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Fruit characterization and plant quality of Spanish cedar (*Cedrela odorata* L.) during the early nursery stage

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ABSTRACT

Objective: The aim of this study was to characterize Spanish cedar (*Cedrela odorata* L.) fruits and seeds, and to evaluate the effects of provenance, substrata, and fertilizer on germination and plant quality in nursery.

Design/Methodology/Approach: The fruits and seeds from Spanish cedars were collected in three different towns: C-32 (Francisco Trujillo Gurria), C-40 (Ernesto Aguirre Colorado), and C-41 (Carlos A. Madrazo). Those towns are in Plan Chontalpa, Tabasco, Mexico. After they were harvested, the samples were morphometrically characterized. Seed production efficiency (SPE), germination (%), and Dickson Quality Index (DQI) were estimated. Two completely randomized experimental designs with factorial arrangement of treatments were used. The factors were the provenance, four or three substrata, and two levels of Greenfool® 600 fertilizer.

Results: Fruits of 3.46 cm in length and 1.81 cm in width were collected; the mean number of seeds per fruit was 49.36. Seed production efficiency ranged from 48.1% to 52.72%, with 32.86% germination. The seeds from Town C-41 obtained the highest germination percentage, with the use of black soil:sand as substrate. The plants fertilized and developed in black soil:sand substrate obtained a higher DQI.

Study Limitations/Implications: The activity restriction caused by the Sars-Cov-2 pandemic was the main limitation. The lower number of producers and plantations from Town C-32 was the implication.

Findings/Conclusions: Fruit and seed characteristics were different among provenances. The provenance impacted on seed germination, but not on the plant quality index (DQI). Instead, the substrate and fertilizer impacted on the DQI.

Keywords: *Cedrela odorata*, fruit and seeds, morphometric characteristics, Dickson quality index, Meliaceae.

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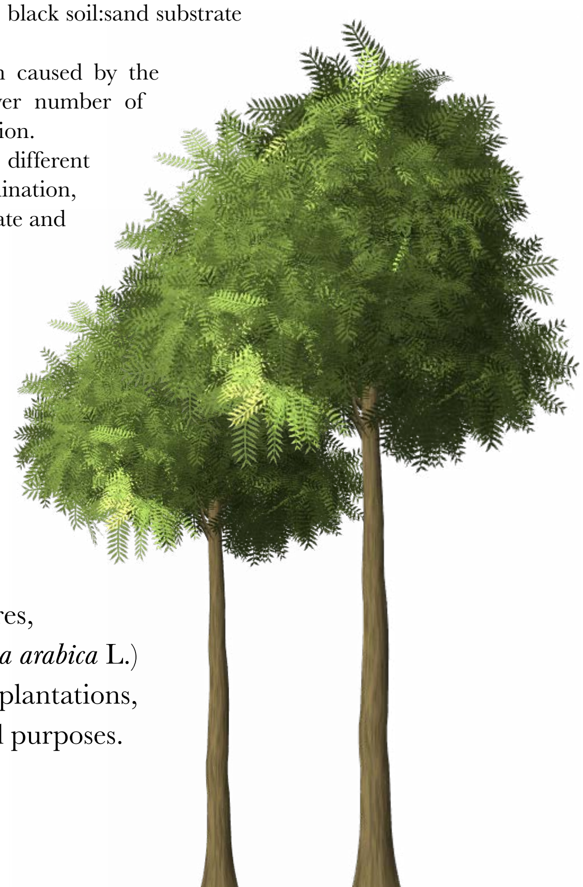
INTRODUCTION

The timber of Spanish cedar (*Cedrela odorata* L., Meliaceae) has a significative value. They can be commonly found as scattered trees in anthropogenic landscapes (such as milpas, pastures, and hedgerows) and provide shade in coffee (*Coffea arabica* L.) (Soto *et al.*, 2008) and cacao *(Theobroma cacao* L.) plantations, from where they are also collected for commercial purposes.



Timber commercialization and harvesting of Spanish cedar have been limited in order to guarantee its survival. However, seeds are gathered from the trees without prior selection, a practice that does not guarantee the quality of the plants. Therefore, determining the use and characteristics of the tree, fruits, and seeds is fundamental to establish the quality of future plants.

The evaluation of the quality of the plant will determine its capacity to adapt and develop under the different environmental conditions of the sowing site (Rueda *et al.*, 2012). Morphological and physiological parameters define plant quality in nurseries. Appropriate cultural labors with the seeds, the substrata, the plant containers, and the nutrition are required to fulfill the said parameters (Rodríguez-Ortiz *et al.* 2020). Ramos-Huapaya and Lombardi-Indacochea (2020) attribute plant quality to the genetic characteristics of the seeds and the nursery management. For example, even seeds that come from the same site can have different quality levels (Cano and Cetina, 2004).

Various indexes are used to measure plant quality. For instance, the slenderness rate relates the height and the diameter of a plant (León-Sánchez *et al.*, 2019); the lignification index evaluates the weight parameters (Sáenz *et al.*, 2014); the above ground/below ground part of the plant ratio (Sáenz *et al.*, 2014), and the Dickson Quality Index (DQI) which integrates all the parameters of these indexes (Villalón-Mendoza *et al.*, 2016). High DQI values show a better plant quality (Ramos-Huapaya and Lombardi-Indacochea, 2020). In order to produce good quality plants, nurseries use commercial substrata, such as peat moss, agrolite, and vermiculite. However, the use of these materials reduces profit margins. Consequently, communities use the resources that are available to them as growth substrata: sand, compost, peat, or mountain floor.

Therefore, the objective of this study was to characterize the Spanish cedar fruits harvested in cacao plantations in Plan Chontalpa, Tabasco and to evaluate the impact of provenance, substrata, and fertilization on plant germination and quality during the early nursery stage.

MATERIALS AND METHODS

Study site and selection of the trees from which the fruits were harvested

The identification and selection of the Spanish cedar trees from which the fruits were harvested was carried out in cacao plantations in Town C-32 (Francisco Trujillo Gurría), Town C-40 (Ernesto Aguirre Colorado), and Town C-41 (Carlos A. Madrazo), located in the municipality of Huimanguillo, Tabasco, Mexico. The area has a subhumid warm climate, with abundant rainfall in summer (Am). It has a 26.2 °C mean annual temperature and a 2,290.3 mm mean annual precipitation (IMTA, 2009).

In order to enter the plantations, we approached the community authorities, the technicians from the Sembrando Vida program, and the producers. We asked the producers how many Spanish cedar trees grew in their plantations and if they were willing to harvest the fruits. All the Spanish cedar trees in the plantations were counted and measured (height and diameter; DBH 1.30). A Suunto® clinometer (Sáenz *et al.*, 2014) was used to measure total height and a diametric tape was used to measure the diameter at breast height (DBH).

Based on the CONAFOR (2016) classification, fruits and seeds were harvested from Category 1 trees.

Harvest and characterization of fruits and seeds

The largest number of fruits possible was harvested from each tree. Subsequently, the fruits were weighted, and 100 fruits were randomly selected. Then, their diameter and length were measured. Afterwards, each fruit was placed in a paper bag to ease their identification and the counting of seeds at the dehiscence stage. The seeds were separated in viable (winged seeds with embryo) and embryoless seeds. Subsequently, the seeds of each tree were mixed, and 100 seeds were randomly selected per tree, in order to measure their length.

Plant germination and development in the nursery

The DQI was used to evaluate plant quality, after a plant germination and development analysis was carried out. The experimental design for the germination was completely random, with a factorial arrangement of treatments. The first factor was the provenance (Towns C-32, C-40, and C-41) and the second factor was the substrata: 1, black soil + sand substrate (1:1); 2, compost; 3 black soil + sugar cane waste (1:1); 4, peat moss + agrolite (1:1). A total of 12 treatments with four repetitions of 100 seeds each were established.

The same experimental design and factorial arrangement with treatments were used for plant development. The first factor was provenance (three towns), the second factor was the substrata (1, 2, and 3) and the third factor was the Greenfool® 600 fertilizer, with a 15-31-15 formulation (2: with and without). A total of 18 treatments with four repetitions and four plants per repetition were established.

The following variables were measured: germination (%), root collar diameter (RCD), and plant height (H). Germination was recorded at 65 days after the sowing; the plants that came out of the soil were considered as germinated seeds. Germination percentage was obtained dividing the number of germinated seeds by the number of sown seeds and multiplying the result by 100. The RCD was measured using a Surtek® digital vernier and H was measured from the base of the stem to the apical bud using a 50-cm rule. Both variables were recorded according to the Mexican Standard NMX-AA-170-SCFI-2016 (DOF, 2016) every 8 days for 3 months.

At the end of the development experiment, a destructive sampling was carried out to quantify above ground and root biomasses: one randomly selected plant was extracted per repetition, the root was washed to remove the substrate, and the root was separated from the above ground part of the plant in order to record fresh weight. The samples were placed in paper bags and were dried until they reached a constant weight. A VE-5000 VELAB electronic scale with milligram accuracy was used to measure fresh and dry weight and the result was used to estimate DQI. The following formula was used:

$$DQI = \frac{Total\ dry\ mass\,(g)}{\dfrac{Height\,(cm)}{Diameter\,(mm)} + \dfrac{Above\ ground\ dry\ mass\,(g)}{Root\ dry\ weight\,(g)}}$$

Data analysis

The data were subjected to an analysis of variance and a mean comparison test (Tukey, $p \leq 0.05$), using the InfoStat software. Previously, a normality and homogeneity of variance tests were carried out, as well as a data transformation (if required).

RESULTS AND DISCUSSION

Tree selection and fruit harvest

Twenty out of 239 Category 1 trees were selected as source of fruits and seeds. According to CONAFOR (2016), Category 1 includes high-quality, straight, and vigorous trees, without forks and with few branches in the upper two thirds. These trees have a circular crown, are dominant or codominant, are pest and disease free, and they must be good seed producers. Therefore, Town C-41 had the greatest number of trees and the tallest and widest trees, as well as the highest fruit production rate (Table 1).

Characterization of fruits and seeds

The ANOVA found differences ($F_{1,2}$=23.72 and 100.70; $p<0.001$) in fruit width and length and in the number of viable, empty, and total seeds per provenance. The Town C-32 fruits had the same statistical size and the same statistical number of viable seeds than Town C-40 fruits; however, their viable seeds were bigger and more numerous than Town C-41 fruits. The same trend was observed in the length of the winged seeds and of seeds without wings (Table 2).

Overall, the fruits from the three towns were longer and wider than the fruits recorded by Ureta *et al.* (2019) which were 2.51 cm long and 0.76 cm wide. In contrast, Márquez *et al.* (2020) reported similar or longer (3.25 cm) and narrower (1.87 cm) fruits. Specifically, the fruits collected at Town C-32 were longer and had a similar diameter than those reported by Rodríguez *et al.* (2001), who recoded 3.34-cm long and 1.82-cm wide fruits.

Table 1. Descriptive measurements of the Spanish cedar trees and quantity of fruits harvested from three provenances in Plan Chontalpa, Tabasco, Mexico.

Variable	Provenance	Mean	SD	Minimum	Maximum
DBH (cm)	C-32	37.1	7.5	28.0	48.0
	C-40	39.0	1.0	38.0	40.0
	C-41	42.2	14.0	26.0	75.0
Total height (m)	C-32	14.1	0.9	13.0	16.0
	C-40	18.0	4.0	14.0	22.0
	C-41	18.4	4.2	10.0	25.0
Fruits (kg)	C-32	24.5	3.7	20.0	32.0
	C-40	24.5	1.5	23.0	26.0
	C-41	26.6	7.7	18.0	45.0
Crown diameter (m)	C-32	15.5	3.6	10.8	22.0
	C-40	15.2	3.6	11.6	18.8
	C-41	14.2	3.3	11.3	22.0

DBH, Diameter at breast height (1.30 m). SD, Standard deviation.

Table 2. Descriptive measurements of the Spanish cedar trees and quantity of fruits harvested from three provenances in Plan Chontalpa, Tabasco, Mexico.

Variable	Provenance	Mean	SD	Minimum	Maximum
Fruit diameter (cm)	C-32	1.81 b	0.17	1.10	3.20
	C-40	1.78 b	0.10	1.50	2.10
	C-41	1.74 a	0.22	1.20	3.70
Fruit length (cm)	C-32	3.46 b	0.33	2.30	4.20
	C-40	3.42 b	0.27	2.70	3.90
	C-41	3.21 a	0.45	1.90	4.30
Viable seeds per fruit	C-32	24.37 b	5.51	8.00	41.00
	C-40	25.12 b	3.29	14.00	36.00
	C-41	22.76 a	5.72	0.00	37.00
Vain seeds per fruit	C-32	24.99 b	5.61	10.00	49.00
	C-40	23.19 a	3.43	9.00	32.00
	C-41	25.71 b	5.37	0.00	55.00
Total seeds per fruit	C-32	49.36 b	6.42	22.00	69.00
	C-40	48.30 a	3.31	31.00	59.00
	C-41	48.46 a	4.05	21.00	64.00
Seed length with wing (mm)	C-32	24.53 b	2.61	16.95	30.28
	C-40	24.77 b	2.60	18.75	31.23
	C-41	22.53 a	3.29	8.61	30.35
Seed length without wing (mm)	C-32	8.75 b	1.14	5.49	12.28
	C-40	8.62 b	0.86	6.37	10.67
	C-41	8.17 a	1.14	5.02	11.41

SD, Standard deviation. Different letters for each variable indicate significant differences between provenances (Tukey, $P \leq 0.05$). $n=100$.

Regarding the production of total seeds, Town C-32 had the highest production: 49.36 seeds in average, 24.99 of which were empty. The production of seeds from this origin is greater than the one reported by Rodríguez *et al.* (2001), who recorded an average of 43 total seeds (including 21 embryoless seeds). According to the coefficient of variation, the fruits showed a greater variation in seed weight and its SPE and greater homogeneity regarding their width and seed production potential. The seed production recorded by Márquez *et al.* (2020) was also different (39.9 seeds per fruit). Likewise, there were differences regarding the production reported by Alderete and Márquez (2004), who recorded 42.35 seeds per fruit and a 56.35% SPE. Meanwhile, Márquez *et al.* (2020) reported a 58.86% SPE. Both reported higher SPEs than those reported in this work: 52.72% (C-41), 50.62% (C-32), and 48.01% (C-40).

The morphometric variables of the fruits collected in Town C-32 had a highly significative correlation ($p<0.05$), which proves that there is a close relationship between the size and seed number variables. The variables with higher correlation were fruit width vs fruit length (59%) and empty seeds *vs.* total seeds (59%). No correlation was higher than 50% in Town C-40, while fruit width *vs.* fruit length had a 77% correlation in Town C-41 (non-tabulated data).

Seed germination

The ANOVA showed that provenance has an impact on germination. This effect was corroborated by the comparison of means: the germination percentage of the seeds from Town C-41 was statistically greater than the seeds from Town C-32 (Table 3). Germination in the substrata was statistically the same; nevertheless, the germination percentage of seeds in black soil+sand was 7.04% higher than in black soil+sugarcane waste (Table 3).

The germination percentages obtained in this study were lower than the results reported by Ureta *et al.* (2019) and Torres-Torres *et al.* (2018): 85 and 47.2%, respectively. Nevertheless, the seed used in this study did not receive any pre-germination treatment, unlike the seeds germinated by Torres-Torres *et al.* (2018), who soaked them for 24 h, before sowing them in a substrate made of chicken manure and sand (2:1).

Plant Development

Different RCD and H statistics were recorded in the various levels of the evaluated factors at 15, 45, and 90 days after the experiment was established. The plants with highest RCD and H were grown in Town C-40, using fertilizer and a black soil:sand substrate (Table 4).

For this experiment, an average height of 18.66 cm was recorded in Town C-40; the height of the plants was statistically higher than plants from other provenances. Nevertheless, the said height is lower than the 38.12 cm reported by Orozco *et al.* (2020) for three-month old

Table 3. Effect of provenance and substrate on the germination of cedar seeds.

Provenance	Germination (%)	Substrate	Germination (%)
Town C-32	14.96 b	Black soil + sugarcane cachaza	29.02 a
Town C-40	24.03 ab	Compost	22.41 a
Town C-41	32.86 a	Black soil + sand	21.98 a
		Peat Moos + Agrolite	22.39 a

Different letters for each column indicate significant differences between provenances. (Tukey, $p<0.05$).

Table 4. Effect of provenance, fertilizer, and substrate on root collar diameter and plants height of Spanish cedar, at 15, 45, and 90 days after transplanting.

Variable	Day 15			Day 45			Day 90		
	Provenance	Fertilizer	Substrate	Provenance	Fertilizer	Substrate	Provenance	Fertilizer	Substrate
RCD (mm)	1) 1.38 b	1) 1.51 a	1) 1.52 a	1) 2.74 b	1) 3.03 a	1) 3.50 a	1) 4.63 b	1) 5.27 a	1) 5.79 a
	2) 1.70 a	2) 1.25 b	2) 1.35 b	2) 3.29 a	2) 2.47 b	2) 2.18 c	2) 5.33 a	2) 3.99 b	2) 3.81 c
	3) 1.07 c		3) 1.27 b	3) 2.27 c		3) 2.57 b	3) 3.92 c		3) 4.29 b
PH (cm)	1) 7.91 b	1) 7.98 a	1) 8.62 a	1) 10.78 b	1) 10.47 a	1) 12.27 a	1) 16.95 b	1) 16.75 a	1) 17.63 a
	2) 10.34 a	2) 7.52 b	2) 7.81 b	2) 12.45 a	2) 9.62 b	2) 9.02 b	2) 18.66 a	2) 14.89 b	2) 16.65 a
	3) 5.00 c		3) 6.83 c	3) 7.27 c		3) 9.01 b	3) 11.84 c		3) 13.18 b

RCD, Root collar diameter. PH, plant height. Provenances: 1, Town C-32; 2, Town C-40; 3, Town C-41. Fertilizer: 1, With; 2, Without. Sustrates: 1, Black soil + Sugarcane cachaza; 2, Compost; 3, Black soil + sand. Different letters for each column and variable indicate significant differences (Tukey, $p<0.05$). $n=12$.

Spanish cedars. Meanwhile, Torres-Torres *et al.* (2018) describe 15-cm tall plants produced with chicken manure, sand, and anthill soil (1:1:1), without pre-germination treatment.

Dickson Quality Index

According to the DQI, the best quality was recorded in Spanish cedars grown in 60:40 black soil:sand substrate with fertilizer (Table 5). Based on the comparison of means, there were no significant statistical differences among provenances. Therefore, proper nursery management is essential to obtain quality plants that guarantee the success of reforestation efforts or the establishment of a commercial plantation.

Table 5. Effect of provenance, fertilizer, and substrate in the Dickson Quality Index of three-month old Spanish cedars.

Provenance	DQI	Sustrate	DQI	Fertilizer	DQI
Town C-32	0.86 a	Black soil + sugarcane cachaza	1.02 b	With	1.04 b
Town C-40	0.87 a	Compost	0.94 b	Without	0.71 a
Town C-41	0.88 a	Black soil + sand	0.65 a		

DQI, Dickson quality index. Different letters for each column indicate significant differences (Tukey, $p<0.05$). n=12.

Mateo-Sánchez *et al.* (2011) used a substrate made of 70% raw sawdust and 30% peat moss-agrolite-vermiculite (60:20:20) and applied 12 kg/m^3 of Osmocote plus® (15-9-12); 100 days later, they obtained a lower DQI (0.19) than the one obtained for plants grown with seeds collected from the towns of Plan Chontalpa, Tabasco. Díaz *et al.* (2013) also recorded lower results (0.39 DQI), 90 days after the sowing, with plants produced with cacao compost. Finally, Basave *et al.* (2016) grew plants in 500-ml black polyethylene bags and recorded a 0.3 DQI.

CONCLUSIONS

Although they come from the same region and study area, the fruit and seed characteristics varied between the three towns, which points out a provenance effect. The said characteristics influenced seed germination. Regardless of the substrate, the biggest seeds from the biggest fruits had a lower germination percentage than the smallest seeds from the smallest fruits. This provenance effect is lost with a proper nursery management.

Under nursery conditions, irrespective of their origin, Spanish cedar plants fertilized with Greenfol® 600 and grown in a 60:40 black soil:sand substrate had better quality than those produced without fertilizer or grown in other evaluated substrata, according to the DQI.

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