ROOTS CHARACTERISTICS AND EFFECTS OF CONTAINERS ON THE QUALITY OF *TOONA CILIATA* M. ROEMER SEEDLINGS

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Resumo

Características radiciais e efeitos de recipientes na qualidade de mudas de Toona ciliata M. Roemer. Objetivou-se avaliar os efeitos de recipientes e características radiciais na qualidade de mudas de cedro australiano**.** A pesquisa foi desenvolvida em duas etapas, a primeira constou da produção das mudas no viveiro e avaliação dos parâmetros morfológicos, e a segunda consistiu na avaliação do potencial de regeneração de raízes. Foram cinco tratamentos envolvendo dois sistemas de produção de mudas, tubetes e sacolas plásticas: T1 – tubete (288 cm^3); T2 – tubete (120 cm^3); T3 - tubete (55 cm^3); T4 - sacolas plásticas (424 cm^3); e T5 - sacolas plásticas (216 cm^3). As sementes foram coletadas de uma árvore matriz situada no *Campus* da Universidade Estadual do Sudoeste da Bahia - UESB. O experimento foi instalado em delineamento inteiramente casualizado com quatros repetições. Avaliou-se os parâmetros morfológicos: a) altura da parte aérea (H); b) diâmetro de colo (D); c) biomassas frescas e seca das partes aérea e raiz; d) relações H/D, H/MSPA e MSPA/MSR; e) índice de qualidade dickson (IQD); e f) número total de raízes regeneradas e presentes nas partes superior e inferior de cada recipiente. Os resultados mostraram, que os tubetes com 288 cm^3 de capacidade volumétrica, produziram mudas com maiores médias para as características morfológicas e radiciais, constituindo o sistema de produção ideal para a produção de mudas de cedro australiano. Na ausência de tubetes com 288 cm^3, recomenda-se o uso de sacolas plásticas (424 cm^3) para essa espécie. O potencial de regeneração de raízes avaliado, demonstra ser um prognóstico positivo de rápido estabelecimento e desempenho das mudas no campo.
*Palavras-chave***:** Sacolas plásticas; tubetes; parâmetros morfológicos; potencial de regeneração de raízes.

Abstract

The objective was to evaluate the effects of recipients and root characteristics on the quality of Australian cedar seedlings. The research was carried out in two stages, the first consisted of seedling production in the nursery and evaluation of morphological parameters, and the second consisted of evaluating the potential for root regeneration. There were five treatments involving two production systems for seedlings, tubes, and plastic bags: T1 – tube (288 cm^3); T2 – tube (120 cm^3); T3 - tube (55 cm^3); T4 - plastic bags (424 cm^3); and T5 - plastic bags (216 cm^3). The seeds used are from a matrix tree located at the State University of Southwest Bahia. The design of the experiment was a completely randomized design with four replications. The morphological parameters evaluated were a) shoot height (H); b) neck diameter (D); c) fresh and dry biomass of shoots and roots; d) H/D, H/SDM, and shoot and root dry mass ratio (SDM/RDM); e) Dickson Quality Index (DQI), and f) the total number of regenerated roots present in the upper and lower parts of each container. The results showed that the tubes with 288 cm^3 of volumetric capacity produced seedlings with higher averages for the morphological and root characteristics, constituting the ideal production system for Australian cedar seedlings. In the absence of tubes with 288 cm^3, it is possible to use plastic bags (424 cm^3) for this species. The evaluated root regeneration potential proves to be a favorable prognosis of rapid establishment and performance of seedlings in the field.
Keywords: Plastic bags; tubes; root regeneration potential.

INTRODUCTION

Brazil is a world reference in the cultivation of trees for industrial purposes, and according to data from the IBGE (2019), the area occupied by planted forests today reaches about 10 million hectares. The demand to produce seedlings of commercial forest species has been increasing, with a growing trend, since Brazil voluntarily assumed national and international commitments to restore and reforest at least 12 million hectares of forests with native and exotic species until 2030 (ONU, 2015). However, most of the research related to forest seedlings in Brazil has focused on *Eucalyptus* and *Pinus*; intending to boost forest production, other species with proven timber potential have shown to be essential and promising to integrate industrial/ commercial plants, including Australian Cedar (*Toona ciliata* M. Roem var. australis). (MORETTI *et al.*, 2011).

Australian Cedar is a fast-growing species with strong timber potential, whose origins extend from India, Indonesia, Malaysia, Australia, the Pacific Islands to southern China (LI *et al.*, 2019). In Brazil, this species is mainly adapted to the edaphoclimatic conditions of the southeastern regions of Minas Gerais and southern Bahia. (ALMEIDA *et al.*, 2012). The use of high-quality seedlings is essential for profitable forest production because it reflects in more remarkable survival in the field, reducing the high costs generated with replanting, increasing the speed of establishment of the stand, reducing the frequency of cultural treatments (DIONISIO *et al.*, 2019). An essential factor in ensuring quality in seedling production is the containers' type, design, and size; these characteristics are important as they directly impact seedling quality and production costs.

Seedling quality standards vary by species, between species, and locations. The evaluation of these standards presupposes specific parameters and definition criteria. Morphological parameters are the most used to determine seedling quality indices due to the ease of measurement and visualization in nursery conditions. However, the physiological parameters, such as the potential for root regeneration, must be considered given the relevant information on their performance in the field regarding the percentage of survival and initial growth of the seedlings after planting, as observed in other species (BOMFIM *et al.*, 2009; NOVAES *et al.*, 2014). In this context, the objectives of this study were: 1) to determine the effects of two types of containers (tubes and plastic bags) of different volumes on the growth of Australian cedar (Toona Ciliata M. Roemer) seedlings, and 2) to Evaluate the Root Regeneration Potential - RRP of the seedlings in the nursery when they are sent to the field.

MATERIAL AND METHODS

Search location information

The research was carried out at the Forest Nursery and Forestry Laboratory of the State University of Southwest Bahia, located in the city of Vitória da Conquista - BA, located at the cartographic coordinates of 14º51' South latitude and 40º50' West longitude of Greenwich, with precipitation varying between 700 and 1,100 mm/year, with the wettest months being from November to March with an average annual temperature of 21°C. The predominant vegetation in the region is the Montana Seasonal Semi-deciduous Forest, also known as “Mata de Cipó”.

Containers used in the production of seedlings

Plastic bags

Two sizes of plastic bags were used. The first had dimensions of 11.0 cm in height, 5.0 cm in width, and a volumetric capacity of 215.87 cm^3 of the substrate. And the second model with dimensions of 15.0 cm high, 6.0 cm wide, and a volumetric capacity of 423.9 cm^3 of the substrate.

Tubes

Three sizes of tubes were used. The first model had dimensions of 12.5 cm height, 3.0 mm in diameter at the top, and 1.0 cm at the bottom, with six internal grooves and 55.0 cm^3 of substrate volumetric capacity. The second model was 13.5 cm high, 4.0 cm in diameter at the top and 1.0 cm at the bottom, with a substrate volumetric capacity of 120.0 cm^3. The third model was 19.0 cm high, 6.3 cm in diameter at the top and 1.0 cm at the bottom, with a substrate volumetric capacity of 288 cm^3.

Seedling’s production in the nursery

A combination of 65% of subsoil soil and 40% of tanned barnyard manure was used to fill the plastic bags. As chemical fertilization, 900 g of simple superphosphate, 100 g of KCl, and 100 g of urea were used for each cubic meter of the substrate. As for the filling of the tubes, a commercial substrate based on coconut fiber, pine bark, carbonized rice husk, and vermiculite was used. As base fertilization for this substrate, the slow-release fertilizer Osmocot® (19-06-10) has been used in amounts of 5.0 grams/liter. Sowing was performed manually for the entire experiment, placing five seeds in each container.

Treatments and statistical analysis

The experiment followed a randomized design with five treatments and four replications, totaling twenty plots. Each plot contained eight seedlings, totaling 160 throughout the experiment, involving two seedling production systems (tubes and plastic bags). The five treatments were: T1 – Tube (288 cm^3); T2 – Tube (120 cm^3);

T3 - Tube (55 cm^3); T4- Plastic bag (424 cm^3); and T5- Plastic bag (216 cm^3). Australian cedar seeds used were from a matrix tree located at the State University of Southwest Bahia.

Morphological parameters

The evaluation of the morphological parameters took place at four months of age of the seedlings, which were initially removed at random from their respective containers, and then the root system of the seedlings was cleaned using running water, aiming at the separation of all the substrate residues adhered to the roots. Posteriorly this procedure, the seedlings were placed on newspaper sheets on the laboratory bench for 12 hours, after which the height of the aerial part and diameter of the neck were measured with the aid of a graduated ruler and digital caliper respectively. Subsequently, the aerial and root parts were separated to determine the H/D ratio and the respective weights of this material. In the next step, the stem and roots of each seedling were placed separately in two paper packages, labeled, and taken to an oven at approximately 75 °C, where they remained for approximately 48 hours until reaching constant weight, after which the weighing was carried out and obtaining the dry biomass of the material with the aid of a digital scale. For the evaluation of the morphological parameters, samples consisting of eight seedlings per plot were used, aiming at the determination of the following parameters: a) shoot heigh (SH); b) stem base diameter (SBD); c) SH/SBD ratio; d) shoot fresh matter (SFM) – the sum of stem base fresh matter and leaf fresh matter, e) shoot dry matter (SDM)- the sum of stem base dry matter and leaf dry matter, f) root fresh matter (RFM), g) root dry matter (RDM), h) total fresh matter (TFM), i) total dry matter (TDM), j) SDM/RDM ratio, l) SH/SDM ratio and, Dickson quality index - DQI (DICKSON *et al.*, 1960).

$$DQI = \frac{TDM(g)}{\frac{SH(cm)}{SBD(mm)} + \frac{SDM(g)}{RDM(g)}}$$

Physiological parameters (Root Regeneration Potential - R.R.P)

For the evaluation of the R.R.P, the methodology proposed by Novaes *et al.* (2002), using transparent plastic bottles without bottlenecks in the form of tubes, also called rhizotrons, in the dimensions of 25.0 cm in height and 10.0 cm in diameter, with a volumetric capacity of 1.9 liters of the substrate and wrapped in black plastic tarpaulin. The same substrate used to produce seedlings was chosen to fill these containers. Wich the same methodology, the seedlings were randomly removed from the trays and then subjected to a careful cleaning with running water from the root system to remove the substrate, and then the lateral roots were pruned at approximately 4, 0 cm from the axis of the taproot which was also pruned at an approximate distance of 12.0 cm from the seedling stem base. After this procedure, the seedlings were transplanted into the tubes and then subjected to intense watering homogeneously throughout the experiment. The R.R.P was evaluated every other day in 25 days after transplanting the seedlings to the tubes. The adopted procedure consisted of marking points on the transparent walls of the recipients using an atomic brush, precisely in the places touched by the ends of the regenerated roots.

This parameter was evaluated by determining the following parameters: a) the total number of regenerated roots; b) the total number of roots regenerated in the upper part and, c) the total number of roots regenerated in the lower part.

RESULTS

According to Table 1 and considering the two types of containers adopted separately, the seedlings produced in plastic bags with greater volume of substrate (T4) obtained the highest averages for SH (31.89 cm) and SH/SBD (7.76). As for the results obtained from the seedlings produced in tubes, it was found that the container with the highest volume (T1) had the highest average, with a statistical difference concerning the others.

Table 1. Mean shoot heigh (SH) and stem base diameter (SBD) and SH/SBD ratio of Australian cedar seedlings (*Toona ciliata*) four months after sowing.
Tabela 1. Altura média da parte aérea (H) e diâmetro da base do caule (D) e relação H/D de mudas de cedro australiano (*Toona ciliata*) quatro meses após a semeadura.

Treatments	SH (cm)	SBD (mm)	SH/SBD
T1 - Tube (288 cm^3)	25,08 b	5,12 a	5,01 b
T2 - Tube (120 cm^3)	14,04 c	3,46 c	4,11 c
T3 - Tube (55 cm^3)	12,00 c	2,92 c	4,15 c
T4 - Plastic bag (424 cm^3)	31,89 a	4,21 b	7,76 a
T5 - Plastic bag (216 cm^3)	22,48 b	3,33 c	7,09 a
CV (%)	8,26	7,54	6,95

Means followed by the same letter do not differ from Tukey's test at 5% probability. CV: coefficient of variation.

For the fresh, dry, and total biomass parameters, there was a significant difference between treatments (Table 2). In general, we realize a trend of decreasing the values of these variables by reducing the volume of the containers. The best averages were those from seedlings produced in larger plastic bags. There were no significant differences between medium, small-sized tubes and small plastic bags. Analyzing the total biomass of roots, in addition to the largest tubes with the best averages for this variable, the most oversized plastic bags had the second-highest average.

Table 2. Mean shoot fresh matter (SFM), root fresh matter (RFM), total fresh matter (TFM), shoot dry matter (SDM), root dry matter (RDM), and total dry matter (TDM) of Australian cedar (*Toona ciliata*) seedlings, four months after sowing.
Tabela 2. Matéria fresca média da parte aérea (MFPA), matéria fresca da raiz (MFR), matéria fresca total (MFT), matéria seca da parte aérea (MSPA), matéria seca da raiz (MSR) e matéria seca total (MST) do cedro australiano (*Toona ciliata*) mudas, quatro meses após a semeadura.

Treatments	Fresh mass (g)			Dry mass (g)		
	SMF	RFM	TFM	SDM	RDM	TDM
T1 - Tube (288 cm^3)	9,46 a	4,85 a	14,31 a	2,78 a	2,05 a	4,83 a
T2 - Tube (120 cm^3)	2,39 c	1,52 b	3,91 c	1,12 cd	0,88 b	2,00 bc
T3 - Tube (55 cm^3)	1,14 c	0,82 b	1,96 c	0,63 d	0,53 b	1,16 c
T4 - Plastic bag (424 cm^3)	6,33 b	1,87 b	8,19 b	1,98 b	0,99 b	2,97 b
T5 - Plastic bag (216 cm^3)	2,88 c	1,1 b	3,98 c	1,21 c	0,7 b	1,91 c
CV (%)	18,62	32,33	22,09	14,86	25,68	18,33

Means followed by the same letter do not differ from Tukey's test at 5% probability. CV: coefficient of variation.

The containers with the highest SH/SDM ratio averages corresponded to the tubes with the small dimensions, T3-55 cm^3 and T2-120 cm^3, respectively. Also, the highest SDM/RDM ratio averages were obtained in plastic bags, T4-424 cm^3 and T5-216 cm^3, respectively, compared to tubes. Likewise, there was no statistical difference between the three studied tube sizes for this variable. For DQI, the highest average was from seedlings produced in tubes with larger dimensions, and the other treatments showed no statistical differences between them (Table 3).

Table 3. Mean SH/SDM and SDM/RDM ratios, and Dickson quality index (DQI) of Australian cedar (*Toona ciliata*) seedlings, four months after sowing.
Tabela 3. Médias das relações H/MSPA, MSPA/MSR e índice de qualidade de Dickson (IQD) de mudas de cedro australiano (*Toona ciliata*), quatro meses após a semeadura.

Treatments	SH/SDM	SDM/RDM	DQI
T1 - Tube (288 cm^3)	9,08 d	1,38 bc	0,77 a
T2 - Tube (120 cm^3)	12,53 c	1,30 bc	0,37 b
T3 - Tube (55 cm^3)	19,17 a	1,19 c	0,22 b
T4 - Plastic bag (424 cm^3)	16,18 b	2,08 a	0,31 b
T5 - Plastic bag (216 cm^3)	18,94 ab	1,75 ab	0,22 b
CV (%)	8,51	16,23	25,8

Means followed by the same letter do not differ from Tukey's test at 5% probability. CV: coefficient of variation.

For the root regeneration potential, the results showed that the seedlings produced in plastic bags and tubes with larger dimensions (T4 and T5, respectively) had the highest number of regenerated roots, although there was no statistical difference related to the other treatments. Seedlings produced in tubes with smaller dimensions obtained the lowest number of roots regenerated equally, without statistical differences concerning the other containers (Table 4). As for the number of regenerated roots obtained in the upper and lower portions of the containers, no statistical differences between the treatments, except for T3 and T4 were detected; however, it was possible to numerically observe, for all containers, a higher concentration of new roots in the lower portion of the containers (Table 4).

Table 4. Mean of root regeneration potential (R.R.P.) of the seedlings of (*Toona ciliata*) four months after sowing.
Tabela 4. Médias do potencial de regeneração radicular (P.R.R.) das mudas de (*Toona ciliata*) quatro meses após a semeadura.

Treatments	Total regenerated roots	Roots regenerated in the upper portion	Roots regenerated in the lower portion
T1 - Tube (288 cm^3)	61,00 a	23,83 ab	37,17 a
T2 - Tube (120 cm^3)	45,16 a	09,17 b	36,00 a
T3 - Tube (55 cm^3)	35,00 a	11,67 ab	23,33 a
T4 - Plastic bag (424 cm^3)	65,67 a	28,83 a	36,83 a
T5 - Plastic bag (216 cm^3)	42,00 a	17,67 ab	24,33 a

Means followed by the same letter do not differ from Tukey's test at 5% probability. CV: coefficient of variation.

DISCUSSION

In general, the results obtained for this research showed, proportionally, for the larger volume containers the best results for most of the variables evaluated (stem base diameter, DQI, shoot fresh and dry matter, root fresh and dry matter, and total fresh and dry matter), given the greater volume of the substrate and, consequently, more significant space and free conditions for root growth, especially plastic bags. These results corroborate those obtained by Lisboa *et al.* (2012), who also verified that the size of the container affects the development of Australian cedar seedlings, of which the seven characteristics evaluated, five (diameter, height, dry mass of the shoot, dry mass of the roots, total dry mass) presented a better performance for seedlings planted in larger tubes (288 cm^3) than in smaller tubes (180 cm^3 and 115 cm^3). However, there is still a need for more in-depth and detailed knowledge about these containers in all their economic and technical aspects to reach more consistent conclusions at the species level, focusing on determining the adequate volume and container to produce seedlings (LISBOA *et al.*, 2012). The lower the value of the volumetric ratios (SH/SDM and SH/SDM), the better the quality of the seedlings (DUTRA *et al.*, 2013). In this sense, the results showed that the seedlings produced in tubes and plastic bags of greater volume possibly would present a greater capacity of survival after planting in the field.

For the production of fresh and dry biomass of shoot and root and total biomass, the results obtained for this work, possibly, is related to the more significant space for root growth and the greater volume of substrate that had positive effects on the development of the roots, which allows for a good supply of water and nutrients and also, root growth, requirements for the development of the shoot root (Baldin *et al.* (2015). It is possible to infer that the volume of the containers has influenced the seedling formation time (Table 2); those produced in larger tubes had faster growth, requiring less time for formation, as well as in larger bags. Lisboa *et al.* (2012) mention that the restriction of root growth, imposed by the reduced volume and the walls of smaller containers, reduce some critical parameters of seedling quality, such as height and leaf area, which will reduce growth and biomass production, increasing the number of interventions in the production cycle. Therefore, considering the hardening process, these results point to reducing the costs of seedling formation in the nursery.

The DQI serves as a useful quality indicator for seedling selection. A higher value of this index indicates a more desirable phenotype, better the seedling vigor, indicating robustness and balance in the distribution of biomass in the seedling (SCALON *et al.*, 2014). The DQI values obtained showed that the larger tube (T1-288 cm^3) provided greater vigor and seedling quality. These linkages may vary according to the species and growing conditions in the greenhouse, such as the substrate, seedling's age, container's size, among others (MELO *et al.*, 2018). This study agrees with those of Lisboa *et al.* (2012) when working with Australian cedar, who identified tubes with a volumetric capacity of 288 cm^3 as the best containers to produce seedlings of these species. Moreover, Freitas *et al.* (2018) found that tamboril seedlings produced, among others, with tubes of the same dimensions, showed promising results.

Regarding the RRP, more precisely in terms of the total number of regenerated roots, the results showed the superiority of the effects of larger tubes in terms of the best averages obtained compared to the other variables evaluated in the present study. It shows the importance of this parameter to the prognosis of the seedlings produced in these containers regarding their performance in the field. The seedlings produced in larger plastic bags showed potential for root regeneration and will probably obtain similar results in the field to those assumed for the larger tubes. This parameter, which expresses several physiological parameters (LANDIS *et al.*, 2010), also makes it possible to evaluate the vigor, and for this reason, it is recommended to determine the quality of forest seedlings. This criterion portrays the ability of the seedling to develop new roots in a given period (RITCHIE *et al.*, 2010).

According to Ritchie *et al.* (2010), a more developed root system provides more significant growth when compared to seedlings that have malformed roots. In this way, seedlings capable of regenerating their root system more quickly also will be more apt to be established in the field. With a root system able to regenerate, resuming the synthesis of new roots, the seedling, when implanted in the field, will quickly be able to expand its root system, which is a second moment, will guarantee the exploration of the soil aiming at the supply of nutritional and water demands, boosting their growth. Furthermore, a higher concentration of new roots was observed in the lower portion of the containers, indicating that this species, since its seedlings will be planted in the field, could be established in a shorter period and, consequently, obtain a higher rate of survival and initial growth.

The larger plastic bag (T4-424 cm^3) proved to be the second-best option for producing Australian cedar seedlings; however, the technical and economic feasibility of the tube must be considered. Other authors also recommended plastic bags for the production of seedlings of *Parkinsonia aculeata* L. (FARIAS JÚNIOR *et al.*, 2007), *Pterogyne nitens* (BOMFIM *et al.*, 2009), and native species of the Atlantic Forest (JUNIOR *et al.*, 2020). The main advantage of plastic bags is the low acquisition cost compared to tubes. Despite this, the tubes are reusable and have advantages such as occupying a smaller area in the nursery, reducing labor, greater practicality in planting, and greater practicality due to easy handling (CORREIA *et al.*, 2013, FREITAS *et al.* 2018). Therefore, using tubes leads to higher planting yields, which can reduce the costs of this operation and favor mechanized planting.

CONCLUSIONS

- Tubes with 288 cm^3 of volumetric capacity produced seedlings with higher averages for most of the morphological and root characteristics evaluated, constituting the ideal production system for Australian cedar seedlings.
- In the absence of tubes with 288 cm^3, plastic bags with a capacity of 424 cm^3 of substrate for this species are recommended.
- The evaluated root regeneration potential proves to be a favorable prognosis of rapid establishment and performance of seedlings in the field after planting.

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