. Nutritional characteristics and antioxidant activity in the pulp are also important to consider in future studies.

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Table 4. Mean values of fourteen variables of 56 trees in the three groups of white sapote (Casimiroa edulis Llave & Lex.) formed by cluster analysis.

| Group | N  | FW   | HS   | TSS  | SW   | PDF  | EDF  | NUS | TSW | SPA  | LPA  | LEA  | SRI  | FD    |
|-------|----|------|------|------|------|------|------|-----|-----|------|------|------|------|-------|
| 1     | 53 | 100.56 | 1.67 | 18.62 | 9.84 | 5.36 | 5.60 | 3.46 | 1.34 | 19.30 | 4.50 | 3.23 | 1.81 | 0.68  | 2.37 |
| 2     | 2  | 26.76  | 0.92 | 19.85 | 3.59 | 3.48 | 3.14 | 2.50 | 2.17 | 1.99  | 1.31 | 1.80 | 0.91 | 0.63  | 1.25 |
| 3     | 1  | 323.69 | 2.32 | 20.77 | 20.41 | 7.97 | 8.53 | 3.14 | 2.00 | 23.60 | 7.69 | 4.78 | 2.14 | 0.55  | 3.12 |

FW = fruit fresh weight; HS = hardness of the skin; TSS = total soluble solids; SW = seed weight per fruit; PDF = polar diameter of the fruit; EDF = equatorial diameter of the fruit; NUS = number of undeveloped seeds; TSW = total seed weight per accession; SPA = surface projected area of the seed; LPA = length of the polar axis of the seed; LEA = length equatorial of the seed; SRI = seed roundness index; FD = Feret diameter.