Colegio de Postgraduados

Organic substrates improve the quality of *Swietenia mahagoni* (L.) Jacq. under nursery conditions

Osorio-Espinoza, Humberto[1]; **Marroquín-Agreda, Francisco J.**[1*]; **Falcón-Oconor, Emir**[2]; **Toledo-Toledo, Ernesto**[1]; **Barrera-Rodríguez, Efrain**[1]; **Lerma-Molina, José N.**[1]

[1] Universidad Autónoma de Chiapas, Huehuetán Chiapas, C. P. 30660. México.
[2] Universidad de Guantánamo, Facultad Agroforestal, Guantánamo, C. P. 95100. Cuba.
* Correspondence: francisco.marroquin@unach.mx

ABSTRACT

Objective: To determine the best substrates that favor the quality of mahogany seedlings under nursery conditions.

Design/methodology/approach: The variables evaluated were plant height, stem diameter, aerial and root dry weight, main root length, slenderness, and Dickson quality index. The treatments were: cocoa husk (Ch), coconut fiber (Cf) and pine sawdust (Ps) and volumetric mixtures of cocoa husk, coconut fiber and pine sawdust, established under a completely randomized design with eight treatments.

Results: The results of the analysis of variance showed statistically significant differences ($p<0.05$) for all the variables analyzed. The species showed a more favorable morphological response in the Ch60 (Ch-60% + Cf-20% + Ps-20%) and Ch50 (Ch-50% + Cf-30% + Ps-20%) mixtures. Furthermore, the discriminant analysis allowed the differentiation of the substrates from the linear combination of the variables, where the height and aerial dry weight were the greatest contributors.

Limitations on study/implications: The study was conducted in a nursery, where conditions (irrigation, temperature, pest protection) are ideal. In the field, results may vary due to factors such as water stress, weed competition, or pathogen attacks. Therefore, it opens avenues for studying substrate combinations, mycorrhizal inoculation, or adaptation to post-transplant stress conditions.

Findings/conclusions: It is concluded that the treatments composed of the highest percentage of cocoa husk were the best substrates, so their use is recommended for the production of mahogany in containers.

Keywords: sawdust, cocoa husk, coconut fiber, morphology, nursery.

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INTRODUCTION

The use of containers in seedling production has proven to be highly effective. Physiologically, it promotes root formation, since their use fosters the development of an abundant root system and functional absorbent hairs capable of branching and producing a denser system; these hairs remain attached to the growing medium, which facilitates taking root, especially when removing the plants from the containers (Cobas *et al.*, 2020).

For nursery production, it is important to choose a substrate with chemical and physical characteristics that provide sufficient nutrients and physical support for good seedling growth (Svartz and Raimondo, 2022). These characteristics include slightly acidic pH, fertility, freedom from pests and diseases, in addition to presenting values in total porosity of 70%, aeration porosity of 10%, and water retention porosity of 55% (Rasool *et al.*, 2024).

According to López *et al.* (2018), the type of substrate used in nurseries is one of the factors that influence the quality and production cost of a plant; therefore, it is essential to look for options that reduce costs and guarantee plant quality. In Cuba, forest soil is the most frequently used substrate in forest nurseries that employ the traditional system (Falcón *et al.*, 2019). However, organic residues such as coconut fiber, cocoa husks, and sawdust can be used in the formulation of substrates and/or mixtures, for the production of different native species in containers.

Mahogany is one of the species selected for the enrichment of secondary forests (Álvarez, 2017), taking into account that it has characteristics such as being: facultative heliophilous, stabilizing, colonizing of different successional stages, tolerant to competition, and with a broad ecology that colonizes both primary plant formations (from which they originate) and secondary ones (Ricardo *et al.*, 2016).

Due to its multiple uses, this species is highly valued for its wood, but considering the slow growth of the species and overexploitation in many of its natural distribution areas, it has been included in Appendix II of the Convention on National Trade of Endangered Species of Wild Fauna and Flora (*Convención sobre Comercio Nacional de Especies Amenazadas de Fauna y Flora Silvestres*, CITES), making it necessary to undertake reforestation and enrichment programs with this valuable species (Labrador *et al.*, 2017).

For the reasons stated above, and due to the importance of the species for multiple uses and because it is under threat, this study was carried out with the objective of determining the best substrates that favor the morphological attributes of *S. mahagoni* seedlings under nursery conditions, for their incorporation into reforestation plans.

MATERIALS AND METHODS

The research was carried out in a nursery under a green mesh shade net with 50% shade (Figure 1A), at the facilities of the Center for the Study of Agricultural, Livestock and Forestry Technologies (Centro de Estudio de Tecnologías Agropecuarias y Forestales, CETAF), belonging to the University of Guantánamo (UG), located at 20° 12’ 21” latitude North and 75° 13’ 37” longitude West at 87 meters above sea level.

The climatic characteristics of the region reflected in the climograph, with a 10-year data series (Figure 1B) are marked by three dry stages: January-April, June-July, and November-December. Rainfall was slightly above 100 mm in the months of May and October, while in August and September it was lower, according to information from the Cuban Meteorological Institute (INSMET, 2023).

Mahogany seeds with a germination capacity of 92% were used, obtained from ripe fruits collected from the mass located in the municipality of Jamaica, belonging to the Guantánamo Agroforestry Company (20° 11’ 44” N, 75° 08’ 38” W). Sowing was carried

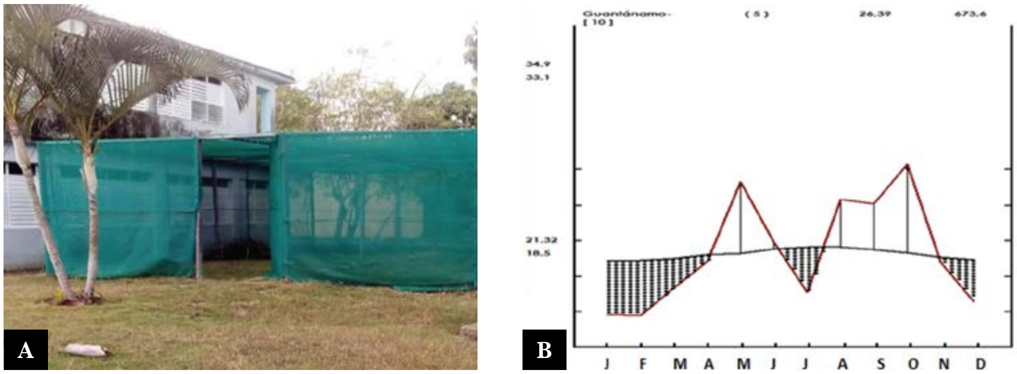

Figure 1. Growing house (A) and climatic conditions (B).

out in plastic containers with a volume of 200 cm^3, using different volumetric mixtures of decomposed cocoa husk (*Theobroma cacao* L.), coconut fiber (*Cocos nucífera* L.), and pine sawdust (*Pinus cubensis*). The composition of the substrates, as well as the treatments used, are shown in Table 1.

Likewise, Table 2 shows the chemical-physical composition of each of the substrates that were analyzed in the soil laboratory of the UBCT Guantánamo. The methodology described by Ansorena (1994) was used to determine the physical properties: apparent density (AD), true density (TD), total porosity (TP) and moisture retention (MR). Chemical analyses were performed based on Cuban standards (CS) for this type of analysis (CS-XX 2009), where the percentage of organic matter (OM), potassium (K), sodium (Na), phosphorus (P), calcium (Ca), nitrogen (N), pH and electrical conductivity (EC) content were determined.

Experimental design

The experiment consisted of eight treatments defined by different concentrations of cocoa husk, coconut fiber, pine sawdust, and volumetric mixtures between them (Table 1). Four replicates were used for each treatment, with 30 plants each, for a total of 960 plants in the experiment. A completely randomized design was used for treatment distribution.

Table 1. Composition of the substrates used in the experiment.

Substrate	Abbreviation	Treatment	Composition (%)
Cocoa husks	Cc	Cc	100
Coconut fiber	Fc	Fc	100
Pine sawdust	As	As	100
Cocoa husks+coconut fiber+pine sawdust	Cc+Fc+As	Cc60	60+20+20
	Cc+Fc+As	Cc50	50+30+20
	Cc+Fc+As	Cc40	40+40+20
	Cc+Fc+As	Cc30	30+50+20
	Cc+Fc+As	Cc20	20+60+20

Table 2. Chemical and physical characteristics of the substrates used in the experiment.

	Treatments							
	Cc	**Fc**	**As**	**Cc60**	**Cc50**	**Cc40**	**Cc30**	**Cc20**
pH	5,90	5,49	5,76	6,20	6,31	6,57	6,66	6,70
OM (%)	89,18	71,73	50,41	77,20	73,78	68,96	66,66	66,02
N (%)	1,87	1,43	0,52	1,86	1,82	1,54	1,33	1,40
P (%)	1,45	0,11	0,093	1,43	1,42	1,42	1,36	0,10
K^+ (%)	1,81	1,39	1,18	1,79	1,74	1,55	1,59	1,19
Ca^{2+} (%)	0,69	0,45	0,54	0,68	0,68	0,46	0,68	0,56
Na^+ (%)	0,09	0,06	0,03	0,08	0,07	0,05	0,04	0,05
EC (dS m^{-1})	0,65	3,54	3,27	3,13	2,61	2,68	3,08	2,27
AD (g mL^{-1})	0,28	0,19	0,54	0,38	0,37	0,42	0,33	0,31
RD (g mL^{-1})	1,53	1,48	2,05	1,67	1,70	1,72	1,73	1,68
TP (%)	84,97	55,45	70,26	82,02	81,87	77,60	78,40	76,16
HR (%)	62,60	78,09	50,88	65,49	64,41	66,33	71,54	70,76

Percentage of organic matter (OM), potassium content (K), sodium (Na), phosphorus (P), calcium (Ca), nitrogen (N), hydrogen potential (pH) and electrical conductivity (EC), apparent density (AD), true density (RD), total porosity (TP) and moisture retention (HR).

Attributes evaluated and sampling procedure

After four months in the nursery, the height of 50 plants, located in the center of each tray (usable plot) per treatment avoiding the edge effect, was measured. This measurement was taken from the root collar to the tip of the apical bud, every 15 days, using a 0.1 mm precision graduated ruler.

A vernier caliper was used to measure stem diameter, with a precision of 0.02 mm. This measurement was made every 15 days.

The aerial and root dry weights were determined after the samples were placed in a forced-air circulation oven (BINDER) for 72 hours, at a temperature of 70 °C until constant mass was reached. The determination was performed on a Sartorius CPA324S balance with a margin of error of 0.1 mg.

The length of the main root was measured from the neck to the apex, using a 0.1 mm precision ruler. The fine and thick roots were also counted.

Based on the above attributes, the following relationships and indices were evaluated:

- Aerial part to root part ratio (ADW/RDW): estimated as the quotient between the dry weight of the aerial part and the dry weight of the root in grams.
- Slenderness Index (H/Drc): calculated with the quotient between the height in centimeters and the diameter of the stem at the root neck in millimeters.
- Dickson Quality Index (DQI): was determined using equation (1):

$$DQI = \frac{Total\ dry\ weight\ (g)}{\frac{Height\ (cm)}{Diameter\ (mm)} + \frac{Dry\ aerial\ weight\ (g)}{Root\ dry\ weight\ (g)}}$$

Statistical analysis

For the comparison of morphological attributes and indices between substrates, an analysis of variance was performed and when there was a significant difference ($p \leq 0.05$), the means were compared according to Duncan's Multiple Range Test ($p \leq 0.05$), since the data were adjusted to a normal distribution, verified by the Shapiro-Wilks Test.

Discriminant analysis was used to analyze the position of each substrate defined by the first two classification functions, and to identify the morphological attributes that most contributed to their differentiation. The substrates were considered as groups *a priori*. Data processing was performed using the SPSS statistical package, version 23 for Windows.

RESULTS AND DISCUSSION

Morphological attributes and indices evaluated

Table 3 shows the means of the different morphological attributes and indices, where significant differences were observed between the substrates used, except for substrates Ch60 and Ch50, which had the best values for all the attributes evaluated. These values may be influenced by a correct or abundant supply of nutrients from the substrates, so these combinations were more favorable for plant development and growth.

Similar results were obtained by Aguirre *et al.* (2018), who found that the use of organic substrates with adequate physical and chemical characteristics favored the growth and development of the species *Azadirachta indica* A. Juss. and *Ceiba pentandra* (L.) grown in a nursery.

Like height, diameter showed the best values in substrates Ch60 and Ch50, with no significant differences between them, but with differences from the rest of the substrates. These increases may be related to the concentrations of nitrogen, phosphorus, and potassium present in these substrates (Table 2). In this regard, Da Ros *et al.* (2015) propose that the presence of nitrogen in the initial phase of seedling production increases the growth rate of stem mass due to cell expansion, owing to the function of proteins in the development of cell walls and the cytoskeleton.

Table 3. Mean values and standard error of morphological attributes and indices.

Substrate	A (cm)	DT (mm)	PSA (g)	PSR (g)	LRP (cm)	A/DT	PSA/PSR	ICD
Cc	$18{,}89^{c}$	$3{,}87^{d}$	$0{,}62^{b}$	$0{,}43^{c}$	$17{,}15^{d}$	$4{,}88^{b}$	$1{,}47^{c}$	$0{,}16^{c}$
Fc	$14{,}81^{g}$	$3{,}16^{f}$	$0{,}50^{d}$	$0{,}30^{e}$	$15{,}15^{g}$	$4{,}68^{c}$	$1{,}68^{b}$	$0{,}12^{e}$
As	$15{,}65^{f}$	$3{,}15^{f}$	$0{,}34^{e}$	$0{,}22^{f}$	$15{,}64^{f}$	$4{,}96^{a}$	$1{,}47^{c}$	$0{,}09^{f}$
Cc60	$25{,}10^{a}$	$5{,}91^{a}$	$0{,}75^{a}$	$0{,}53^{a}$	$19{,}17^{a}$	$4{,}34^{e}$	$1{,}42^{d}$	$0{,}21^{a}$
Cc50	$24{,}20^{a}$	$5{,}56^{a}$	$0{,}74^{a}$	$0{,}52^{a}$	$18{,}25^{ab}$	$4{,}26^{f}$	$1{,}41^{d}$	$0{,}22^{a}$
Cc40	$20{,}38^{b}$	$4{,}10^{b}$	$0{,}64^{b}$	$0{,}47^{b}$	$17{,}50^{bc}$	$4{,}47^{d}$	$1{,}34^{d}$	$0{,}18^{b}$
Cc30	$18{,}28^{d}$	$3{,}98^{c}$	$0{,}58^{c}$	$0{,}29^{e}$	$17{,}16^{d}$	$4{,}60^{c}$	$2{,}01^{a}$	$0{,}13^{e}$
Cc20	$16{,}78^{e}$	$3{,}75^{e}$	$0{,}57^{c}$	$0{,}35^{d}$	$16{,}50^{e}$	$4{,}68^{c}$	$1{,}63^{c}$	$0{,}14^{d}$
Standard error	0,174*	0,048*	0,006*	0,005*	0,065*	0,012*	0,011*	0,002*

A: height; Dcr: root collar diameter; PSA: aerial dry weight; PSR: root dry weight; LRP: main root length; A/Dcr=Slenderness Index; PSA/PSR=ratio of aerial parts to root parts; ICD=Dickson quality index.

Other authors report that optimal nitrogen concentrations in the substrate influence seedling quality (Valkinir *et al.*, 2017), and have documented rapid development of large, dark green stems and leaves containing large amounts of chlorophyll which absorb relatively high amounts of light and produce large amounts of carbohydrates that are used in the formation of absorbent stem, leaf, and root cells.

These results coincide with those obtained by Ricárdez *et al.* (2020), when they stated that the greatest cocoa growth was observed in the presence of optimal nitrogen and phosphorus values. In addition, these same authors observed that the growth rate of aerial biomass, and therefore the area available to intercept radiant energy, is strongly dependent on the availability of nutrients.

Substrates Ch60 and Ch50 promoted the best root and aerial growth (Table 3), which is associated with the improvement in the physical and chemical properties of these mixtures; that is, an adequate relationship between air, water and availability of nutrients favors the increase in biomass accumulation rates. These variables are relevant attributes for the performance and survival of plants in the field and are complementary to height and diameter to better describe the morphological quality of individuals produced in containers (Márquez and Martínez, 2022).

When analyzing the values obtained in the Slenderness index (H/Drc), it is observed that the plants with the best performance were those grown in the Ch60 and Ch50 substrates, because they had a lower value, which is related to greater robustness and vigor in the stem, that is, better quality.

These results agree with those obtained by Venancio *et al.* (2022), who point out that the lower the value of this index, the greater the resistance of plants to the action of stress factors such as wind and competition with weeds, which indicates greater mechanical resistance during planting operations; and that on the one hand, the total development of the plant is large and, at the same time, the aerial and root fractions are balanced.

Similar responses were reached by Falcón *et al.* (2022), who highlight among the relationships of the morphological parameters used to evaluate the quality of seedlings of tree species, the slenderness index, which constitutes one of the most important attributes to estimate the growth of seedlings after establishment in the field and relates the resistance of the plant with its photosynthetic capacity.

Regarding the ADW/RDW ratio (Table 2), substrates Ch60, Ch50, and Ch40 recorded the best values, that is, the lowest averages; this indicated high quality, due to a good balance between the biomass of the aerial part and the root (Falcón *et al.*, 2021), as well as greater chances of success when planted in sites with low rainfall.

The results obtained agree with Rueda *et al.* (2014), who stated that to obtain quality seedlings, the ADW/RDW ratio should be less than 2.0, resulting in a greater capacity to overcome the critical rooting period. In the experiment, this ratio was found to be both above and below the recommended range, being lower in substrates Ch60, Ch50, and Ch40, which demonstrates the capacity of the seedlings obtained in these substrates to adapt to stressful environments.

Regarding the Dickson quality index (DQI), the highest means were obtained in substrates Ch60 and Ch50 with 0.21 and 0.22, respectively (Table 3), indicating that the plants produced in these substrates are within quality parameters and suitable for planting, since their DQI was ≥0.2 (Falcón *et al.*, 2019). According to Villar *et al.* (2003), the DQI is a fairly solid index that expresses, in a single value, the quality of the plants.

Venancio *et al.* (2022) agree with the aforementioned and also express that the DQI is a good indicator, since it weighs important characteristics for the evaluation of plant quality and considers the vigor and balance of mass distribution in the plant.

In this study, the best results were obtained with substrates Ch60 (60% cocoa husk+20% coconut fiber+20% sawdust) and Ch50 (50% cocoa husk+30% coconut fiber+20% sawdust). In this sense, the study demonstrates that the addition of organic compounds to the substrates provided better conditions for the growth of mahogany plants by having a good balance between the availability of nutrients and the physical conditions, mainly aeration and water retention.

Discriminant analysis to select the best substrates

The two discriminant functions used for the classification (Table 4) explained 99.5% of the variation between substrates. According to the standardized coefficients, the most important variable in discriminating between substrates in the first function was height, while in the second function the most important discriminating variable was aerial dry weight (Table 4). These variables can be proposed as predictors for substrate selection.

Table 4. Results of the discriminant analysis, standardized coefficients of each variable, and centroids of the substrates in the two discriminant functions.

	Function	
	1	**2**
Eigenvalues	438,863	3,683
% variation	98,7	0,8
% cumulative variation	98,7	99,5
Attributes	**Standardized coefficients of discriminant functions**	
Height	0,801	0,226
Diameter	0,531	−0,667
Root dry weight	0,157	0,259
Aerial dry weight	0,110	0,852
Total dry weight	−0,112	0,053
Substrates	**Centroids**	
Cc	−3,702	3,434
Fc	−25,641	−0,381
As	−22,712	−1,216
Cc60	29,028	−0,363
Cc50	35,083	−1,306
Cc40	5,083	2,575
Cc30	−6,634	−2,642
Cc20	−10,505	−2,800

Alonso *et al.* (2015) obtained similar results when they used discriminant analysis to differentiate the substrates, which also facilitated the recognition of the height variable as the one with the greatest contribution to the discrimination.

Figure 2 represents the multivariate observations in the discriminant space made up by the two functions, where the separation of the substrates into three well-defined groups is evident. On the left of the graph there are the Cf and Ps substrates, while substrates Ch60 and Ch50 were located at the opposite end, and the remaining substrates (Ch, Ch40, C30, and Ch20) remained in the center.

The attributes height and aerial dry weight were those that had the greatest weight in the distribution of the groups (Table 3), with substrates Ch60 and Ch50 being the ones where seedlings showed the greatest growth and development, while the Cf and Ps substrates (individual components) were the ones with the lowest values in these attributes.

According to Valenzuela (2019), substrates should be made with more than one organic material that promotes an adequate balance of nutrients, with the aim of promoting plant growth and development. This aspect could have influenced the better results obtained with substrates Ch60 and Ch50, made with three organic materials.

Based on the discriminant analysis, it was established that the best treatments were always associated with substrates Ch60 and Ch50, and therefore, these mixtures favored the morphophysiological attributes of mahogany plants. This result is similar to those obtained by Alonso *et al.* (2015), who used discriminant analysis as a tool to select the best substrates studied in the nursery.

Frequently, statistical analyses used for the evaluation and selection of substrates based on morphological variables consist of simple variance analysis (Reyes *et al.*, 2018; Domínguez-Liévano and Espinosa-Zaragoza, 2021). In many cases, the variables evaluated do not clearly indicate the differentiation between them and the selection due to limitations of the analysis method. Therefore, the discriminant analysis statistical method as an interpretation tool may be a useful option in these cases.

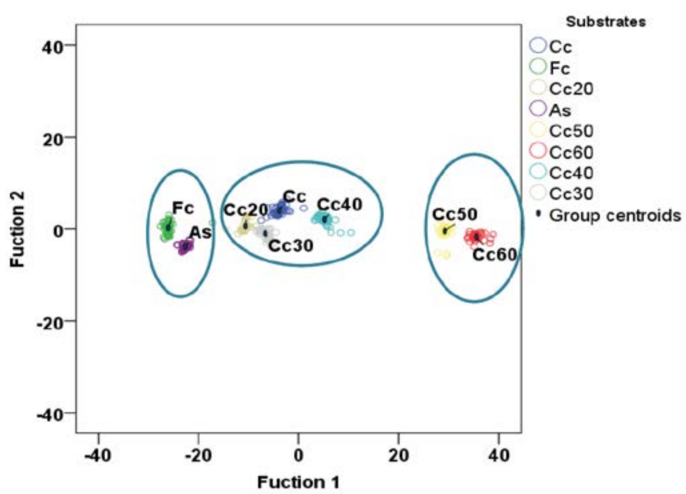

Figure 2. Scatter plot of the substrates in the two discriminant functions.

CONCLUSIONS

The best morphological attributes were obtained in the mixtures of cocoa husk, coconut fiber, and sawdust in proportions 60:20:20 and 50:30:20 (Ch60 and Ch50).

The use of organic substrates made from local materials proves to be a viable alternative to implement in the production of mahogany forest plants.

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