SUBSTRATES, SEEDLING AGE AND ENVIRONMENT IN THE INITIAL GROWTH OF *Cariniana pyriformis* Miers

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Resumo

Substratos, idade de mudas e ambientes no crescimento inicial de Cariniana pyriformis Miers. A produção massal de mudas de alta qualidade pode melhorar os planos de conservação e reflorestamento do mogno colombiano (*Cariniana pyriformis* Miers), uma espécie florestal nativa da Colômbia. Para contribuir com esse objetivo, dois ambientes foram avaliados. O primeiro, constituído de uma casa de vegetação em arco com cobertura plástica antitérmica, 50% de sombreamento e fotosseletivo à radiação U.V, enquanto o segundo de um viveiro agrícola coberto com tela preta de monofilamento e 65% de sombreamento. Para cada ambiente adotou-se um delineamento experimental de blocos completoscasualizados em esquema de parcelas divididas. A parcela principal correspondeu a cinco substratos com diferentes formulações volumétricas de areia (SA), casca de pinus (PB), fibra de coco (CF), composto comercial obtido a partir da compostagem de estrume de aves, pó de cana-de-açúcar e pó de serragem (CC) e subsolo da região (SS). A subparcela correspondeu a duas idades das mudas: 77 e 95 dias após a semeadura. Os valores para o índice de qualidade de Dickson, área foliar, massa seca da parte aérea e do sistema radicular para ambas idades foram maiores quando cultivadas em casa de vegetação. Dentro do viveiro agrícola não houve efeito dos substratos. Para ambos ambientes e idades, atributos morfológicos ótimos não foram atingidos nas mudas para seu estabelecimento em campo. O substrato à base de 20% SA + 20% CC e 60% SS é o mais indicado pois aumenta o vigor das mudas, seguido pela composição de 20% PB + 20% CC + 60% SS.
Palavras-chaves: mogno colombiano, índice de qualidade de Dickson, ambiente protegido, Lecythidaceae.

Abstract

The massive production of high-quality seedlings can improve the conservation and commercial reforestation plans of the Colombian mahogany (*Cariniana pyriformis* Miers), a native forest species of Colombia. To contribute to this objective, two environments were evaluated. The first was an arched protected environment of structure covered with anti-thermal low-density polyethylene film to offer 50% shade and photoselective to U.V radiation, while the second was an agricultural nursery covered with black monofilament screen and mesh to offer 65% shading. Each environment adopted an experimental design of complete random blocks into a split-plot scheme. The main plot comprised five substrates that contained different volumetric proportions of river sand (SA), pine bark (PB), coconut fiber (CF), commercial compost obtained from composting poultry manure, cane dust and sawdust powder (CC), and subsoil from the study region (SS). The subplot was two seedling ages: 77 and 95 days after sowing. The values for the Dickson quality index, leaf area, dry mass of the aerial part and the root system, for both ages, was higher inside the protected environment. The agricultural nursery did not evidence substrates effect. For both environments and ages, optimal morphological attributes were not reached in the seedlings to be established in the field. The substrate based on 20% SA + 20% CC and 60% SS is the best as it increases seedling vigor, followed by the 20% PB + 20% CC + 60% SS composition.
Keywords: Colombian mahogany, Dickson quality index, greenhouse, Lecythidaceae

INTRODUCTION

The Neotropics have a wide diversity of native species with high timber potential for the recovery of natural forests, the conservation of biodiversity and commercial reforestation (BREUGEL *et al*., 2011; CALVIÑO *et al*., 2012). However, the silviculture of the countries located in this region has been based on few introduced species, e.g., *Acacia* spp., *Eucalyptus* spp., *Pinus* spp., and *Tectona* spp., which are characterized by their rapid growth in field and adaptability to different environments (CALVIÑO *et al*., 2012). In the case of Colombia, the situation is even more dramatic because although its territory has 24.8 million ha with forest potential, it is estimated that only 350 thousand hectares have been cultivated, which generates a deficit in demand for wood and high deforestation rates (PROFOR, 2017). Although Colombia holds a wide diversity of native species, only some have sufficient information on their dispersion and management, which undervalues its potential for socioeconomic and environmental purposes.

Colombian mahogany or abarco (*Cariniana pyriformis* Miers) is an arboreal species that belongs to the Lecythidaceae botanical family with high timber and ecological attributes in Colombia, Panama and Venezuela, and natural occurrence in humid and very humid forests (HUANG *et al*., 2015). Given the excessive exploitation of their populations and loss of habitat, in Colombia, the species is categorized as Critically Endangered (CARDENAS *et al*., 2015; HUANG *et al*., 2015). Recently, agroforestry system arrangements with cocoa and as pure plantations have been assessed (CARDENAS *et al*., 2015).

Among the main factors that affect the production and quality of the seedlings are the substrates used, which are formulated with a diversity of constituents. Substrates or their combination differ widely in their physical and chemical attributes, i.e., bulk density, total porosity, aeration space, nutrient availability, pH or N/C ratio (SCHAFER *et al*., 2015; KRATZ *et al*., 2017). In Colombia, the soil is still the most widely used substrate for the production of seedlings due to its lower cost and lack of other constituents on a commercial scale. Some alternative substrates of organic and inorganic origin have gained acceptance in the country, with special emphasis on horticulture and recently in silviculture, justified by high soil pathogen proliferation and their difficult control (CUERVO *et al*., 2012; OSORIO *et al*., 2014; FAJARDO *et al*., 2016).

Several species of the *Cariniana* genus have been considered as semi-heliophytes or of moderate tolerance to light during their first growth phases (LIMA *et al*., 2010), that is, climax species or late secondary species with high phenotypic plasticity. Thus, the production of seedlings in a protected environment could offer advantages over their production in a nursery because it allows the protection of seedlings against climatic adversities and increases the quality and precocity of these. Furthermore, also, water and fertilizer use efficiencies and cultural practices (VIEIRA *et al*., 2016). However, the lack of knowledge regarding the vigor of the seedlings inside these environments and use of alternative substrates is still extensive in Colombia for diverse species, including to *C. pyriformis*.

With the aim of improving the existing technologies for the massive production of high-quality *C. pyriformis* seedlings and at a reasonable cost, their production was evaluated in two environments and at two seedling ages using different substrate formulations.

MATERIALS AND METHODS

Study area and experimental design

The study was conducted in the facilities of Centro de Investigación La Suiza of Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA) located in the municipality of Rionegro, Department of Santander, Colombia, between September and November 2017. The region is located at 7°22'10'' N and 73°10'33'' W, and at 550 m of altitude. The area has an equatorial tropical climate (AF) according to Köppen's classification system where rainfall is distributed from April to May, and from October to November, with an annual average of 1.982 mm and an annual average temperature of 27 °C.

Experiments were performed with C. *pyriformis* seedlings comparing substrates and seedling age under two environments. Initially, the seeds of *C. pyriformis* were purchased from the company Recolsemillas (Bogota, Cundinamarca) and were germinated in sand covered with a black monofilament screen that gives 65% shading. Pregerminative treatment consisted of imbibition in water for 12 hours.

Substrates comprised five volumetric formulations containing pine bark (PB), coconut fiber (CF), commercial compost (CC), subsoil from the region (SS) and river sand (SA). These formulations are as follows: S1= 20% SA + 20% CC + 60% SS, S2= 20% PB + 20% CC + 60% SS, S3= 20% CF + 20% CC + 60% SS, S4= 25% CF + 25% CC + 50% SA and S5= 25% PB + 25% CC + 50% SA.

The pine bark *in natura* (bags of 80 liters, COP $650,000 per m^3) was obtained in Pamplona (department of Norte de Santander). Before using, particles were crushed three times in a stationary forage chopper (Nogueira model Sertaneja Master). Coconut fiber with a granulometry from 0 to 10 mm (bags of 80 liters, COP $496,000 per m^3) and commercial compost (bags of 80 liters, COP $130,000 per m^3) were purchased from the companies Sustitutos Ecológicos (Medellín, Antioquia) and Biotropica (Mesa de los Santos, Santander), respectively. This compost is obtained from composting poultry manure, cane dust, and sawdust powder for 60 to 70 days. River sand and subsoil (a truckload with 1 m^3, COP $36,000 per m^3) were obtained from areas cultivated with cocoa and coffee next to C.I. La Suiza, collecting samples at a depth of 20 to 40 cm. All these materials were sifted through a sieve mesh of 5 mm.

Two seedling ages considered as days after sowing (DAS): T1 = 77 DAS and T2 = 95 DAS were assessed. Finally, the following environments were employed. The first was an arched protected environment (E1), having 5 m wide x 18 m long x 3 m high, covered with anti-thermal low-density polyethylene film (LDPE) of 200 micron and photoselective to U.V radiation, with 50% shade and opening in the sides from the ground up to 0.8 m. The protected environment had micro-aspersion irrigation (drippers of 55 L h^{-1}, 7 mm day^{-1} blade) operated using time controllers four times a day, each lasting 3 min. The second was an agricultural nursery (E2), having 5 m wide x 4 m long x 2.5 m high, covered with black monofilament screen and mesh to offer 65% of shading. The nursery had sprinkler irrigation (sprinklers of 120 L h^{-1}, 5 mm day^{-1} blade) and operated twice a day in the absence of rain, each lasting 30 min. In both environments, seedlings were placed in elevated working surfaces 0.8 m from the ground, and the temperature and relative air humidity were recorded at intervals of 30 min with a data logger (CEM model DT-172). Monthly precipitation (September = 224 mm, October = 240 mm and November = 258 mm), and global solar radiation and photosynthetically active radiation outside the environments were recorded through a mobile meteorological station (WatchDog model 2900ET) at 15 min intervals.

Substrate characterization and seedling evaluation

Physical and chemical properties of substrates were characterized before establishing the experiments in the Laboratory of Chemistry and Soil Physics of C.I. Tibaitata of AGROSAVIA (Table 1). For this, the humidity retention curve was obtained through the tension table method with cylinders calculating total porosity, which corresponds to the maximum moisture content (saturation in macro and micropores) after the free water has drained, and whose value coincides with a tension of 0 hPa. Also, the aeration space was calculated corresponding to the air volume of the substrate after the free water in the macropores has drained, and whose value coincides with the difference between the total porosity and the water volume retained at a tension of 10 hPa (DE BOODT *et al.*, 1974).

Table 1. Cost per m^3, chemical and physical properties, and concentration of macro and micronutrients of the substrates before establishing the experiment.
Tabela 1. Custo por m^3, propriedades químicas e físicas, e concentração de macro e micronutrientes dos substratos antes da instalação do experimento.

**	Cost * m^3	pH[1]	EC[1] dS m^{-1}	Db[2] g cm^{-3}	OM[3] g 100 g^{-1}	PT[4] %	EA[4] %	Ca^{+2} (1) cmol$_{(+)}$ kg^{-1}	Mg^{+2} (1) cmol$_{(+)}$ kg^{-1}	K^+ (1) cmol$_{(+)}$ kg^{-1}
S1	$69,200	6.74	3.20	1.24	3.64	61.9	4.8	8.81	2.37	1.12
S2	$177,600	6.34	5.88	1.05	5.56	72.4	5.0	14.09	3.83	2.32
S3	$146,800	6.22	4.67	0.99	8.32	65.7	5.3	10.48	3.15	2.70
S4	$174,500	6.14	7.45	1.00	9.32	55.9	5.6	12.65	4.04	3.61
S5	$213,000	6.39	5.16	0.96	3.86	56.5	4.8	7.70	2.83	1.91

**	Na^+ (1) mg kg^{-1}	CEC (2) cmol$_{(+)}$ kg^{-1}	P (3) mg kg^{-1}	S (4) mg kg^{-1}	Cu (5) mg kg^{-1}	Fe (5) mg kg^{-1}	Mn (5) mg kg^{-1}	Zn (5) mg kg^{-1}	B (5) mg kg^{-1}
S1	0.42	12.71	281.98	91.90	2.26	58.37	4.76	11.70	0.76
S2	0.73	20.97	314.62	185.95	2.69	70.10	12.09	15.98	0.92
S3	0.97	17.29	235.16	145.48	2.38	55.92	14.07	13.70	0.92
S4	0.99	21.29	323.13	281.90	2.44	64.68	15.93	16.25	1.08
S5	0.52	12.95	342.99	151.43	1.59	56.45	7.53	12.56	0.98

* USD $ 1 = COP $ 3,053 (August 30, 2018). ** Substrate composition (v: v: v): S1= 20% SA + 20% CC + 60% SS, S2= 20% PB + 20% CC + 60% SS, S3= 20% CF + 20% CC + 60% SS, S4= 25% CF + 25% CC + 50% SA and S5= 25% PB + 25% CC + 50% SA. Where SS= subsoil from the region, CC= commercial compost, SA= river sand, CF= coconut fiber, and PB= pine bark. [1] pH and EC (electrical conductivity) in water at a relation of 1: 5, [2, 4] bulk density (Db), total porosity (PT) and aeration space (EA) according to De Boodt *et al*. (1974), [3] organic matter (OM) according to Walkey; Black, (1) 1 N of ammonium acetate, pH 7, (2) Bray II, (3, 5) calcium monobasic phosphate, (4) Olsen modified.

On the other hand, the self-compaction method was used to calculate the bulk density (DE BOODT *et al.*, 1974), which is defined as the ratio between the mass of dry material at 105% and the volume occupied, including the intermediate pore space. The other properties followed standard methodologies employed for soil samples.

After 21 DAS, homogenous seedlings (height means = 8 cm) were selected for transplantation to black polyethylene bags of 10 cm wide x 16 cm long. At 63 DAS, compound fertilizer 15-15-15 (N-P_20_5-K_20) was applied at a dose of 0.3 g $plant^{-1}$. The total amount was diluted in water, and the solution was applied with a syringe (10 mL $seedling^{-1}$). Seedling production of *C. pyriformis* in the E2 environment using the S1 substrate formulation until these reached 90 to 100 days of age, and employing plastic bags with the dimensions mentioned above, is the conventional management method used by nurseries in the study area.

At 77 and 95 DAS, plant height (H) from the level of the substrate surface to the terminal bud, and stem diameter (SD) in the neck of the plant, employing a flexometer (precision of 0.1 cm) and a digital caliper (precision of 0.01 mm), respectively, were measured. The number of leaves, dry mass of the aerial part (DMA) and the root system (DMR) were determined after drying the samples separately in the oven (65 °C for 72 hours) and their subsequent weighing using an electronic balance (accuracy of 0.01 g).

To calculate the foliar area per plant (FA) leaves were removed with the help of scissors and were then fixed on a white ceramic plate (50 x 50 cm) and covered by a transparent glass. A flexometer was used to measure the dimension. Afterward, the photographs taken with a digital camera were analyzed in the image analysis software ImageJ 1.45. The following quality indices were established: plant height/stem diameter relation (H/SD), dry mass of the aerial part/dry mass of the root system relation (DMA/DMR) and the Dickson quality index (DQI) (DICKSON *et al*., 1960), the latter according to the following formula:

$$\mathrm{DQI} = \mathrm{DMT} \, / \, [(\mathrm{H/SD}) + (\mathrm{DMA/DMR})]$$

Where DMT is total dry mass (g); H is the height of the aerial part (cm); SD is the stem diameter (mm); DMA is the dry mass of the aerial part (g); DMR is the dry mass of the root system (g).

Statistical analysis

Because there were no repetitions in the environments, each was considered as an experiment. In each one, an experimental design of complete random blocks into a split-plot scheme was established, with four replications and each with five seedlings. The main plot comprised five substrate formulations, and the subplot was two seedling ages.

Initially, an analysis of variance ($p < 0.05$) was carried out for each environment that evaluated the effect of substrate and seedling age. Then, the joint experiment analysis that included the two environments was carried out. Once the mean square of the error (MSQ) was verified in the analysis of individual variance, the relation between the highest and lowest MQE was less than 7 (BANZATTO; KRONKA, 2013). Then, means were separated by the Tukey test when they were significant ($p < 0.05$) using the statistical program S.A.S 9.4®.

RESULTS

The relation between the MSQ of the individual analysis in all the variables was not higher than 7; therefore, a joint analysis was carried out. There was no triple interaction between the two factors. Except for the H/SD and the DMA/DMR relations, the other variables showed significant differences for the interactions substrate x age, substrate x environment and/or environment x age (Tables 2, 3 and 4). As shown in Table 2, substrate composition influenced plant height and number of leaves. However, substrate S4 showed the lowest values (19.1 cm and 24.3 leaves), meanwhile, the environment influenced the DMA/DMR and H/SD relations, and the age of the seedlings influenced this last variable. These quality indices were lower in the nursery and at 77 DAS.

Table 2. Plant height (H), number of leaves (NL), relation between dry mass of the aerial part and dry mass of the root system (DMA/DMR), and relation between plant height and stem diameter (H/SD) of *Cariniana pyriformis* seedlings as a function of substrate, environment and seedling age.

Tabela 2. Altura de planta (H), número de folhas (NL), relação massa seca da parte aérea e massa seca do sistema radicular (DMA/DMR), relação entre altura de planta e diâmetro do colo (H/SD) de plântulas de *Cariniana pyriformis* segundo o substrato, ambiente e idade de mudas.

*	**H (cm)** cv[1]= 5.6%	**NL** cv= 10.8%	**Environment**	**DMA/DMR relation** cv= 7.6%	**H/SD relation** cv= 4.6%
S1	21.48 a	32.79 a	protected environment	3.63 a	8.02 a
S2	21.18 a	29.76 ab	agricultural nursery	3.26 b	7.52 b
S3	20.20 ab	28.14 bc			
S4	19.14 b	24.35 c	**Seedling age**	**H/SD relation** cv= 2.9%	
S5	19.99 ab	27.58 bc	77 DAS **	7.61 b	
			95 DAS	7.93 a	

[1]cv = coefficient of variation. * Substrate composition (v: v: v): S1= 20% SA + 20% CC + 60% SS, S2= 20% PB + 20% CC + 60% SS, S3= 20% CF + 20% CC + 60% SS, S4= 25% CF + 25% CC + 50% SA and S5= 25% PB + 25% CC + 50% SA. Where SS = subsoil from the region, CC= commercial compost, SA= river sand, CF= coconut fiber and PB= pine bark. Means followed by the same letter in the column do not differ from each other according to the Tukey test ($p < 0.05$). ** Days after sowing.

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Table 3 shows the interactions between environments and substrates. Variables did not show significant differences according to substrates grown in the agricultural nursery. On the contrary, in the protected environment seedlings showed greater vigor when they were produced in the S1 substrate, which showed SD (3.0 cm), DMR (0.234 g plant^{-1}), DQI (0.093) and FA (102.9 cm^2 plant^{-1}) values that were higher in 17, 59, 69 and 94% compared to the S4 substrate. Furthermore, this last substrate showed the lowest performance compared to all others. The substrates showed significant differences between environments being smaller for the agricultural nursery, except the S4 substrate.

Table 3. Interactions between environment and substrate (E x S) for stem diameter (SD), dry mass of the root system (DMR), dry mass of the aerial part (DMA), leaf area (LA) and Dickson quality index (DQI) of *Cariniana pyriformis.*

Tabela 3. Interação entre ambiente e substratos (E x S) para o diâmetro de colo (SD), massa seca do sistema radicular (DMR), massa seca da parte aérea (DMA), área foliar (AF) e índice de qualidade de Dickson (DQI) de *Cariniana pyriformis*.

*	**SD (mm)** cv[1]= 6.4%		**DMR (g plant^{-1})** cv= 24.1%	
	E1 [2]	**E2** [3]	**E1**	**E2**
S1	3.00 a A	2.52 a B	0.234 a A	0.142 a B
S2	2.74 ab A	2.52 a A	0.208 ab A	0.134 a B
S3	2.77 ab A	2.49 a B	0.153 c A	0.129 a A
S4	2.56 b A	2.49 a A	0.147 c A	0.115 a A
S5	2.65 b A	2.55 a A	0.182 bc A	0.136 a B

*	**DQI** cv= 24.2%		**FA (cm^2 plant^{-1})** cv= 26.4 %	
	E1	**E2**	**E1**	**E2**
S1	0.093 a A	0.056 a B	102.87 a A	65.22 a B
S2	0.079 ab A	0.052 a B	87.01 ab A	53.81 a B
S3	0.066 bc A	0.051 a B	83.30 ab A	57.36 a B
S4	0.055 c A	0.046 a A	52.82 c A	46.65 a A
S5	0.071 b A	0.053 a B	75.80 bc A	60.10 a A

[1] cv = coefficient of variation. [2] protected environment; [3] agricultural nursery. * Substrate composition (v: v: v): S1= 20% SA + 20% CC + 60% SS, S2= 20% PB + 20% CC + 60% SS, S3= 20% CF + 20% CC + 60% SS, S4= 25% CF + 25% CC + 50% SA and S5= 25% PB + 25% CC + 50% SA. Where SS= subsoil from the region, CC= commercial compost, SA= river sand, CF = coconut fiber and PB= pine bark. Means followed by the same lowercase letter (column) and uppercase letter (row) do not differ from each other by the Tukey test ($p < 0.05$).

The interaction between the environment and seedling age is described in Table 4. For the variables influenced, there were higher values for seedlings within the protected environment in both ages, being stronger at 95 DAS. In addition, for both environments, seedlings increased their DMR (E1= 54%, E2= 45%), DMA (E1= 60%, E2= 48%), FA (E1= 35%, E2= 28%) and DQI (E1= 50%; E2= 45%) values in about 50% at 95 DAS compared to 77 DAS. The increase for SD and H was less severe.

Table 4. Interactions between environment and seedling age (E x A) for stem diameter (SD), plant height (H), dry mass of the root system (DMR), dry mass of the aerial part (DMA), foliar area (FA), Dickson quality index (DQI) and number of leaves (NL) of *Cariniana pyriformis.*

Tabela 4. Interação entre ambiente e idade de plântulas (E x A) para diâmetro de colo (SD), altura de planta (H), massa seca do sistema radicular (DMR), massa seca da parte aérea (DMA), área foliar (FA), índice de qualidade de Dickson (DQI) e número de folhas (NL) de *Cariniana pyriformis*

	SD (mm) cv= 7.5%		H (cm) cv= 11.9%		FA (cm² plant⁻¹) cv= 30%	
	77 DAS *	**95 DAS**	**77 DAS**	**95 DAS**	**77 DAS**	**95 DAS**
E1[1]	2.58 a B	2.90 a A	20.23 a B	23.61 a A	63.31 a B	97.41 a A
E2[2]	2.43 b B	2.60 b A	17.98 b B	19.76 b A	47.45 b B	65.81 b A

	DMR (g plant⁻¹) cv= 31.6%		DMA (g plant⁻¹) cv= 36.5%		DQI cv= 30.1%	
	77 DAS	**95 DAS**	**77 DAS**	**95 DAS**	**77 DAS**	**95 DAS**
E1	0.148 a B	0.221 a A	0.517 a B	0.826 a A	0.058 a B	0.087 a A
E2	0.107 b B	0.155 b A	0.347 b B	0.505 b A	0.042 b B	0.061 b A

	NL cv= 43.7%	
	77 DAS	**95 DAS**
E1	27.60 a B	45.84 a A
E2	16.38 b B	24.27 b A

[1] protected environment; [2] agricultural nursery. * Days after sowing. Means followed by the same lowercase letter (column) and uppercase letter (row) do not differ from each other by the Tukey test (p <0.05)

In Table 5, the interaction between substrate and seedling age is appreciated. Confirming the previous results, the differences between the substrates were less evident for some variables, being significant at 75 DAS only for DMA; however, at 95 DAS, all variables were significant. The better seedling performance obtained in the S1 substrate was evidenced in the SD (3.0 mm), DMA (0.841 g plant^{-1}), FA (107.9 cm^2 plant^{-1}) and DQI (0.092) values, as these were much higher than the ones found in substrate S4 (2.54 mm, 0.467 g plant^{-1}, 59.9 cm^2 plant^{-1} and 0.056, respectively) at 95 DAS. In general, substrate S2 showed the second best performance.

Table 5. Interactions between the substrate and seedling age (S x A) for stem diameter (SD), dry mass of the aerial part (DMA), foliar area (FA) and Dickson quality index (DQI) of *Cariniana pyriformis.*

Tabela 5. Interação entre substratos e idade de plântulas (S x A) para diâmetro de colo (SD), massa seca da parte aérea (DMA), área foliar (FA) e índice de qualidade de Dickson (DQI) de *Cariniana pyriformis*.

**	SD (mm) cv= 6.3%		DMA (g plant⁻¹) cv= 28.8%		FA (cm² plant⁻¹) cv= 26.4%		DQI cv= 24.7%	
	77 DAS*	**95 DAS**	**77 DAS**	**95 DAS**	**77 DAS**	**95 DAS**	**77 DAS**	**95 DAS**
S1	2.52 a B	3.00 a A	0.496 a B	0.841 a A	60.4 a B	107.9 a A	0.057 a B	0.092 a A
S2	2.56 a A	2.70 b A	0.500 a B	0.669 b A	61.6 a A	79.2 b A	0.055 a B	0.076 b A
S3	2.48 a B	2.78 ab A	0.401 ab B	0.692 b A	56.1 a B	84.5 ab A	0.046 a B	0.071 b A
S4	2.51 a A	2.54 b A	0.352 b A	0.467 c A	39.5 a A	59.9 c A	0.045 a A	0.056 c A
S5	2.48 a A	2.72 b A	0.411 ab B	0.662 b A	59.2 a A	76.7 bc A	0.050 a B	0.074 b A

* Days after sowing. ** Substrate composition (v: v: v): (S1) 20% SA + 20% CC + 60% SS, (S2) 20% PB + 20% CC + 60% SS, (S3) 20% CF + 20% CC + 60% SS, (S4) 25% CF + 25% CC + 50% SA and (S5) 25% PB + 25% CC + 50% SA. Where SS: subsoil from the region, CC: commercial compost, SA: river sand, CF: coconut fiber and PB: pine bark. Means followed by the same lowercase letter (column) and uppercase letter (row) do not differ from each other by the Tukey test (p <0.05).

DISCUSSION

The least expensive formulation, including the transport costs of the constituents to C.I La Suiza, corresponds to substrate S1 (COP 69,200 per m^3). The other four treatments showed higher but similar values among each other (between COP 177,600 to COP 213,000 per m^3), as these had a higher cost due to the use of coconut fiber and pine bark (see Table 1). According to the results of the physical and chemical analyses of the substrates, these showed high bulk density values (0.96 to 1.24 g cm^{-3}) well above the recommended values, i.e., between 0.50 to 0.85 g cm^{-3} (KÄMPF, 2005). This is because its main component was soil (S1, S2, and S3) or river sand (S4 and S5), which are characterized by having high values (SCHÄFER *et al*., 2015). Besides, total porosity showed a value above the ideal, that is, higher than 80% (DE BOODT *et al*., 1974). Only substrates S2

(72.4%) and S3 meanwhile substrates S4 and S5 were the least adequate. All substrates had a range of less than 6% of aeration space, i.e., very low, indicating low aeration conditions and seedlings with a reduced growth due to the poor drainage. Values between 10 to 20% are recommended for most of the seedlings (MATHERS *et al*., 2007).

The S1 substrate had a pH of 6.7 that exceeded the recommended limit between 5.5 and 6.5 (KÄMPF, 2005), although its EC of 3.2 dS m^{-1} was the lowest compared to the S4 substrate that showed a value of 7.45 dS m^{-1} that was the highest value registered. Probably, the improvement in physical and chemical properties of the S1 and S2 substrates, together with the contribution of macro and micronutrients made these stand out in the protected environment. Nonetheless, Faria *et al*. (2016) recommend the formulation with 25% of the commercial substrate based on pine bark, 35% compost from poultry manure and 40% of subsoil to obtain high-quality *Mimosa setosa* Benth seedlings. Furthermore, for *Chamaecrista desvauxii* Benth, another Neotropical native species, Delarmelina *et al*. (2015) found that this was the best formulation. Namely, similar to substrates S1 and S2 that showed the highest quality means of seedlings.

According to Figure 1, the protected environment recorded more extreme temperature and relative humidity values, especially during daylight hours, with an average maximum temperature of 42.6 °C and a minimum average relative humidity of 42.7% at 11:00 a.m., in comparison to the agricultural nursery that reached extreme values of 31.5 °C and 72.2% at the same time. The temperature of the protected environment varied between 19.2 and 52.6 °C, with a daily average of 3.5 °C above the values found in the agricultural nursery that varied between 18.5 to 38.1 °C, i.e., 28.3 °C vs. 24.8 °C. These conditions did not harm seedling growth and development within the protected environment, but on the contrary, they promoted their precocity.

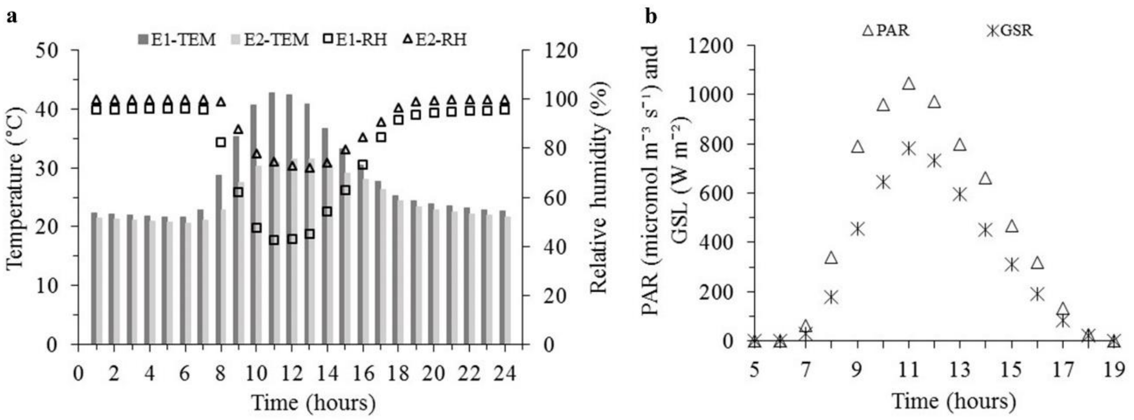

Figure 1. a) hourly average temperature (TEM) and relative humidity (RH) registered inside the protected environment (E1-TEM; E1-RH); and inside the agricultural nursery (E2-T; E2-RH). b) photosynthetically active radiation (PAR) and global solar radiation (GSR) outside the environments.

Figura 1. a) Médias horárias de temperatura (TEM) e umidade relativa (RH) registradas dentro da casa de vegetação (E1-TEM; E1-HR) e dentro do viveiro agrícola (E2-TEM; A2-RH). b) radiação fotossinteticamente ativa (PAR) e radiação solar global (RSR) no exterior dos ambientes.

Nevertheless, perhaps, also the inhibitory action of the plastic to the U.V. radiation enhanced the photosynthetic efficiency of seedlings within the protected environment because when this radiation is blocked in the plastic covers of the greenhouses, it causes two main physiological effects. First, it increases the accumulation of total dry mass, and second, and in a smaller proportion, internode length and plant height (LAMNATOU; CHEMISANA, 2013). This response was verified by the dry mass values obtained (Tables 4 and 5).

In seedlings of *Cariniana estrellensis* (Raddi) Kuntze, *Cedrela odorata* L. and *Manilkara salzmannii* (A. DC.) H. J. Lam that are classified as non-pioneer species as well as in *C. pyriformis*, Gaburro *et al*. (2015) found that their tolerance to full sun versus shade conditions after 150 days could be attributed to the high plasticity of the physiological variables assessed rather than to the morphological variables (e.g., height, H/SD, DQI and leaf area). On the other hand, Vieira *et al*. (2016) despite not finding drastic temperature and relative humidity amplitudes among two agricultural nurseries and one under full sun exposure, indicated that *Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg. seedlings showed higher values in nurseries. This is probably because the available radiation in these environments, i.e., between 40 and 50% of the external radiation, was adequate for the species. The absence of differences between substrates for seedlings in the agricultural nursery could be justified, in addition to the higher efficiency in the use of light and environmental conditions within the protected environment, by a lower susceptibility to stress by excess rainfall (total accumulated precipitation in the study= 722 mm).

Plant height varied between 19.1 and 21.5 cm within substrates, and between 19.8 and 23.8 cm within environments at 95 DAS. This is contrary to what was found for SD that was influenced by the interactions environment x substrate, environment x age, and substrate x age, with a general average of 2.63 mm. The easiness to measure these variables in the field, in addition to being non-destructive, makes them good quality indexes for seedlings. In the current study, for seedling dimensions, even at 95 DAS, the cultivation time in both environments was insufficient when compared to other forestry species. Davide; Faria (2008) suggest an adequate seedling size of 25 to 30 cm of height with a stem diameter larger than 3 mm. However, there are yet no established morphological parameters for seedlings of *C. pyriformis* that relate their vigor and later survival in the field. New studies should deepen in these aspects to standardize the minimum commercialization requirements for *C. pyriformis* seedlings, and hence, analyze the data obtained.

The values obtained for DQI, dry mass of aerial part and the root system indicated that although the substrate S1 and S2 contributed to increasing much more the vigor and quality of seedlings when they were cultivated up to 95 DAS, only within the protected environment, there were differences (Table 4 and 6). The DQI gathers the morphological variables and suggests that higher values reflect higher seedling quality attributes; however, it varies according to the species and the cultivation conditions in the nursery, e.g., substrate, seedling age, container size, among others (FERRAZ; ENGEL, 2011; GABURRO *et al*., 2014; MELO *et al*., 2018). Nonetheless, no values in previous studies for *C. pyriformis* were found. The S4 substrate had the lowest quality values.

Another evident appreciation is that the H/SD (8.02) and the DMA/DMR (3.63) relations were higher in the protected environment and that the H/SD relation increased slightly from 77 DAS (7.61) to 95 DAS (7.93). That is to say, with time, the protected environment restricted root growth as seedling height increased. Furthermore, the values obtained indicate imbalances between aerial and root system parts, even for environments and seedling age (Table 2). A value of less than 8 and equal to 2 is suggested for the H/SD and DMA/DMR relations, respectively, for most of the forestry species, because although this last variable is destructive, it helps to predict seedling adaptability to adverse conditions in the field, e.g., water stress, nutrient absorption and susceptibility to falling (MELO *et al*., 2018).

In fact, some seedlings showed root winding, which suggests that the size of the plastic bag used in this study was not the most appropriate. From a practical point of view, even if these conditions were maintained for longer periods, seedlings would probably intensify this damage and inferiority in the quality indexes would be observed. This is corroborated by the higher DMR, DMA and SD values within the protected environment compared to the ones obtained in the agricultural nursery, in addition to the ones obtained at 95 DAS versus 75 DAS (Table 4). Ferraz; Engel (2011) reported that seedlings of *Tabebuia chrysotricha* (Mart. Ex DC.) Sandl, i.e., early secondary species, suffered less influence of the container size in growth height when compared to seedlings of late secondary species such as *C. pyriformis* because these experienced a strong influence on their quality indexes.

Finally, the substrate S1 contributed to increasing *C. pyriformis* seedling vigor, and its formulation was the most economical (COP 69,200 per m^3). The recommendation of this study is to continue evaluations with other alternative constituents that offer adequate physical properties for seedling growth of *C. pyriformis* without increasing the costs of nursery operators exceedingly. Likewise, seedling age, as well as container size, should be evaluated.

CONCLUSIONS

- The arched protected environment of the structure covered with anti-thermal low-density polyethylene film to offer 50% shade and photoselective to U.V. radiation increases strongly the biometric parameters and morphological indexes of *Cariniana pyriformis* seedlings compared to the ones obtained in an agricultural nursery with black mesh that provides 65% shade.
- The substrate composed of 20% river sand + 20% commercial compost + 60% subsoil from the region is the best for the production of *Cariniana pyriformis* seedlings as it increases their vigor, followed by the 20% pine bark + 20% commercial compost + 60% subsoil from the region composition.
- The production of *Cariniana pyriformis* seedlings until they reach an age of 77 or 95 days after sowing, independent of their environment and substrate, does not achieve the minimum quality parameters recommended for their establishment in the field, according to results obtained in other native forestry species.

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