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Artículo

Mortalidad y sanidad de procedencias de *Enterolobium cyclocarpum* (Jacq.) Griseb. en la costa de Oaxaca

Mortality and health of provenances of *Enterolobium cyclocarpum* (Jacq.) Griseb. in the coast of *Oaxaca*

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Resumen

En México existe un vacío de conocimiento sobre la mortalidad y sanidad de plantaciones forestales tropicales. Por tanto, un ensayo de procedencias de *Enterolobium cyclocarpum* se estableció en dos sitios (Pinotepa de Don Luis y Valdeflores) de la región Costa de Oaxaca, México, para conocer los factores y agentes bióticos relacionados con esta especie. La mortalidad y sanidad de las plantas se registró durante 18 meses, y se determinaron diferencias entre sitios y procedencias. *Orthogeomys grandis* (tuza) en Pinotepa de Don Luis (27.9 %) y la sequía (29.2 %) en Valdeflores causaron mayor mortalidad de individuos. Cenicilla (*Oidum*), pulgón (*Aphis*), cochinilla algodonosa (*Pseudoccocus longispinus*), corta palos (*Oncideres*), un barrenador (Lepidoptera) y un defoliador (Lepidoptera) se vincularon con la sanidad de *E. cyclocarpum.* Las cenicillas y los pulgones afectaron el mayor número de ejemplares; en Pinotepa de Don Luis, las cenicillas infectaron 58.8 % de las plantas y los pulgones a 29.2 %; mientras que, en Valdeflores la afectación fue de 3.3 % y 0.8 %*,* respectivamente. En Pinotepa de Don Luis, Cortijo y Colotepec tuvieron menor infección de cenicilla y la infestación de pulgones no fue significativa entre las procedencias. En Valdeflores, cinco procedencias carecieron de presencia de cenicilla y, únicamente, El Zarzal tuvo evidencia de pulgones. La ubicación y la precipitación de los sitios influyeron en los niveles de mortalidad y sanidad de las plantas de *E. cyclocarpum*.

Palabras clave: *Aphis*, *Oidium*, *Oncideres*, plantaciones tropicales, *Pseudococcus longispinus* (Targioni Tozzetti, 1867), sequía.

Abstract

In Mexico, there is a knowledge gap on plant mortality and health of tropical forest plantations. Therefore, a provenances test of *Enterolobium cyclocarpum* was established in two sites (*Pinotepa de Don Luis* and *Valdeflores)* in the coastal region of *Oaxaca*, Mexico to determine the mortality factors and biotic agents related to the health of this specie. Mortality and plant health were recorded during 18 months; also, differences between sites and between provenances were determined. *Orthogeomys grandis* (pocket gopher) in *Pinotepa de Don Luis* (27.9 %) and drought (29.2 %) in Valdeflores caused higher plant mortality. Powdery mildews (*Oidum*), aphid (*Aphis*), cottony cochineal (*Pseudoccocus longispinus*), twig girdlers (*Oncideres*), borer (Lepidoptera) and defoliator (Lepidoptera) were the biotic agents related to health of *E. cyclocarpum*. The powdery mildews and the aphids infected the highest number of plants; in *Pinotepa de Don Luis*, the powdery mildews and the aphids infected 58.8, 29.2 % of the plants, respectively; whereas, in *Valdeflores*, the powdery mildews and aphids infected 3.3 % and 0.8 % of the plants, respectively. In *Pinotepa de Don Luis*, plants from *Cortijo* and *Colotepec* had the lowest powdery mildews infection, and the aphid infestation was not different in plants between provenances. In *Valdeflores*, plants from five provenances were free of powdery mildews infection, and the aphids only infested plant from the *El Zarzal* provenance. The location and precipitation of the sites influenced the levels mortality and infection of *E. cyclocarpum* plants.

Key words: *Aphis*, *Oidium*, *Oncideres*, tropical plantations, *Pseudococcus longispinus* (Targioni Tozzetti, 1867), drought.

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Introduction

In Mexico, 4.708 million ha of forest have been planted for commercial and conservation purposes between years 2000 and 2018; however, their survival rate is 20 to 64 % (GEUM, 2018). This rate is similar in experimental plantations, ranging between 22 and 82 % (Pedraza and Williams-Linera, 2003; Alvarez-Aquino *et al.*, 2004; Muñoz *et al*., 2013; Sigala *et al*., 2015). This low survival is due to a number of factors, including the quality of the plant, the production systems and the provenance of the seeds (Ramírez-Contreras and Rodríguez-Trejo, 2004; Rodríguez-Trejo, 2006; Sigala *et al*., 2015), as well as to the conditions of the plantation site, predation, pests and diseases (Alvarez-Aquino *et al.*, 2004; Ramírez-Contreras and Rodríguez-Trejo, 2004; Cibrián, 2013).

Enterolobium cyclocarpum (Jacq.) Griseb. is a multipurpose tree (Couttolenc-Brenis *et al*., 2005) of significant forestry importance. It is native of Mexico and Central America (Vázquez-Yanes *et al*., 1999; Pennington and Sarukhán, 2005). In tropical zones of Mexico, it is used for restoration programs, agroforestry and silvopastoral systems and commercial forest plantations (Vázquez-Yanes *et al*., 1999; Muñoz-Flores *et al.,* 2016). Nevertheless, the survival rate ranges between 50.8 and 64 % (Foroughbakhch *et al.*, 2006; Muñoz *et al*., 2013), although the causes of mortality in these plantations are unknown, they may be assumed to be related to the provenance of the seeds, and plantation site (Foroughbakhch *et al.*, 2006; Muñoz *et al*., 2013) and to pests and diseases (Cibrián, 2013).

In Mexico, there is a huge gap in the knowledge on the predation and the biotic agents related to the health of *E. cyclocarpum* in forest plantations. However, these delay the growth, affect the productivity and may cause the death of the trees (Cibrián, 2013). As for the health of *E. cyclocarpum*, insects of the *Aphis* genus, the citrus mealy bug, and the pink mealy bug have been found to affect the shoots, leaves, branches and fruits of adult individuals across the country (Solares, 2008; López-Arriaga *et al.*, 2010; Sinavef, 2011; Isiordia-Aquino *et al*., 2012). Furthermore, three bark beetle species, including *Xyleborus volvulus* (F.), damage the tree stem (Cibrián *et al.*, 1995; Solares, 2008).

On the other hand, knowledge of the geographic adaptive variation allows the creation of movement rules of forest seeds (Zobel and Talbert, 1988; White *et al*., 2007), which increase the likelihood of success of the plantations. It is essential to choose the adequate provenance for each particular site, in order to reduce the mortality, increase the productivity and improve the health of the planted trees (White *et al.*, 2007). For this reason, provenance assays are necessary to select plants that are resistant to predation and biotic agents associated with to health (Zobel and Talbert, 1988; White *et al*., 2007).

Within this context, an assay of the provenances of *E. cyclocarpum* was performed in two sites of the region of the Coast of *Oaxaca*, Mexico, with the following purposes: 1) to determine the mortality factors and to assess the percentage of dead plants in provenances of *E. cyclocarpum*; 2) to identify biotic agents related to health and to evaluate the affectation percentage in provenances of *E. cyclocarpum*. The proposed hypothesis was that the ecological conditions of the plantation sites may favor or affect the mortality and health of the provenances of *E. cyclocarpum*.

Materials and Methods

A provenance assay of *E. cyclocarpum* was established at two sites in the Coast of *Oaxaca* region (Figure 1, Table 1). The seeds from 10 provenances were collected between March and May 2008 in the coast of *Oaxaca*. The germination and production of plants took place on a substrate constituted by 35 % soil, 35 % bark, and 305 sawdust. The age of the plants was six months, and the average height at the time of the planting, in June 2009 in *Valdeflores*, and in July 2009 in *Pinotepa de Don Luis,* was 25 cm. The nearest provenance to the first locality was *Colotepec,* and the second provenance was local. In both, the experimental design consisted of randomized complete blocks with 10 treatments (provenances), six replications and four plants per experimental unit.

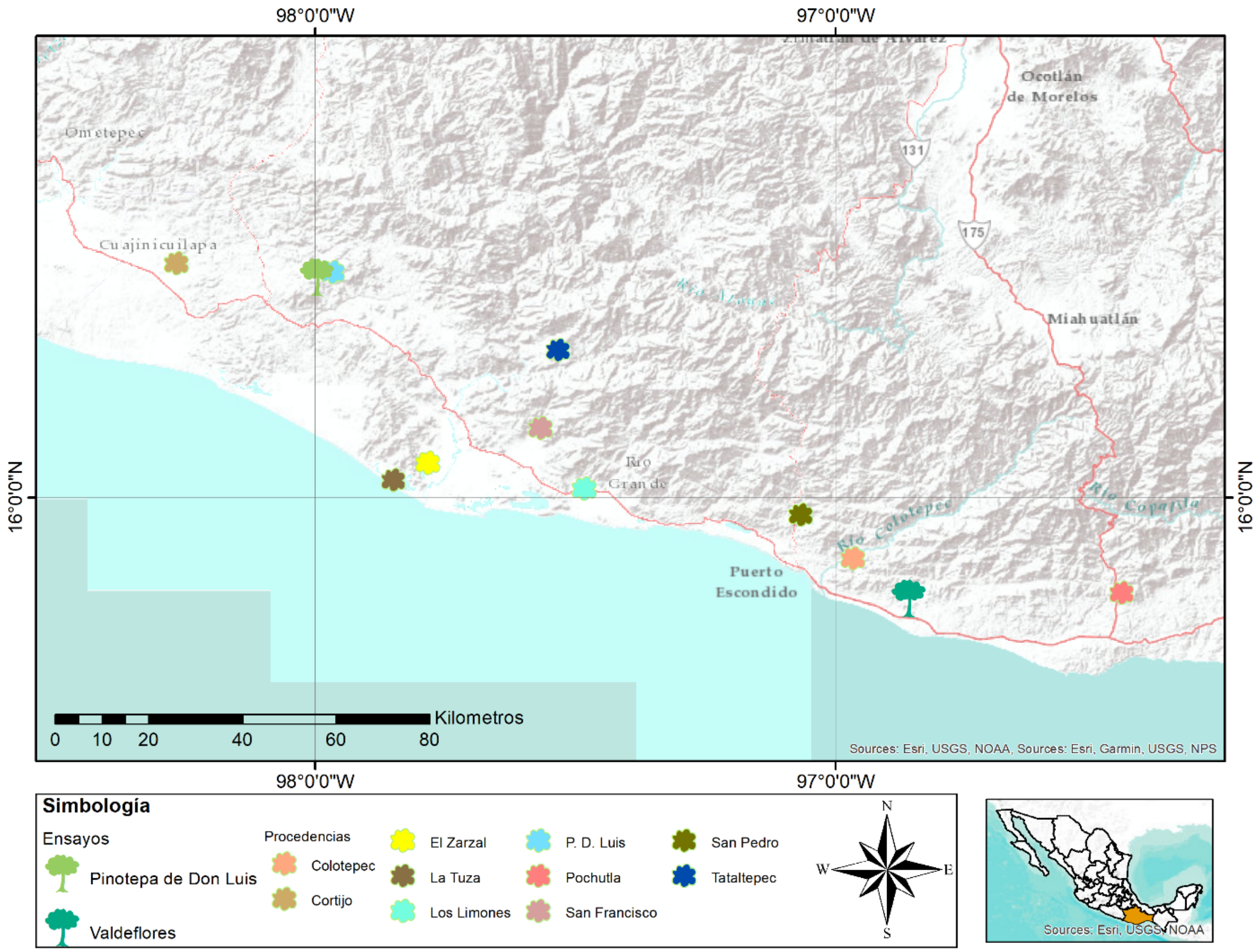


Figure 1. Spatial distribution of the provenances of *Enterolobium cyclocarpum* (Jacq.) Griseb. and geographic location of the assay sites in the Coast of *Oaxaca.*

Table 1. Characteristics of the sites and provenances of *Enterolobium cyclocarpum* (Jacq.) Griseb. evaluated in the Coast of *Oaxaca* region.

	Altitude (m)	**MAT (°C)**	**MAP (mm)**	**AI**	**ST**
Sites					
Pinotepa de Don Luis	455	25.9	1645	4.6	Regosol
Valdeflores	90	25.8	910	8.2	Phaeozem
Provenances					
Cortijo	59	26.9	1176	6.7	Luvisol
Pinotepa de Don Luis	420	26.1	1658	4.6	Regosol
El Zarzal	14	26.8	1194	6.6	Phaeozem
La Tuza	15	26.8	1185	6.6	Regosol
Tataltepec	370	26.5	1296	6.0	Regosol
San Francisco	67	26.9	1215	6.5	Phaeozem
Los Limones	23	26.9	1197	6.6	Phaeozem
San Pedro	240	25.9	1102	6.8	Phaeozem
Colotepec	37	26.3	938	8.2	Cambisol
Pochutla	234	25.4	1331	5.5	Cambisol

MAT = Mean annual temperature; MAP = Mean annual precipitation; AI = Aridity index, provided by the Moscow Forestry Science Laboratory (Crookston, 2018); ST = Soil type (INEGI, 2013).

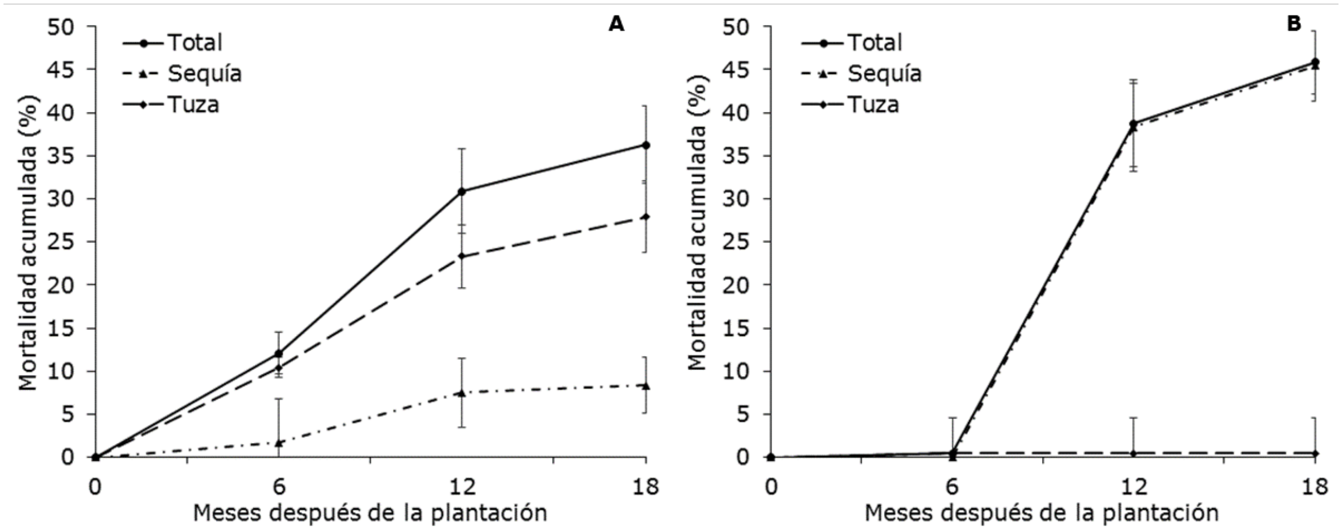
The plantation was inspected fortnightly during the first 18 months; the cause of mortality and the biotic agents present (pests or pathogenic organisms) present in the plants were recorded in each visit. At the end of the period, the mortality rate and the number of infected and infested individuals was estimated. These were identified (by class, family, genus or species) by comparing the specimen and its damage with the information cited in books, manuals, brochures, data sheets and specialized taxonomic codes (Cibrián *et al.*, 1995; Cibrián *et al.*, 2007a; Solares, 2008; Barriga, 2009; Monné and Bezark, 2011; Cibrián, 2013); in addition, specialists in certain taxonomic groups were consulted.

The assumptions of normality and homogeneity of variances of the data were verified with the Shapiro-Wilks test and Levene's test, respectively. Neither variable met any of the two assumptions; therefore, the differences between sites and between provenances in each site were determined by means of a variance analysis and RT-3 multiple range RT-3 comparisons (Conover, 2012).

Results and Discussion

Mortality

In both plantations, drought and gophers were the main factors that caused the largest plant mortality percentages. The symptoms of death by drought were curling of the leaflets, followed by withering and death of young leaves and, subsequently, by downward withering and death of the adult leaves and stem; the roots exhibited no damage due to predation. The individuals killed by gophers exhibited gnawed roots and the presence of gopher tunnel entrances at the base of the plant stems. The identified species was *Orthogeomys grandis* (Thomas, 1893), which is widely distributed in the Coast of *Oaxaca* (Lira *et al*., 2005). Total mortality rates increased during the evaluation period (Figure 2), and there were significant differences between sites ($p= 0.03312$); mortality due to drought ($p< 0.0001$) and to gophers ($p< 0.0001$) also increased. In both *Pinotepa de Don Luis* and *Valdeflores*, the total mortality rate was 38.3 and 45.8 %; mortality due to drought was 8.3 and 29.2 %, and mortality due to gophers, 27.9 y 0.4 %, respectively (Figure 2).



Mortalidad acumulada = Accumulated mortality; *Meses después de la plantación* = Months after planting.

Figure 2. Mortality (total, due to droughts and to gophers) of *Enterolobium cyclocarpum* (Jacq.) Griseb. accumulated in three periods (6, 12 and 18 months) in *Pinotepa de Don Luis* (A) and *Valdeflores* (B), in the Coast of *Oaxaca* region.

The mortality factors were differentiated between plantation sites: drought was the main cause of mortality in *Valdeflores*, and attack by gophers, in *Pinotepa de Don Luis*. The difference in mortality rates due to drought between the sites was rain-related: the mean annual precipitation in *Valdeflores* (910 mm) was lower than that registered in *Pinotepa de Don Luis* (1 645 mm), while the aridity index (AI) in *Valdeflores* (8.2) was higher than that of *Pinotepa de Don Luis* (4.6). In the latter locality, predation by gophers was greater, due, perhaps, to the fact that, during the first six months, the plantation was mixed with corn crops, which may have induced a greater damage because corn is food for the gophers. Viveros-Viveros *et al*. (2005) cited mortality caused by gophers in a *Pinus pseudostrobus* Lindl. assay in which the population of this rodent increased in response to the agricultural history of the site, the availability of food, and the elimination of its natural predators. Furthermore, the soils of *Pinotepa de Don Luis* are silty and deep, which facilitates the digging of burrows by this mammal; on the other hand, in *Valdeflores* the soil is clayey and shallow (INEGI, 2013).

The total mortality was significantly different (p≤ 0.0355) between provenances at both sites. In *Pinotepa de Don Luis*, the plants from the San Pedro provenance had a lower total mortality and those from *Colotepec* had the highest; likewise, the plants from *San Pedro* and *Pochutla* were less affected by the gophers, and those from *Cortijo* were most affected. On the other hand, individuals from four provenances showed more tolerance to drought (Table 2). In *Valdeflores*, plants from the *Cortijo* and T*ataltepe*c provenances had a lower total mortality and exhibited a higher tolerance to drought, unlike those of *San Francisco*, which had the highest total mortality rate and less tolerance to drought (Table 2).

Table 2. Percentage and mean comparison of mortality rates between *Enterolobium cyclocarpum* provenances in *Pinotepa de Don Luis* and *Valdeflores*, in the Coast of *Oaxaca* region.

Provenances	***Pinotepa de Don Luis***			***Valdeflores***		
	Total	**Drought**	**Gophers**	**Total**	**Drought**	**Gophers**
Cortijo	50.0cd	8.3ab	41.7b	29.2a	29.2ab	0.0a
Pinotepa de Don Luis	29.2abcd	4.2a	25.0ab	50.0abc	50.0abcd	0.0a
El Zarzal	37.5abcd	4.2a	33.3ab	37.5ab	37.5abc	0.0a
La Tuza	45.8bcd	8.3ab	37.5ab	45.8abc	45.8abcd	0.0a
Tataltepec	41.7abcd	12.5ab	29.2ab	29.2a	25.0a	4.2b
San Francisco	41.7abcd	4.2a	37.5ab	66.7c	66.7d	0.0a
Los Limones	25.0abc	8.3ab	16.7ab	54.2abc	54.2bcd	0.0a
San Pedro	16.7a	4.2a	12.5a	37.5ab	37.5abc	0.0a
Colotepec	54.2d	20.8b	33.3ab	45.8abc	45.8abcd	0.0a
Pochutla	20.8ab	8.3ab	12.5a	62.5bc	62.5bcd	0.0a

Values with different letters in the same column indicate significant differences (p≤ 0.0389).

In *Pinotepa de Don Luis*, the plants produced with seeds from the same locality evidenced a higher tolerance to drought, which proved that the local provenance is better adapted. However, the specimens from *San Pedro* were tolerant to drought and to predation by gophers. This response may be due to the fact that it is one of the provenances with a similar altitude to that of the plantation site and a high AI (6.8); thus, it is a better location for planting than *Pinotepa de Don Luis*, which is more humid (AI= 4.6). In *Valdeflores,* the *Colotepec* provenance was the closest to the plantation site and had the same AI as this (8.2); therefore, it was expected to have the lowest plant mortality rate. Nevertheless, it exhibited an intermediate value, which is statistically equal to all the provenances. The result for *Colotepec* in *Valdeflores* may have been due to the difference in the soil type, which is Cambisol in *Colotepec* and Phaeozem at the site of establishment (Inegi, 2013).

Health

Six biotic agents related to the health of *E. cyclocarpum* were identified (Table 3, figures 3 and 4) during the assessment period; of these, powdery mildew of the genus *Oidium* Link and aphids (*Aphis* L.) were more prevalent on the assay plants. In Mexico, there are few records of attack by powdery mildew in forest species, particularly in tropical ones. Robles (2010) refers to cases of infection by *Oidium* sp. in nursery-grown *E. cyclocarpum* saplings. García and Cibrián (2007) cite infections in nursery-grown *Acacia* spp., *Erythrina* spp. and *Quercus* spp. saplings, while Cibrián *et al.* (2007b) document infection by powdery mildew (*Podosphara* Kunze, *Micrisphaera* Lév. and *Phyllactina* Lév.) in adult *Acacia* spp., *Fraxinus* spp., *Quercus* spp., *Ulmus* spp., *Acer negundo* L., *Erythrina coralloides* DC. and *Platanus occidentalis* L. plants.

Table 3. Biotic agents associated to health and description of damages in *Enterolobium cyclocarpum* (Jacq.) Griseb. provenances of the Coast of *Oaxaca*.

Biotic agent	Description of the damage
Powdery mildew: *Oidium* sp. (Erysiphales: Erysiphaceae)	The apical buds and tender stems were affected: a white powder was observed (Figure 3A). The main stem stopped growing, and multiple buds emerged (Figure 3B).
Aphid: *Aphis* sp. (Homoptera: Aphididae)	These insects sucked the sap of apical buds, shoots and tender leaves, causing a yellowing and the growth in height was stalled (Figure 3C).
Long-tailed mealybug: *Pseudoccocus longispinus* (Targioni Tozzetti, 1867) (Hemiptera: Pseudococcidae)	The shoots and apical buds were affected: the insect sucked the sap and thereby limited the growth in height (Figura 3D).
Longhorn beetles: *Oncideres* sp. (Coleoptera: Cerambycidae)	This insect attacked the stem and the main branches: it made a (spiraling) circular cut that caused the toppling of the upper part of the spiral. The standing stem (below the cut) produced new shoots, and forking occurred (Figure 4A, 4B).
Bark beetle: (Lepidoptera)	This insect attacked the main stem: the larvae drilled the pith; first, a borehole was observed close to the apical bud (which died); subsequently, several lumps of sap oozed from the stem (Figure 4C, 4D).
Defoliator: (Lepidoptera)	This insect attacked young leaves: the larvae (Figure 4E) fed on these and produced silk, with which they surrounded the branches, causing their death (Figure 4F).

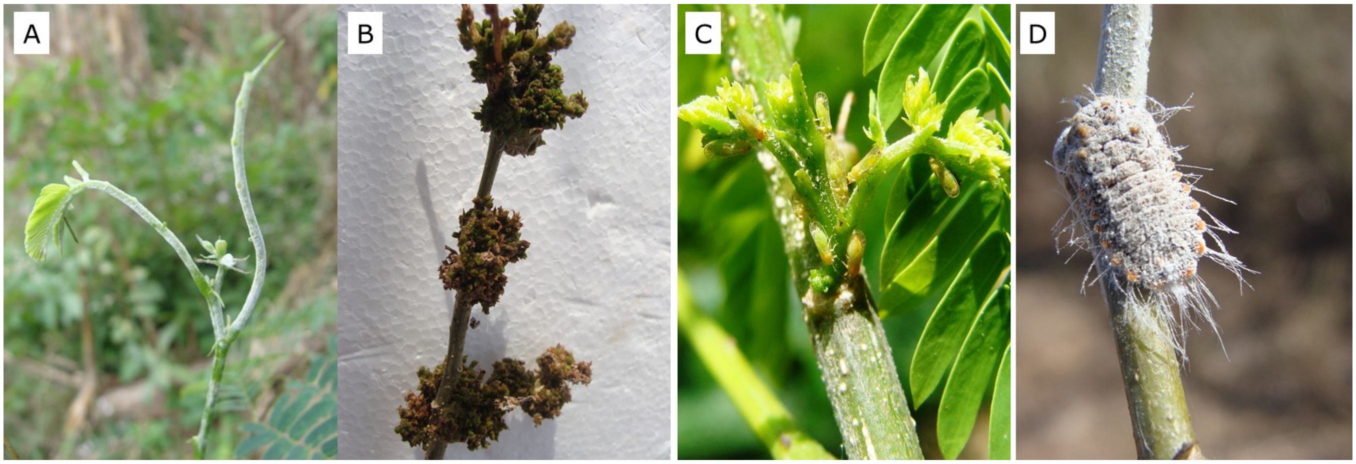


Figure 3. Powdery mildew of the genus *Oidium* (A) and its effect (B), aphids of the *Aphis* genus (C) and *Pseudoccocus longispinus* (Targioni Tozzetti, 1867) (D) in provenances of *Enterolobium cyclocarpum* (Jacq.) Griseb. in the Coast of *Oaxaca.*

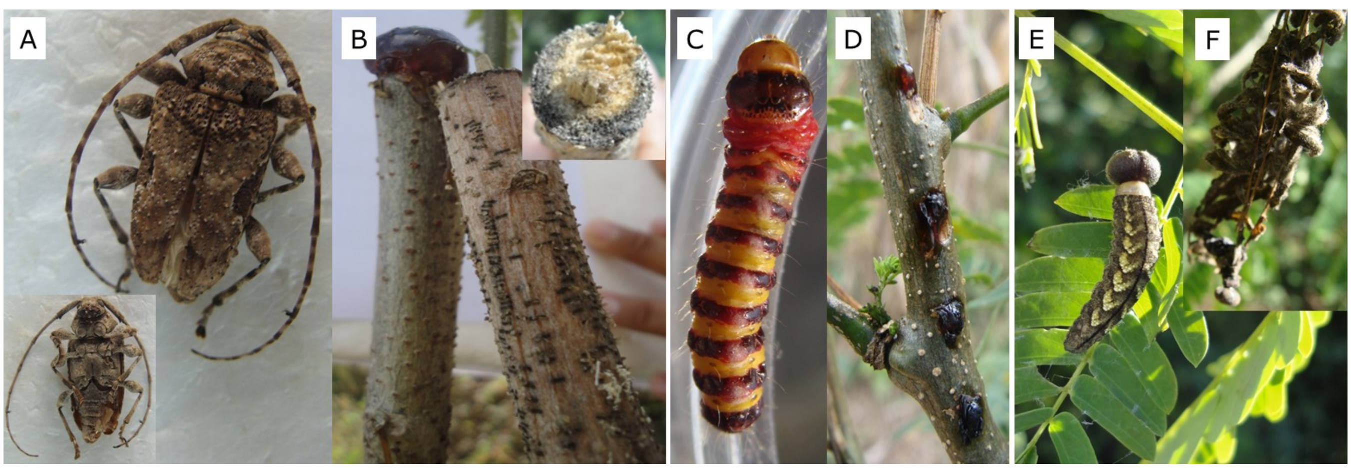


Figure 4. Longhorn beetle of the genus *Oncideres* (A), larva of the stem bark beetle (C) and larva of the defoliator insect (E), and their respective damages (B, D, F) in *Enterolobium cyclocarpum* (Jacq.) Griseb. provenances of the Coast of *Oaxac*a.

In Mexico, aphids of the genus *Aphis* damage the rachis of the leaves and tender stems of nursery-grown *E. cyclocarpum* saplings and adult plants (Solares, 2008; Robles, 2010); in Venezuela, *Aphis spiraecola* Pach affects adult plants of the same species (Evelin and Marcos-García, 2004). In Mexico City and in the State of Mexico, *Aphis nerii* Boyer de Fonscolombe aphids damage *Nerium oleander* L. leaves (Cibrián *et al*., 1995). In other countries, like *Costa Rica, Cuba, Colombia* and *Venezuela*, *Aphis* sp. attacks *Eucalyptus deglupta* Blume (Arguedas, 2008), *A. gossypii* Glover affects *Tectona grandis* L. Fil, *A. spiraecola* Patch damages *Cordia alliodora* (Ruiz & Pav.) (Cibrián, 2013), and *A. craccivora* Coch affects *Gliricidia sepium* (Jacq.) Steud and *Cordia alba* (Jacq.) Roem & Schult (Evelin and Marcos-García, 2004).

The occurrence of *Oidium* sp. and *Aphis* sp. was significantly different between sites ($p< 0.0001$). In *Pinotepa de Don Luis*, an average of 58.8 % and 29.2 % of the plants exhibited infection by *Oidium* and *Aphis*, respectively, while in *Valdeflores* the average percentages were 3.3 % and 0.8 %. This may be due to the difference in location and precipitation of the sites. *Pinotepa de Don Luis* is located at a higher altitude, and there is a greater precipitation in this site than in *Valdeflores* (Table 1). Accordingly, the risk of attack by *Oidium mangiferae* Berthet increases with the altitude of the sites (Arias *et al.,* 2004). Furthermore, infection by the fungus *Cercospora coffeicola* Berk & Cooke is related to high precipitation (Montes *et al.*, 2012).

In each of the plantations, the incidence of *Oidium* sp. was significantly different between provenances ($p\leq 0.0389$). In *Pinotepa de Don Luis*, the *Cortijo* and *Colotepec* provenances had a lower percentage of plants infected by *Oidium* sp. (41.7 %); conversely, *Los Limones* registered a higher percentage of infection (70.8 %) (Table 3). In V*aldeflores*, the *Cortijo, El Zarzal, La Tuza, Tataltepec* and *San Francisco* provenances exhibited infection (4.2 to 8.3 %), while the others had none. Since the provenances *Cortijo, El Zarzal* and *La Tuza* showed lower percentages of infection by *Oidium* sp. in *Pinotepa de Don Luis*, no infection was expected to be found in *Valdeflores*; however, the opposite was the case, due to the genotype x environment interaction ($p= 0.049$) in the occurrence of *Oidium* sp. on *E. cyclocarpum*.

As for the occurrence of *Aphis*, there were no significant differences between the provenances in *Pinotepa de Don Luis* ($p= 0.0603$); conversely, such differences were found in *Valdeflores* ($p= 0.0012$), but the effect of the genotype X environment interaction was not significant ($p= 0.5300$). In *Pinotepa de Don Luis*, infection by *Aphis* varied from 16.7 to 41.7 % between provenances. However, in *Valdeflores* only 8.3 % of the plants of *El Zarzal* exhibited infection (Table 4).

Table 4. Percentage and comparison of measures of plants affected by two biotic agents related to the health of the provenances of *Enterolobium cyclocarpum* (Jacq.) Griseb., in the Coast of Oaxaca.

Provenances	***Pinotepa de Don Luis***		***Valdeflores***	
	Oidium	***Aphis***	***Oidium***	***Aphis***
Cortijo	41.7a	20.8a	8.3ab	0.0a
Pinotepa de Don Luis	62.5ab	33.3a	0.0a	0.0a
El Zarzal	54.2ab	41.7a	4.2ab	8.3b
La Tuza	54.2ab	25.0a	4.2ab	0.0a
Tataltepec	62.5ab	25.0a	12.5b	0.0a
San Francisco	58.3ab	29.2a	4.2ab	0.0a
Los Limones	70.8b	41.7a	0.0a	0.0a
San Pedro	70.8b	16.7a	0.0a	0.0a
Colotepec	41.7a	20.8a	0.0a	0.0a
Pochutla	70.8b	37.5a	0.0a	0.0a

Values with different letters in the same column indicate significant differences ($p \leq 0.0389$).

The difference between the occurrence of *Oidium* sp. and that of *Aphis* sp. in *E. cyclocarpum* allows selecting of adequate provenances for each plantation site. However, the existence of the genotype x environment interaction in young plants hinders their early selection for various sites. Nevertheless, the instability of certain characteristics in different environments is usual in trees or in wild provenances (Salaya-Domínguez *et al*., 2012). On the other hand, subsequent assessments are required, as the effect of the interaction may vary according to age (Salaya-Domínguez *et al*., 2012).

During the study period, powdery mildew affected only three plants in *Pinotepa de Don Luis*. In Mexico, these insects are documented to affect the leaves and stems of adult *E. cyclocarpum* trees, causing yellowing, reduced growth, and branch death (Solares, 2008).

Likewise, the pink mealy bug (*Maconellicoccus hirsutus* (Green)) also causes malformation in *E. cyclocarpum* shoots, leaves, branches and fruits (López-Arriaga *et al.*, 2010; Sinavef, 2011; Isiordia-Aquino *et al*., 2012). There are no records of attack by powdery mildew in other forest species; only the pink mealy bug has been documented in *Tectona grandis*, *Artocarpus hererophyllus* Lam. and *Acacia* spp*.* (Sinavef, 2011).

In Mexico, 20 species of the *Oncideres* Lacordaire genus have been registered (Monné and Bezark, 2011), which are in the habit of forming rings around adult tree branches or trunks of young specimens in order to deposit their eggs (Villaverde and Acosta, 2013), as was observed in one and three *E. cyclocarpum* plants in *Valdeflores* and *Pinotepa de Don Luis*, respectively. Although the presence of *Oncideres* species, which no attack of *E. cyclocarpum* was observed in *Huatulco* (in the Coast of *Oaxaca* region), the occurrence of *Oncideres pallifasciata* Noguera (Noguera *et al*., 2018) has been registered at a linear distance of 108 and 57 km from *Pinotepa de Don Luis* and *Valdeflores*, respectively. However, there is no documentary evidence of infestation by *Oncideres* spp. in *E. cyclocarpum* plants; therefore, this study is the first record of its occurrence. Notably, in Costa Rica, *Oncideres punctata* Dillon & Dillon causes the same damage in *E. cyclocarpum* trunks (Hilje and Arguedas, 1996).

The presence of *Oncideres ocellaris* Bates, *O. scitula* Bates; O. *senilis* Bates and *O. albomarginata chamela* (Noguera, 1993; Toledo *et al*., 2007; MacRae *et al.*, 2012; Nearns *et al.*, 2014) is cited in *Oaxaca*, Mexico. The third of these species affects *Amphipterygium adstringens* Schide ex Schlecht, *Bursera* Jacq. *ex* L. spp. y *Ceiba pentandra* (L.) Gaertn trees (Calderón-Cortés *et al*., 2011). In *Tamaulipas*, Mexico, *O. pustulata* LeConte is hosted by *Acacia farnesiana* (L.) Willd. and *Leucaena leucocephala* (Lam.) de Wit plants (Rodríguez-del-Bosque and Garza-Cedillo, 2008; Rodríguez-del-Bosque, 2013). In the Desert of *Chihuahua*, Mexico, *O. rhodosticta* attacks *Prosopis glandulosa* var. *torreyana* (L. Benson) M.C. Johnston (Martínez *et al*., 2009), while, in *Nuevo León* and *Tamaulipas,* Mexico, *O. cingulata texana* Horn and *O. pustulatus* infest specimens of *Acacia farnesiana* (L.) Willd., *Acacia* spp., *Citrus* spp., *Leucaena* spp., *Pithecellobium* spp. and *Prosopis* spp. (Cibrián *et al*., 1995).

The stem bark beetle of *E. cyclocarpum* (Lepidoptera) affected 22 plants in *Pinotepa de Don Luis,* and five in *Valdeflores.* Although this species was not identified due to a lack of adult specimens, this is the first record of damage by a bark beetle in young *E. cyclocarpum* plants in Mexico. On the other hand, an unidentified bark beetle that bores superficial galleries in the stems and another one that bores numerous galleries damaging the vascular cambium, the xylem and the phloem (Solares, 2008) were observed in adult trees. *Xyleborus volvulus* (F.) (Coleoptera) forms galleries at various levels of the tree trunk (Cibrián *et al.*, 1995). The damage caused by *X. volvulus* (Cibrián *et al.*, 1995) and by the bark beetles mentioned by Solares (2018) do not correspond with the damage observed in the present study, in which the main shoot is the affected part (Table 3, Figure 4C and 4D).

At both plantation sites, a defoliator insect of the Lepidoptera order was observed in four *E. cyclocarpum* plants. In Mexico, there are no records of defoliator insects in *E. cyclocarpum*; therefor, the present study is the first record of the present of these insects; however, more studies are required in order to be able to identify the species, its life cycle, and its effect on *E. cyclocarpum* plants. *Coenipita bibitrix* Huebner (Noctunidae), *Mocis latipes* Guenée (Noctunidae), *Hylesia lineata* (Saturniidae), and an unidentified species of the family Meloidae are known to defoliate *E. cyclocarpum* plants in *Costa Rica* (Janzen, 1981; Arguedas, 2008).

Conclusions

Drought and damage caused by pocket gophers are the main causes of mortality in *E. cyclocarpum* plants. The two mortality factors affect the plants differently; this has to do with the humidity level and with the soil type of the plantation sites. The six health-related agents described constitute the first record in Mexico of damage in young *E. cyclocarpum* plants. The difference between sites in the occurrence of *Oidium* and *Aphis* are related to the location of the plantation sites and to the precipitation levels in each of them.

The existence of an interaction between the genotype and the environment renders the selection of tolerant provenance for all the plantation sites difficult. However, the differential response of the various provenances to the mortality factors and biotic agents related to the health of *E. cyclocarpum* allows selecting adequate provenances for each plantation site.

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Conflict of interests

The authors declare no conflict of interests.

Contribution by author

Mario Valerio Velasco-García: director and leader of the project, establishment of the in-field assays, data collection and analysis and drafting of the manuscript; María Luisa Hernández-Hernández: production of plants, establishment of the assays, data collection and first draft of the manuscript; Carlos Ramírez-Herrera, Martín Enrique Romero-Sánchez and Liliana Muñoz-Gutiérrez: drafting and editing of the manuscript.

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