

Influence of container type and volume on the production of *Calophyllum brasiliense* and *Cariniana estrellensis* seedlings for recovery of degraded areas

Influência do tipo e volume do recipiente na produção de mudas de *Calophyllum brasiliense* e *Cariniana estrellensis* visando a recuperação de áreas degradadas

Tânia Fontana Dias¹; José Ricardo Macedo Pezzopane²; Fábio Ribeiro Pires³; Adriel Lima Nascimento^{4*}; André Orlandi Nardotto Júnior⁵

Highlights

The ideal container volume is essential for the development of plants in the field. Seedling production is a crucial process that ensures optimal field performance. For *Calophyllum brasiliense*, it is recommended to use 180-cm³ tube containers. For *Cariniana estrellensis*, using a 280-cm³ tube container is recommended.

Abstract

Owing to the growing demand for seedlings of native forest species and interest about their behavior in nurseries, this study aimed to assess the effect of container volume on the growth and quality of *Calophyllum brasiliense* (guanandi) and *Cariniana estrellensis* (jequitibá-branco). The experimental design employed randomized blocks with four replicates and five container treatments, comprising 53-, 115-, 180-, and 280-cm³ tubes as well as a 560-cm³ plastic bag. Each species was used in independent experiments. The cultivation period lasted 150 d, after which various biometric parameters (shoot height, stem diameter, and leaf area) and quality indicators of the seedlings (height-to-diameter ratios, aerial and root dry biomass, and Dickson Quality Index) were evaluated. *C. brasiliense* seedlings demonstrated statistically similar results among the mean values for all evaluated parameters in the

¹ Forestry Engineer, Master's Degree in Tropical Agriculture, Universidade Federal do Espírito Santo, UFES, São Mateus, ES, Brazil. E-mail: taniafontanadias@gmail.com

² Researcher, Empresa Brasileira de Pesquisa Agropecuária, EMBRAPA, São Carlos, SP, Brazil. E-mail: jose.pezzopane@embrapa.br

³ Prof. Dr., Department of Agricultural and Biological Sciences, DCAB, UFES, São Mateus, ES, Brazil. E-mail: pires.fr@gmail.com

⁴ Dr., Agronomist, UFES, São Mateus, ES, Brazil. E-mail: adriellima23@gmail.com

⁵ Forestry Engineer, Master's Degree in Tropical Agriculture, UFES, São Mateus, ES, Brazil. E-mail: andreorlandinardotto@gmail.com

* Author for correspondence

180-, 280-, and 560-cm³ containers. For *C. estrellensis*, the mean values of most of the assessed parameters were similar for the 280- and 560-cm³ containers. Therefore, using 180- and 280-cm³ tube containers for *C. brasiliense* and *C. estrellensis*, respectively, is recommended because of their smaller spatial requirements, reduced substrate costs, and increased production capacity.

Key words: Guanandi. Jequitibá-branco. Seedling quality. Container seedlings. Container volume.

Resumo

Devido ao aumento da demanda por mudas de espécies florestais nativas e à necessidade estudos sobre o comportamento destas espécies em viveiro, objetivou-se avaliar a influência do volume do recipiente no crescimento e na qualidade de mudas de *Calophyllum brasiliense* (guanandi) e *Cariniana estrellensis* (jequitibá branco). O delineamento utilizado foi blocos casualizados, com quatro repetições e cinco tratamentos, compostos por recipientes de capacidade volumétrica de 53, 115, 180, 280 e 560 cm³ (cada espécie constituiu um experimento independente). As espécies foram cultivadas por 150 dias e ao final avaliaram-se parâmetros biométricos (altura da parte aérea, diâmetro de coleto e área foliar) e índices que indicam a qualidade das mudas (relações altura e diâmetro de coleto, biomassa seca aérea e radicular e o Índice de Qualidade de Dickson). As mudas de *C. brasiliense* apresentaram semelhança estatística entre as médias dos tubetes de 180, 280 cm³ e o saco de 560 cm³, para todos os parâmetros avaliados. Para a espécie *C. estrellensis*, as médias do tubete de 280 cm³ e do saco de 560 cm³ foram similares na maioria dos parâmetros avaliados. Dessa maneira, o uso do tubete de 180 cm³, para *C. brasiliense*, e de 280 cm³, para *C. estrellensis*, são indicados devido ao menor espaço ocupado, à redução dos custos com substrato e ao aumento da capacidade produtiva.

Palavras-chave: Guanandi. Jequitibá-branco. Qualidade de mudas. Recipiente de mudas. Volume de recipiente.

Introduction

The Atlantic Forest is a Brazilian biome with great botanical diversity and is recognized as one of the global biodiversity hotspots. The intense changes in land use and occupation in Brazil threaten the continued existence of this biome (Silva et al., 2020). Restoration of the Atlantic Forest has become increasingly necessary owing to constant deforestation of the biome. In the first half of 2022, more than 210 km² of area belonging to the biome was deforested (SOS Mata Atlântica, 2023). Planting of native seedlings is a useful tool for forest restoration, which aims not only to re-establish the former

“natural” state of the environment, but also to recompose the structure, processes, and desired species; reconstruct communities; restore soil characteristics; and support species replacement during successions (Stanfurt et al., 2014).

Seedling production is a crucial forestry process that ensures optimal field performance. The use of container seedlings has been widely explored; however, to obtain high-quality seedlings, implementation of appropriate techniques that consider essential factors, such as container volume, substrate quality, and nutritional and water requirements, is necessary (Landhäuser et

al., 2019). Seedling quality directly influences seedling survival and growth in the field, thereby affecting the overall success of forest recomposition (Melo et al., 2018).

The demand for high-quality native seedlings has been increasing owing to the need for environmental compensatory measures and the potential of these species to restore degraded areas, support revegetation, and enhance the environmental suitability of rural properties (Acevedo et al., 2021). The introduction of high-quality native seedlings expedites the natural regeneration process (Vloon et al., 2022), and evaluation of the ideal tube size is an initial and crucial step in the development of good seedlings for forest restoration projects.

Several studies have been published on the optimal tube size for native seedlings (Oliveira et al., 2019; Aghai et al., 2014). Determining the optimum container volume for native species, particularly endangered species, is essential for ensuring the proper development of plants in the field (Chu et al., 2020). In recent years, numerous studies have been published on the production of seedlings and plants from various native species, including: Baobab native to Africa (Salami et al., 2020); Austrian pine (*Pinus nigra*), Scottish pine (*Pinus sylvestris*), and Maritime pine (*Pinus pinaster*) native to Europe (Kolevska et al., 2020); Canafistula (*Peltophorum dubim*) native to America (Massad et al., 2017); and red seed tree (*Ormosia hosieii*), Zhejiang phoebe (*Phoebe chekiangensis*), Zhejiang camphor (*Cinnamomum japonicum*), and red bark oak (*Cyclobalanopsis gilva*) native to Asia (Chu et al., 2020).

Certain species, such as guanandi (*Calophyllum brasiliense*), which naturally occurs in Central and South America and jequitibá-branco (*Cariniana estrellensis*), which is recommended for riparian forest restoration in Brazil, have significant potential in reforestation programs (M. L. F. Andrade & Boaretto, 2019; Silva et al., 2020). In particular, guanandi holds economic value for civil construction, carpentry, and shipbuilding in Brazil (Sousa et al., 2021).

Recognizing the importance of tree species reinforces the need for suitable seedlings capable of withstanding adverse field conditions (Di Sacco et al., 2021). The establishment and development of trees with beneficial characteristics begins with an understanding of the species and production of high-quality seedlings for transplantation. The volume and shape of the container directly influence nutrient and water availability, thereby affecting seedling quality. Larger container volumes facilitate a better root system architecture (Schorn et al., 2019). However, the use of larger containers significantly increases the production, maintenance, and distribution costs (Marco et al., 2019). Conversely, reducing container volume while fulfilling the minimum threshold promotes root system differentiation, increases the number of radicles and absorbent hairs, and improves nutrient uptake (Araújo et al., 2018).

Despite the extensive literature on seedling production, few studies have addressed the fundamental question of determining the optimal container volume for native forest seedling production. Therefore, this study aimed to evaluate the effects of container volume on the growth and quality of *C. brasiliense* and *C. estrellensis* seedlings.

Materials and Methods

Experimental area

The research was conducted in an open-air commercial nursery located in the coastal region of southern Bahia, with an average altitude of 18.9 m, on the border between the municipalities of Teixeira de Freitas and Caravelas (17°31'08" S and 39°44'30" W). The climate of this region, classified as type "Af" according to Köppen, is characterized as hot climate. The region experiences well-distributed rainfall throughout the year, with a historical annual average of 1,411 mm and average annual temperature of 23.1 °C (Instituto Nacional de Meteorologia [INMET], 2023). According to Almeida et al. (2020), this region belongs to the Atlantic Forest biome and has vegetation typical of dense rainforests.

Collection and storage of seeds, sowing, pricking, and transplanting

Seeds of the two study species were collected based on their fruiting and maturation periods, considering the autecology of each species. The mother trees used to obtain seeds were located in the remnants of the Atlantic Tropical Forest in the coastal region of southern Bahia.

Upon their removal from the fruits, the seeds were kept at ambient temperature and protected from direct sunlight for 72 h. Subsequently, the seeds were stored in a plastic bag in a cold chamber at 10 ± 1 °C and $75 \pm 3\%$ relative humidity. For the seedbed, sowing was performed on a 0.20-m layer of coarse sand. *C. brasiliense*

(guanandi) and *C. estrellensis* (jequitibá-branco) were sown under complete sunlight conditions at a density of 2.5 kg m⁻² and 1.5 kg m⁻², respectively. Seedbeds were used for germination and subsequent transplantation because of the common non-uniformity of germination among native forest species.

After sowing, the seedlings were carefully removed and stored in containers containing water to prevent wilting until transplantation. Root pruning was performed on the seedlings. Seedlings of both species were transplanted from the sowing site into containers based on the emergence of the first pair of cotyledonary leaves. Seedlings of similar height and stem diameter were standardized for each species. Only plants with good phytosanitary and physical properties were selected for transplantation.

Experimental design, containers, and substrate

The experimental design was a randomized block, with treatments consisting of five volumes of containers (53-, 115-, 180-, and 280-cm³ tubes and a 560 cm³-polyethylene bag) arranged in four replicates with 54 plants per plot. Owing to the autecology of each species, experiments were conducted separately for each species. The containers used in this study were identical to those employed for the commercial production of native forest species (Andrade et al., 2021; Marco et al., 2019). Details regarding the specific characteristics of these containers are provided in Table 1 and visual representation is provided in Figure 1.

Table 1
Treatments based on the volumetric capacity of the containers

Treatment	Container	Format	Height (cm)	Upper Diameter (mm)	Bottom diameter (mm)	number of stretch marks	Volume (cm ³)
T1	tube	Conical	12	28	12	4	53
T2	tube	Conical	16	38	15	4	115
T3	tube	Conical	15	52	13	4	180
T4	tube	Conical	20	52	13	4	280
T5	polyethylene bag	Cylindrical	18	60	60	0	560



Figure 1. Containers used in this study.

The commercial substrate Mecplant Forestal was used in this study. To ensure consistency, the substrates were sieved and homogenized. The containers were filled on a

vibrating table. The chemical characterization of the substrate was conducted prior to the incorporation of the base fertilizer (Table 2).

Table 2
Chemical characterization of Mecplant Florestal substrate

Unit	Elements										
	N g kg ⁻¹	P mg dm ⁻³	K	Ca Cmol _c Kg ⁻¹	Mg	S	B	Fe mg dm ⁻³	Cu	Mn	Zn
Substrate	7,40	209	490	3,0	2,9	81	0,3	202	0,8	40	7,2

Experiment management

For irrigation purposes, a micro-sprinkler system with a flow rate of 420 L h⁻¹ was used. Fertilization practices was conducted according to the chemical analysis of the substrate used and the individual requirements of the plants, following the fertilization routine employed by commercial nurseries (Dias, 2011).

The plants were cultivated for 150 d and divided into the following three sectors. In the initial sector (the rooting sector), plants were kept in a greenhouse for 20 d, with 50% shade cover on the roof and sides. Following this, *C. brasiliense* plants were kept in the growth sector for 45 d, whereas *C. estrellensis* plants were kept there for 75 d. During this stage, the plants were maintained under 50% shade until they reached a height of approximately 15.0 cm and diameter of approximately 3.0 mm. The plants were then moved to the hardening sector, where they were exposed to sunlight and irrigation for 15–20 min, depending on the prevailing weather conditions. The duration of the hardening phase was 85 and 55 d for *C. brasiliense* and *C. estrellensis*, respectively, until they reached a height of >20 cm and a stem diameter of >4 mm (Gomes et al., 2003). Variations in the duration of stay in the nursery sector for each species were

attributed to their unique growth patterns and physiological characteristics.

Evaluation of seedling growth

Seedling growth was assessed on the basis of biometric and morphological variables, dry biomass production, and other indices. The plant height and stem diameter of 15 central plants randomly selected from each plot were evaluated at 30, 60, 90, 120, and 150 d after transplantation. The transplantation event marked the starting point for practical purposes and an evaluation was conducted during this period. Height was measured in centimeters using a graduated ruler positioned between the substrate level and the apical meristem of the plant. The collar diameter was measured in millimeters using a graduated digital caliper and analyzed at the substrate edge following the methodologies employed by Sá et al. (2023) and Tumpa et al. (2021).

On day 150 post-transplantation, the same 15 plants from each plot were sectioned at the height of the stem, and their leaf areas were determined using a digital image processor (CI-203CA, Laser Leaf Area Meter; CID Bioscience, Camas, WA, USA). The substrate was removed from the container and sieved using two overlapping 1-mm

sieves to separate the roots, which were then thoroughly washed to remove the substrate without damaging the roots. Both the aerial parts (leaves and stem) and root system were dried in an oven with forced air circulation at 70 °C, until they reached a constant mass.

The total dry biomass (TDB) was calculated by summing the aboveground and root dry biomass values. The ratio of aboveground to root dry biomasses (ADB/RDB) was also determined. The shoot height-to-stem diameter (H/SD) ratio was calculated and the Dickson quality index (DQI) was determined based on these morphological relationships (Dickson et al., 1960). DQI was derived from the ratio of total dry biomass (TDB) to the sum of two ratios: shoot height (H) to stem diameter (SD) and aerial dry biomass (ADB) to root dry biomass (RDB).

$$DQI = \frac{TDB \text{ (g)}}{[H \text{ (cm)}/SD \text{ (mm)}] + [ADB \text{ (g)}/RDB \text{ (g)}]}$$

Statistical analysis

The collected results were subjected to analysis of variance (ANOVA) using the F-test at significance levels of 1% and 5%. Mean values were compared using Tukey's test at a significance level of 5%. All statistical tests were performed using the R software (version 4.2.1; R Core Team, Vienna, Austria) (R Core Team [R], 2023).

Results and Discussion

Container volume influenced the growth of *C. brasiliense* (guanandi) seedlings in terms of H, SD, and H/SD ratios during most of the evaluated period. Only SD at 30 d and H/SD at 30 and 90 d did not show significant differences among the mean values of the treatments (Table 3).

On the evaluation dates, when significant differences were observed, higher mean values were observed among treatments with larger container volumes (180, 280, and 560 cm³). During evaluation at 30 d only, the plants grown in the 560-cm³ plastic bags showed the lowest H values in comparison to the other treatments. In later evaluations, the highest averages corresponded to the largest recipients. The highest H values corresponded to tubes of 115, 180, and 280 cm³ volume and the plastic bag of 560 cm³ volume after 150 d of capping, with no differences among the mean values of these treatments.

The reduction in shoot development rate at 150 d, compared to 120 d, resulted in a minor increase in H values, mainly in seedlings grown in smaller containers, due to root development and the limited amount of available substrate, providing less nutrients for development; in other words, there was less room for root growth in the final 30 d, which affected seedling growth.

Table 3
Shoot height (H, cm), stem diameter (SD, mm), and height/stem diameter ratio (H/SD) of *C. brasiliense* (guanandi) seedlings, as a function of container volumes, throughout their growth in the nursery

Variables Biometrics	Container volume(cm ³)					ANOVA	
	53	115	180	280	560	Fc (5%)	CV(%)
30 days ¹							
H (cm)	15,11ab	15,20ab	16,03a	16,76a	14,07b	7,67*	4,75
SD (mm)	2,85a	2,73a	2,84a	3,01a	2,66a	2,12	6,63
H/SD	5,35a	5,57a	5,63a	5,56a	5,30a	0,92	5,66
60 days							
H (cm)	19,88b	20,51ab	21,55ab	21,92a	20,37ab	3,64*	4,29
SD (mm)	3,30a	3,34a	3,46a	3,53a	3,00b	9,40*	3,96
H/SD	6,02b	6,14b	6,21b	6,22b	6,79a	8,14*	3,32
90 days							
H (cm)	23,41c	24,37bc	25,43abc	26,18ab	26,92a	7,15*	4,14
SD (mm)	3,67b	3,68b	3,94ab	4,05a	3,87ab	4,54*	4,06
H/SD	6,41a	6,63a	6,45a	6,47a	6,95a	1,64	5,32
120 days							
H (cm)	28,06c	32,97b	34,14b	34,89ab	37,82a	19,14*	4,68
SD (mm)	4,07c	4,29bc	4,71ab	4,91a	4,87a	14,22*	4,29
H/SD	6,90b	7,69ab	7,25ab	7,10ab	7,77a	5,29*	4,49
150 days							
H (cm)	28,4b	33,74ab	35,36a	35,39a	40,07a	8,04*	8,55
SD (mm)	4,52b	4,69b	5,19ab	4,98ab	5,67a	6,87*	6,84
H/SD	6,31b	7,18a	6,82ab	7,08a	7,07a	4,96*	4,59

Mean values followed by the same letter in the lines do not differ significantly according to Tukey's test at 5% probability level. ¹days after capping.

* indicates the significance of the variables at the 5% level.

The volume of the container also affected the growth of *C. estrellensis* seedlings, which differed among treatments. No differences were noted between the mean values of the treatments for H at 30 d and H/SD at 60 d (Table 4). On day 30 no statistically significant difference was observed in the H variable, indicating that the treatments had similar mean values despite the different container volume. However, the other

variables showed significant differences among treatments. During subsequent evaluations, the highest mean values were consistently recorded in the containers with the largest volumes. At day 150, the highest mean values were obtained for the 560-cm³ treatment, followed by the 280-cm³ treatment, which did not significantly differ from the 53- and 115-cm³ treatments, except for the H/SD ratio.

Table 4

Shoot height (H, cm), stem diameter (SD, mm), and height/stem diameter ratio (H/SD) of *Cariniana estrellensis* (Jequitibá-Branco) seedlings as a function of container volumes, throughout their growth in the nursery

Variables Biometrics	Container volume(cm ³)					ANOVA	
	53	115	180	280	560	Fc (5%)	CV(%)
30 days ¹							
H (cm)	6,19a	6,26a	6,01a	5,98a	6,36a	1,15	4,92
SD (mm)	2,00b	2,09ab	2,17a	2,14a	2,13ab	4,95*	2,73
H/SD	3,09a	2,99ab	2,78b	2,79b	2,99ab	5,19*	4,13
60 days							
H (cm)	8,72b	9,01ab	9,23ab	10,26ab	10,49a	4,86*	7,44
SD (mm)	2,61b	2,86a	2,93a	3,02a	3,04a	12,05*	3,43
H/SD	3,34a	3,16a	3,15a	3,39a	3,45a	2,75	5,03
90 days							
H (cm)	13,08d	15,77cd	16,51c	22,77b	26,82a	71,38*	7,02
SD (mm)	3,43d	3,80c	4,12bc	4,49a	4,26ab	29,07*	3,79
H/SD	3,81c	4,16c	4,01c	5,08b	6,30a	33,02*	7,71
120 days							
H (cm)	16,38d	22,66c	22,11c	29,81b	38,49a	128,77*	5,79
SD (mm)	3,99c	4,30c	4,92b	5,18ab	5,52a	54,15*	3,58
H/SD	4,09c	5,28b	4,50c	5,75b	6,98a	70,14*	5,09
150 days							
H (cm)	23,48c	27,05c	27,48c	36,98b	53,33a	68,10*	8,70
SD (mm)	4,43e	4,97d	5,61c	6,20b	6,68a	146,8*	2,69
H/SD	5,40bc	5,44bc	4,90c	5,97b	7,98a	27,35*	7,84

Mean values followed by the same letter in the lines do not differ significantly according to Tukey's test at 5% probability level. ¹days after capping.

* indicates the significance of the variables at the 5% level.

In a previous study, seedlings of *Urundeuva* (*Myracrodruon urundeuva*), a native forest species in Brazil, produced in 180- and 280-cm³ tubes showed higher average growth values than those observed in the 55-cm³ tube (Freitas et al., 2022). Similarly, in a study by Freitas et al. (2021) on the production of *Senegalia bahiensis* seedlings, greater height and stem diameter growth were observed in larger-volume

tubes. This was attributed to the greater container volume, which imposed less restriction on root growth.

In a study by Lima et al. (2019) on the production of *Ceiba spenchirosa* seedlings, greater height and diameter values were observed on day 93 for plants produced in 280-cm³ containers than those produced in 55-, 110-, and 180-cm³ containers. They

attributed this finding to the larger volume of substrate, which provided greater nutrient and organic matter availability.

In the present study, at day 150, although all tube containers had a diameter >3.5 mm, considered adequate for planting native plants (Silva et al., 2022), the plastic bag, followed by the 280- and 180-cm³ tubes, showed the best results for *C. brasiliense*, although no statistical differences were observed among the three. For *C. estrellensis*, the 560-cm³ plastic bag container presented the highest average among all treatments.

Lima et al. (2019) evaluated the effect of tube size on the quality of *C. spenciosa* seedlings, and found similar diameter results, with the highest mean values observed in larger containers. Stem diameter is one of the main indicators of seedling quality (Ivetic et al., 2013; Montoya et al., 2022; Perumal et al., 2021; Tumpa et al., 2021) and is widely used due to its correlation with other morphological characteristics (Ivetic et al., 2013).

Similar results to the present study were reported by Aguilar et al. (2020) for shoot height, stem diameter, and stem height/diameter ratio, with higher averages in seedlings produced in larger volume containers (280- and 180-cm³ tubes) when compared to the smallest container (55-cm³).

The H/SD ratio represents the robustness index, which is related to the development of the apical and secondary meristems responsible for stem robustness and thickening (Mata et al., 2019). The H/SD ratio of *C. brasiliense* on day 150 showed the highest mean values for treatments with the larger container volumes of 115-, 180-, 280- and 560-cm³, which did not differ significantly, with averages ranging from 6.82–7.18. For *C. estrellensis*, the highest average H/SD corresponded to the 560-cm³ treatment (average = 7.98), whereas the 53-, 115-, and 180-cm³ treatments had lower values, ranging from 4.90 to 5.44 on average. The suitable range for forest species is typically 5.4 to 8.1 (Carneiro et al., 1995), indicating that the seedlings grow proportionally in terms of aerial height and stem diameter thickening.

When comparing the growth based on the H/SD ratio of *C. brasiliense*, a decline was observed for all treatments from day 120 onward (Figure 2). This is attributed to the greater increase in SD on day 150 compared to the H values. However, the obtained H/SD values indicated that the seedlings met acceptable quality standards and aligned with the values reported in the literature for comparison.

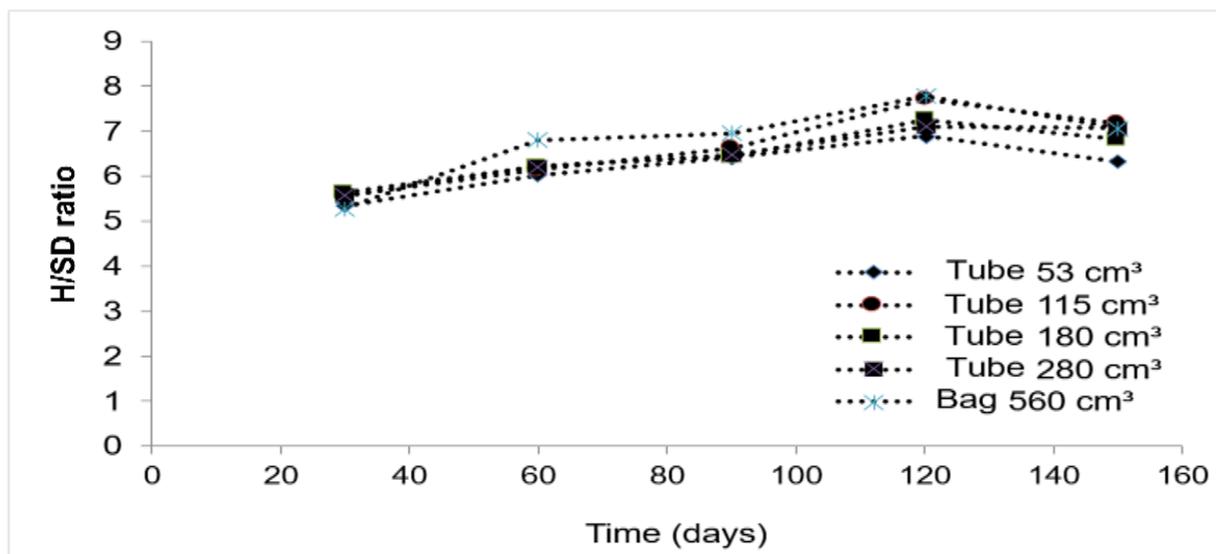


Figure 2. Height/stem diameter (H/SD) ratio of *C. brasiliense* (guanandi) seedlings over the evaluation period.

Regarding *C. estrellensis*, the seedlings produced in all treatments showed linear development for the H/SD variable. This is attributed to the continuous increase in the studied variables over time, with the highest values observed on day 150 (Figure

3). The reduction in the H/SD ratio indicated that, during this period, the stem diameter increased to a greater extent than the height of the aerial part. In other words, plants initiated stem thickening and reached a stable stem elongation phase.

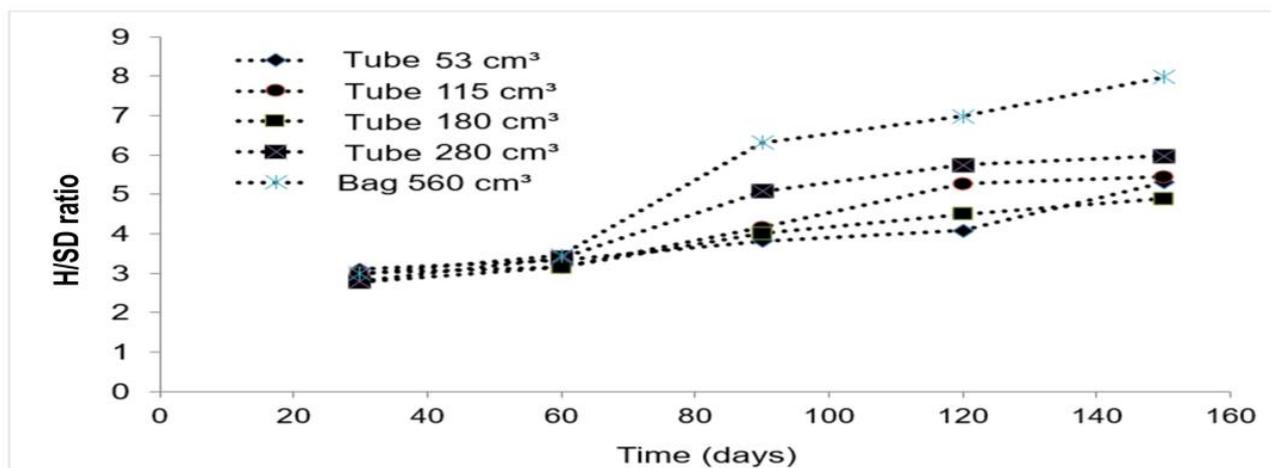


Figure 3. Relationship between height and stem diameter of *C. estrellensis* (Jequitibá-Branco) seedlings during the evaluation period.

Seedlings of forest species must have a diameter of >3.5 mm for field planting (Silva et al., 2022). At 90 and 120 d after capping, the *C. brasiliense* and *C. estrellensis* seedlings presented suitable characteristics for planting; the roots had not yet established a stable attachment to the substrate, which is crucial for maintaining seedling quality during the planting and transportation processes (Silva et al., 2020).

The results for ADB, RDB, TDB, LA, and DQI on day 150 after capping of *C. brasiliense* did not differ among the 180-, 280-, and 560-cm³ containers (Table 5). The 53- and 115-cm³ containers had the lowest averages for these parameters, however, did not show statistical differences, and the 115-cm³ tube did not significantly differ from the 180-cm³ tube. The ADB/RDB ratio did not show significant differences among the mean values of the *C. brasiliense* seedlings across all containers (Table 5).

Table 5
Aerial (ADB, g), root (RDB, g), and total (TDB, g) dry biomass; leaf area (LA, cm²); aerial/root dry biomass ratio (ADB/RDB); and Dickson quality index (DQI) of *Calophyllum brasiliense* (Guanandi) seedlings at 150 d

Dry biomass(g)	Container volume(cm ³)					ANOVA	
	53	115	180	280	560	Fc (5%)	CV(%)
Aerial	1,89c	2,53bc	3,13ab	2,78abc	3,75a	7,5*	17,90
Root	0,75c	0,94bc	1,16ab	1,19ab	1,47a	12,94*	13,68
Total	2,65c	3,47bc	4,29ab	3,97abc	5,22a	8,84*	16,40
LA(cm ²)	115,80c	161,42bc	162,64abc	192,56ab	245,69a	8,13*	18,47
Morphological Indices							
ADB/RDB	2,52a	2,71a	2,71a	2,32a	2,55a	2,29	8,45
DQI	0,30c	0,35bc	0,45ab	0,42abc	0,54a	10,11*	14,16

Mean values followed by the same letter in the lines do not differ significantly according to Tukey's test at 5% probability level.

* indicates the significance of the variables at the 5% level.

For *C. estrellensis*, statistical analyses revealed significant differences among the treatments in terms of ADB, RDB, TDB, LA, and morphological indices. In most cases, the 560-cm³ container presented the highest average values (Table 6). However, for root

dry biomass and the morphological index DQI, the 560-cm³ container did achieve the highest averages but maintained the second highest average among the treatments (Table 6).

Table 6

Aerial (ADB, g), root (RDB, g), and total (TDB, g) dry biomass; leaf area (LA, cm²); aerial/root dry biomass ratio (ADB/RDB); and Dickson quality index (DQI) of *Cariniana estrellensis* (Jequitibá-Branco) seedlings at 150 d

Dry biomass(g)	Container volume(cm ³)					ANOVA	
	53	115	180	280	560	Fc (5%)	CV(%)
Aerial	1,38d	2,14cd	2,39c	3,71b	6,81a	113,84*	12,23
Root	0,98e	1,56d	1,97c	2,78a	2,40b	99,02*	7,31
Total	2,36d	3,70c	4,35c	6,49b	9,21a	123,31*	9,26
LA (cm ²)	172,38c	233,50c	225,99c	372,24b	683,76a	56,47*	16,33
Morphological Indices							
ADB/RDB	1,40b	1,38b	1,22b	1,34b	2,83a	90,67*	8,65
DQI	0,35d	0,55c	0,71b	0,89a	0,86ab	43,80*	10,10

Mean values followed by the same letter in the lines do not differ significantly according to Tukey's test at 5% probability level.

* indicates the significance of the variables at the 5% level.

Similar results were reported by Freitas et al. (2021), who observed higher shoot and stem dry biomass values in seedlings produced in 280-cm³ tubes compared than in those produced in 55- and 180-cm³ tubes, with the 55-cm³ tubes having the lowest mean value for this parameter.

Higher values for the Dickson quality index were reported by Bantis et al. (2019) for seedlings produced in containers of different volumes (820-, 290- and 120-cm³), indicating that tube capacity influences this variable. Higher index values indicated better seedling quality (Bantis et al., 2019; Begum et al., 2021).

At the end of the production cycle (day 150), all seedlings cultivated in tubes showed suitable characteristics for native forest species; however, the seedlings produced in 560-cm³ plastic bags showed visible signs of coiling, bending, and strangulation of the pivoting root (Figure 4), which is undesirable for seedling development (Mosquera-Espinosa et al., 2022; Vargas et al., 2011). Additionally, more time was required for the root system to adequately integrate with the substrate. A growing trend to replace plastic bags with rigid plastic tubes has emerged because of their ease of handling in both nurseries and the field, as well as their reduced risk of root system damage (Alves et al., 2020).

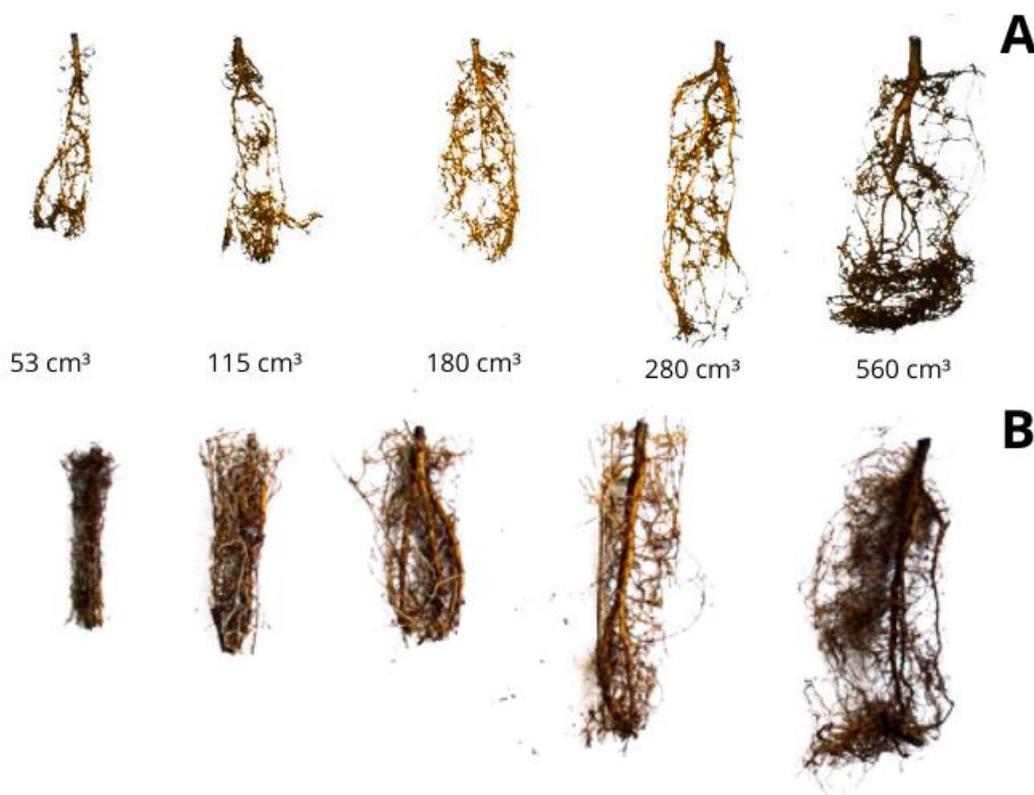


Figure 4. Root development in *C. estrellensis* (A) and *C. brasiliense* (B) at day 150 in different volumes of containers.

Tubes offer various advantages, such as efficient space usage in the nursery, easier handling and transport, and the potential for reuse, which significantly reduces costs (Freitas et al., 2022; Haase et al., 2021). According to Haase et al. (2021) and Silva et al. (2022), the use of tubes as containers is a key factor in driving commercial forestry and greatly contributes to the production of native species seedlings.

Although the 560-cm³ plastic bag container yielded the best results for the majority of the analyzed variables in the study, practical and operational considerations regarding root development problems recommend using 180- and 280-cm³ tubes for both species studied.

Conclusions

C. brasiliense (guanandi) did not exhibit a statistically significant difference between the tubes of 180 and 280 cm³ and plastic bags of 560 cm³ in terms of biomass and morphological indices.

For *C. estrellensis* (jequitibá-branco), the highest mean values were observed in the 560-cm³ plastic bag, except for root dry biomass and Dickson's quality index, where the 280-cm³ tube demonstrated better results.

Seedlings of both species displayed folding, bending, and strangulation of the pivoting root when grown in 560-cm³ plastic

bags. Furthermore, these seedlings required a longer time for the root system to integrate properly with the substrate.

For *C. brasiliense*, the 180- and 280-cm³ tubes showed similar results; therefore, the 180-cm³ container is recommended because of its smaller space requirements and reduced substrate costs. For *C. estrellensis*, the 280-cm³ tube is recommended. The selected tube sizes yielded significant results for morphological characteristics associated with seedling quality and met the standards required for seedlings in silviculture.

Acknowledgments

The authors declare financial support was received for the research, authorship, and/or publication of this article.

This study was financed in part by the Fundação de Apoio à Pesquisa e Inovação do Espírito Santo - Brasil (FAPES), Finance Code 2022-4KDSG.

References

- Acevedo, M., Álvarez-Maldini, C., Dumroese, R. K., Bannister, J. R., Cartes, E., & González, M. (2021). Native plant production in Chile. Is it possible to achieve restoration goals by 2035? *Land*, 10(1), 1-11. doi: 10.3390/land10010071
- Aghai, M. M., Pinto, J. P., & Davis, A. S. (2014). Container volume and growing density influence western larch (*Larix occidentalis* Nutt.) seedling development during nursery culture and establishment. *New Forest*, 45(2), 199-213. doi: 10.1007/s11056-013-9402-8
- Aguilar, M. V. M., Massad, M. D., Dutra, T. R., Silva, F. G., Menezes, E. S., & Santos, A. R. (2020). Development of baru seedlings in response to different volumes of tubes and doses of slow release fertilizer. *Caderno de Ciências Agrárias*, 12(2), 1-10. doi: 10.35699/2447-6218.2020.25629
- Almeida, P. F., Silva, J. B. L., & Neves, F. M. (2020). Environmental vulnerability of the municipality of Teixeira de Freitas-BA. *Revista Brasileira Geografia Física*, 13(4), 1587-1609. doi: 10.26848/rbgf.v13.4.p1587-1609
- Alves, M. V., Naibo, G., Sbruzz, E. K., Machado, J. da S. & Nesi, C. N. (2020). Soil Fauna in Different Land Uses. *Acta Biológica Catarinense*. 7(1), 37-45. doi: 10.21726/abc.v7i1.159
- Andrade, C. R., Melo, B. M. R., Mendes, C. T. E., Castro, D. G., Coelho, E. L., & Francisco, K. C. P. (2021). Growth and quality of seedlings of different coffee cultivars under different substrates and containers. *Research, Society and Development*, 10(2), 1-16. doi: 10.33448/rsd-v10i2.12073
- Andrade, M. L. F., & Boaretto, A. E. (2019). Macronutrient deficiency in *Cariniana estrellensis* (Raddi) Kintze. *Ciência Florestal*, 29(2), 811-823. doi: 10.5902/198050986099
- Araújo, M. M., Navroski, M. C., Schorn, L. A., Tabaldi, L. A., Rorato, D. G., Turchetto, F., Zavistanovicz, T. C., Berghetti, A. L. P., Aimi S. C., Tonetto, T. S., Gasparin, E., Dutra, A. F., Mezzomo, J. C., Gomes, D. R., Griebeler, A. M., Silva, M. R., Barbosa, F. M., & Lima, M. S. (2018). Characterization and analysis of morphological and

- physiological attributes that indicate the quality of seedlings in a forest nursery. In M. M. Araújo, M. C. Navroski, & L. A. Schorn (Eds.), *Production of seeds and seedlings: a focus on forestry* (pp. 345-382). Santa Maria, RS.
- Bantis, F., Koukounaras, A., Siomos, A., Menexes, G., Dangitsis, C., & Kintzonidis, D. (2019). Assessing quantitative criteria for characterization of quality categories for grafted watermelon seedlings. *Horticulturae*, 5(1), 1-10. doi: 10.3390/horticulturae5010016
- Begum, N., Chowdhury, G. M., & Muhammad, A. H. (2021). The selection of nursery polybag size on effect of growth and quality of *Khaya Anthotheca* (Meliaceae) seedlings under nursery condition in Bangladesh. *Journal of Forest and Environment Science*, 37(2), 141-147. doi: 10.7747/JFES.2021.37.2.141
- Carneiro, J. G. A. (1995). *Produção e controle de qualidade de mudas florestais*. Curitiba.
- Chu, X., Wang, X., Zhang, D., Wu, X., & Zhou, Z. (2020). Effects of fertilization and container-type on nutrient uptake and utilization by four subtropical tree seedlings. *Journal of Forestry Research*, 31(4), 1201-1213. doi: 10.1007/s11676-019-01070-0
- Di Sacco, A., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Cecilio, R. L., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G., Shaw, K., Smith, P., Smith, R. J., & Antonelli, A. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. *Global Change Biology*, 27(7), 1328-1348. doi: 10.1111/gcb.15498
- Dias, T. F. (2011). *Assessment of the development and morphological indices of native forest species seedlings in different container volumes*. Universidade Federal do Espírito Santo.
- Dickson, A., Leaf, A. L., & Hosner, J. F. (1960). Quality appraisal of white spruce and white pine seedling stock in nurseries. *Forestry Chronicle*, 36(1), 10-13. doi: 10.5558/tfc36010-1
- Freitas, T. A. S., Lopes, E. C. S., Araujo, J. F. G., Santos, L. B., & Mendonça, A. V. R. (2021). Seedling productions of *Senegalia bahiensis* Benth. in different volumes of tubes. *Ciência Florestal*, 31(3), 1105-1123. doi: 10.5902/1980509829783
- Freitas, T. A. S., Oliveira, M. F., Souza, L. S., Dias, C. N., & Quintela, M. (2022). Seedling qualities of *Myracrodruon urundeuva* Fr. All. conducted under different volumes of containers. *Ciência Florestal*, 32(1), 19-42. doi: 10.5902/1980509837445
- Gomes, J. M., Couto, L., Leite, H. G., Xavier, A., & Garcia, S. L. R. (2003). Growth of *Eucalyptus grandis* seedlings produced in different sized tubes and n-p-k fertilization. *Revista Árvore*, 27(2), 113-127. doi: 10.1590/S0100-67622003000200001
- Haase, D. L., Bouzza, K., Emerton, L., Friday, J. B., Lieberg, B., Aldrete, A., & Davis, A. S. (2021). The high cost of the low-cost polybag system: a review of nursery seedling production systems. *Land*, 10(8), 1-19. doi: 10.3390/land10080826
- Instituto Nacional de Meteorologia (2003). *Normas Climatológicas do Brasil* (1991 - 2020). INMET. <https://portal.inmet.gov.br/normais>

- Ivetic, V., Davorija, Z., & Vilotic, D. (2013). Relationship between morphological and physiological attributes of hop hornbeam seedlings. *Glasnik Sumarskog Fakulteta*, 2023(108), 39-50. doi: 10.2298/gsf1308039i
- Kolevska, D. D., Dimitrova, A., Cokoski, K., & Basova, M. (2020). Growth and quality of *Pinus nigra* (Arn.), *Pinus sylvestris* (L.) and *Pinus pinaster* (Aiton) seedlings in two container types. *Reforesta*, 5(9), 21-36. doi: 10.21750/REFOR.9.04.78
- Landhäuser, S. M., Pinno, B. D., & Mock, K. E. (2019). Tamm review: seedling-based ecology, management, and restoration in aspen (*Populus tremuloides*). *Forest Ecology and Management*, 432(2), 231-245. doi: 10.1016/j.foreco.2018.09.024
- Lima, P., F^o., Leles, P. S. D. S., Abreu, A. H. M., Silva, E. V., & Fonseca, A. C. (2019). Seedling production of *Ceiba speciosa* in different volume of tubes using biosolids as substrate. *Ciência Florestal*, 29(1), 27-39. doi: 10.5902/1980509819340
- Marco, R., Conte, B., & Perrando, B. (2019). Container sizes and doses of slow release fertilizer in the production of *Toona ciliata* seedlings. *Revista do Instituto Florestal*, 31(2), 109-117. doi: 10.24278/2178-5031.201931202
- Massad, M. D., Dutra, T. R., Meireles, I. E. S., Sarmiento, M. F. Q., Santos, A. R., & Menezes, E. S. (2017). *Canafístula* growth evaluation in different seedlings density per tray and tube volumes. *Enelo*, 5(1), 1-9. doi: 10.5902/2316980X24661
- Mata, G. A., Castro, R. V. O., Dias, B. A. S., & Castro, A. F. N. M. (2019). Age for dispatch of eucalyptus clonal seedlings depending on non-destructive morphological variables. *Advances in Forestry Science*, 6(4), 797-802. doi: 10.34062/afs.v6i4.8431
- Melo, L. A., Abreu, A. H. M., Leles, P. S. S., Oliveira, R. R., & Silva, D. T. (2018). Qualidade e crescimento inicial de mudas de *Mimosa caesalpinifolia* Benth produzidas em diferentes volumes de recipientes. *Ciência Florestal*, 28(1), 47-55. doi: 5902/1980509831574
- Montoya, A. B., Rodríguez, E. A., Rodríguez, J. A. S., García, J. E. S., & Carranza, L. D. R. (2022). Evaluation of substrates and treatments for water stress mitigation in an *Enterolobium cyclocarpum* (Jacq.) Griseb. plantation. *Revista Mexicana de Ciencias Forestales*, 13(74), 77-96. doi: 10.29298/rmcf.v13i74.1272
- Mosquera-Espinosa, A. T., Bonilla-Monar, A., Flanagan, N. S., Rivas, A., Sánchez, F., Chavarriaga, P., Bedoya, A., & Riascos-Ortiz, D. (2022). In vitro evaluation of the development of fusarium in vanilla accessions. *Agronomy*, 12(11), 1-15. doi: 10.3390/agronomy12112831
- Oliveira, A. C. C., Forti, V. A., Loiola, P. P., & Viani, R. A. G. (2019). Techniques for seedling production of two native grasses: new perspectives for Brazilian Cerrado restoration. *Restoration Ecology*, 28(2), 297-303. doi: 10.1111/rec.13103
- Perumal, M., Wasli, M. E., & Ho, S. Y. (2021). Outplanting performance of the Bornean tropical indigenous species *Shorea macrophylla* (de Vriese) P. S. Ashton in relation to seedling age. *International Journal of Forestry Research*, 2021(1), 1-12. doi: 10.1155/2021/8859205

- R Core Team (2023). *R: A language and environment for statistical computing (version 4.2)*. R Foundation for Statistical Computing.
- Sá, L. C., Lazarotto, M., Avrella, E. D., Hilgert, M. A., & Fior, C. S. (2023). Water and saline stress on initial growth of *Toona ciliata* var. *australis* seedlings. *Pesquisa Florestal Brasileira*, 43(2), 1-11. doi: 10.4336/2023.pfb.43e202002108
- Salami, K. D., Akinyele, A. O., & Folurunso, W. O. (2020). Effect of pre-treatments, inorganic fertilizer and varying soil volumes on the early growth performance of *Adansonia digitata* (linn) baobab. *Nigeria Journal of Horticultural Science, Horticulture, Society of Nigeria*, 25(1), 1-16. <https://hortson.org.ng/index.php/publications/journals/salami-et-al-2020>
- Schorn, L. A., Pandini, G., Bittencourt, R., & Fenilli, T. A. B. (2019). Definition of optimal ages for shipping *Araucaria angustifolia* (Bertol.)Kuntze(Araucariaceae)seedlings depending on their quality and volume of containers. *Biotemas*, 32(4), 19-27. doi: 10.5007/2175-7925.2019v32n4p19
- Silva, O. M. C., Hernández, M. M., Araújo, G. C. R., Cunha, F. L., Evangelista, D. V. P., Leles, P. S. S., & Melo, L. A. (2020). Potential use of coffee husk as a substrate constituent for the production of forest species seedlings. *Ciência Florestal*, 30(4), 1161-1175. doi: 10.5902/1980509842500
- Silva, O. M. C., Nieri, E. M., Santana, L. S., Almeida, R. S., Araújo, G. C. R., Botelho, S. A., & Melo, L. A. (2022). Phosphate fertilization in the initial growth of seven native forest species intended for the recovery of a degraded area. *Ciência Florestal*, 32(1), 371-394. doi: 10.5902/1980509861339
- SOS Mata Atlântica (2023). *Relatório Anual*. Itu, SP.
- Sousa, E. F., Ferreira, A. C. C., Menezes, M. S., & Simões, E. P. (2021). Macroscopic characterization of the wood of two species sold in the municipality of Itacoatiara-Am. In W. V. Vangelista, (Ed.), *Native and planted wood from Brazil: quality research and current affairs* (pp. 244-254). Guarujá, SP.
- Stanfurt, J. A., Palik, B. J., & Dumroese, R. (2014). Contemporary forest restoration: a review emphasizing function. *Forest Ecology and Management*, 331(2), 292-323. doi: 10.1016/j.foreco.2014.07.029
- Tumpa, K., Vidaković, A., Drvodelić, D., Šango, M., Idžojić, M., Perković, I., & Poljak, I. (2021). The effect of seed size on germination and seedling growth in sweet chestnut (*Castanea sativa* mill.). *Forests*, 12(7), 1-11. doi: 10.3390/f12070858
- Vargas, F. S., Rebechi, R. J., Amândio, S. L., & Bergamo, F. T. A. (2011). Effect of changes in seeding container on the quality of seedlings of *Cassia leptophylla* Vogel, *Eugenia involucrata* DC. and *Cedrela fissilis* Vell in nursery. *Revista Acadêmica Ciência Agrária e Ambiental*, 9(2), 169-177. doi: 10.7213/cienciaanimal.v9i2.11774
- Vloon, C. C., Evju, M., Klanderud, K., & Hagen, D. (2022). Alpine restoration: planting and seeding of native species facilitate vegetation recovery. *Restoration Ecology*, 30(1), 1-10. doi: 10.1111/rec.13479