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Scientific Article

Growth and quality of Brazilian pine tree seedlings as affected by container type and volume

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Abstract

Araucaria angustifolia (Bert.) O. Kuntze (Araucariaceae), commonly known as araucaria and Brazilian pine tree, can be grown for their edible pine nuts (pinhões), medicinal properties, and ornamental purposes. The aim was to assess the shoot and root growth and the overall quality of *A. angustifolia* seedlings grown in containers with different sizes, shapes and composition. Seeds were sowed in five containers: I – 126cm³ polypropylene cone-tainers (small cone-tainers); II – 290cm³ cone-tainers (large cone-tainers); III – 879cm³ polyethylene black bags; IV- 275 cm³ nonwoven fabric (TNT) containers (small TNT container) and; 493 cm³ nonwoven fabric (TNT) containers (large TNT container). Seedlings were evaluated 210 days after sowing, regarding the following variables: aboveground height (cm), root collar diameter (mm), shoot dry mass (g), roots dry mass (g), total dry mass (g), leaf area (cm²), roots area (cm²), roots volume (cm³), sturdiness quotient, root-shoot ratio and Dickson quality index. Height was superior for seedlings grown in the plastic bags (27.6 cm) and the large TNT containers (27.02 cm) when compared to the small and large cone-tainers (21.75 and 21.78 cm, respectively). Plastic bags also presented greater values of root-collar diameter, shoots, roots and total biomass and Dickson Quality index. Small and large TNT containers promoted lower root area and volume when compared to large polyethylene cone-tainers, but allowed for the same or better aboveground growth. Taking all results analyzed together, the polyethylene black bag promoted better growth and quality of Brazilian pine tree seedlings in comparison to the other containers.
Keywords: *Araucaria angustifolia*, pine nut, plastic bag, polypropylene cone-tainer, TNT container.

Resumo

Crescimento e qualidade de mudas de pinheiro brasileiro em função de tipos e volumes de recipiente

Araucaria angustifolia (Bert.) O. Kuntze (Araucariaceae), popularmente conhecida como araucária e pinheiro brasileiro, pode ser cultivada em função de suas sementes comestíveis (pinhões), propriedades medicinais e atributos ornamentais. O objetivo foi avaliar o crescimento de parte aérea e radicular e a qualidade geral de mudas de *A. angustifolia* cultivadas em recipientes com diferentes tamanhos, formas e composição. As sementes foram plantas em cinco recipientes: I - tubetes de polipropileno de 126cm³ (tubetes pequenos); II - tubetes de polipropileno de 290cm³ (tubetes grandes); III - sacos pretos de polietileno de 879cm³; IV- recipientes de tecido não-tecido (TNT) de 275 cm³ (recipiente pequeno de TNT) e; Recipientes de tecido não-tecido (TNT)de 493 cm³ (recipiente grande de TNT). As mudas foram avaliadas aos 210 dias após a semeadura para a determinação das seguintes variáveis: altura (cm), diâmetro do coleto (mm), massa seca da parte aérea (g), massa seca das raízes (g), massa seca total (g), área foliar (cm²), área de raízes (cm²), volume de raízes (cm³), coeficiente de robustez, razão raiz-parte aérea e índice de qualidade de Dickson. A altura foi superior nas mudas cultivadas nos sacos plásticos (27,6 cm) e nos recipientes grandes de TNT (27,02 cm) quando comparados aos tubetes pequenos e grandes (21,75 e 21,78 cm, respectivamente). Os sacos plásticos também apresentaram maiores valores de diâmetro de coleto, biomassa de parte aérea, raízes, biomassa total e índice de qualidade de Dickson. Recipientes grandes e pequenos de TNT promoveram menores área e volume de raizes quando comparados aos tubetes grandes, mas comportaram o mesmo ou melhor crescimento da parte aérea das mudas. Considerando o conjunto das variáveis, o saco de polietileno promoveu melhor crescimento e qualidade das mudas de pinheiro brasileiro em comparação aos demais recipientes.
Palavras-chave: *Araucaria angustifolia*, pinhão, saco plástico, tubete de polipropileno, recipiente de tecido não-tecido (TNT)

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Introduction

Araucaria angustifolia (Bert.) O. Kuntze (Araucariaceae) is a conifer tree native to the highlands of southern Brazil. The plant is commonly known as araucaria, Brazilian pine tree or 'pinheiro-do-paraná' and is documented as a species of pronounced economic value and ecological relevance (Freitas et al., 2009). The abundance of the species in the southern states of Brazil coupled with the quality and versatility of its timber led to extensive exploitation and, consequently, rapid vanishing of large areas of araucaria forest (Machado et al., 2010). The reduction of over 97% of araucaria forest within three tree generations and the replacement of the original area with *Pinus* spp. and *Eucalyptus* spp. forests as well as the conversion of forests for other uses have made the habitat loss irreversible and, as a result, *A. angustifolia* is currently considered a critically endangered species (Thomas, 2013).

Because of the species vulnerability, its logging is now prohibited in Brazil, but the legal reinforcement alone can also entail the economic devaluation of the species and reduce the interest for conservation, encouraging rural landowners to prevent the natural growth of araucaria trees to avoid losses of productive farmland areas in the future (Danner et al., 2012). In addition, according to Zanette (2016), preserving araucaria trees in the forest does not necessarily guarantee their conservation since they cannot grow well in shaded areas. For this reason, the cultivation of araucaria forests/orchards has been proposed as an alternative to satisfy both ecological and economic aspects. The exploitation of *A. angustifolia* for the production of its characteristic edible pine nuts (commonly referred as 'pinhões') appears to currently be the its most promising agricultural goal (Zanette, 2010, 2016; Danner et al., 2012), but the plant can also be cultivated for its medicinal properties, manufacture of dyes and varnishes and craftsmanship activities (Sanquetta et al., 2010; Freitas et al., 2009). Due to the beauty of the canopy in the various stages of growth, *A. angustifolia* also possesses great ornamental potential and landscape impact, a true eponym of the highland forests of southern Brazil (Basso, 2010).

One of the primary information necessary to introduce the cultivation of plant species is defining the most viable propagation method (Nunes Gomes and Krinski, 2018). Although several studies have recently addressed methods for its clonal propagation, (Zanette et al., 2011; Gaspar et al., 2017; Wendling et al., 2017; Constantino and Zanette, 2018), as most of the conifers, araucaria is propagated by seeds (Wendling et al., 2016). The production of *A. angustifolia* seedlings can be important for both direct field transplanting and for the use as rootstocks, since the grafting technique has recently gained importance for the species (Wendling, 2011; Danner et al., 2012; Zanette, 2016).

The success of *A. angustifolia* cultivation depends heavily on the correct management of seedlings at nursery, since well-nourished and high quality seedlings are fundamental for proper growth and survival after field transplanting (Constantino et al., 2019). Several aspects need to be considered to achieve high quality seedlings of forest and fruit trees. Among these aspects, the type and volume of containers to be chosen can exert significant influence on plants growth and development. Containers affect the volume of soil medium available for root growth and overall root volume, which, in turn, will influence shoot growth (Gomes et al., 2002; Kostopoulou et al., 2011; Melo et al., 2018). The optimum container size and type for seedling production can vary according to the plant species, environmental conditions and length of the growing season (Poorter et al., 2012; Bali et al., 2013; Tian et al., 2017).

Although there are a few studies addressing the propagation of *A. angustifolia* by seedlings (Rossa et al., 2011; Constantino et al., 2019), to the best of our knowledge, no study to date has specifically evaluated the effects of different container types on the production of seedlings for this species. Given the above, the aim was to assess the shoot and root growth and the overall quality of *A. angustifolia* seedlings grown in containers with different sizes, shapes and composition.

Material and Methods

Seeds were collected from highly productive *A. angustifolia* trees located in the City of Curitiba, Paraná State, Brazil. The seeds were submerged in water for 24 hours and subsequently planted in different containers (treatments) filled with commercial substrate (Agrofior®-F73 – Biostabilized compost pine bark; coconut husk fiber; controlled-release fertilizer Osmocote®; Yoorin® Master fertilizer and single superphosphate). The chemical composition and density of substrate are presented in table 1. The seeds were sowed according to the methods described by Wendling and Delgado (2008), using one seed per container. Briefly, two thirds of seed length was deepened in the substrate in a way the hilum was covered and the seed remained slightly tilted.

Table 1. Chemical composition and density of the substrate used for *A.angustifolia* seedlings production in different containers types and sizes.

pH	Al^{+3}	$H^{+}+Al^{+3}$	Ca^{+2}	Mg^{+2}	K^{+}	SB	T	P	C	V	D
$CaCl_2$	----------------------- $cmol_c/dm^3$ -------------------------							mg/dm^3	g/dm^3	%	Kg/m
5.4	0.0	4.6	9.7	4.6	1.4	15.7	20.3	205	166.9	77.3	288.3

SB: sum of bases; T: Cation exchange capacity; V: Base saturation percentage; D: density of dry substrate.

The containers used as treatments were: I - 126cm³ polypropylene cone-tainers (small cone-tainers); II - 290cm³ cone-tainers (large cone-tainers); III - 879cm³ polyethylene black bags; IV- 275 cm³ nonwoven fabric (TNT) Agropote® containers (small TNT container) and; 493 cm³ nonwoven fabric (TNT) Agropote® containers (large TNT container). The planting was carried out in June of 2017 and the containers with substrate and seeds/seedlings were kept in a nursery at the following coordinates: 25º25'40" S, 49º16'23" W, and 934m altitude ASL. The climate of the region is classified as Cfb, temperate humid, according to Köppen's system. The weather variables during the period of the experiment are presented in table 2. The control of weeds was performed manually and irrigation was carried out every other day up until substrate saturation level was achieved.

Table 2. Weather conditions during the growth of *A. angustifolia* seedlings in different containers types and sizes.

Variables	Jun	Jul	Aug	Sep	Oct	Nov
Precipitation (mm)	181.30	7.80	92.90	36.20	212.20	129.40
Relative humidity (%)	81.70	78.01	80.70	72.10	80.81	76.40
Mean maximum Temperature (ºC)	20.53	20.88	21.48	26.79	24.00	24.45
Mean minimum Temperature (ºC)	10.85	9.01	11.64	14.25	14.55	14.62
Mean temperature (ºC)	14.72	13.92	15.28	19.07	18.18	18.62

Source: National Institute of Meteorology (INMET), 2017

The seedlings were evaluated 210 days after sowing regarding the following variables: aboveground height (cm), root collar diameter (mm), shoot dry mass (g), roots dry mass (g), total dry mass (g), leaf area (cm²), roots area (cm²) and roots volume (cm³). Based on the biometric variables, the following quality indexes were calculated: sturdiness quotient (aboveground height/root collar diameter ratio), root-shoot ratio and Dickson quality index.

Shoots and roots were manually separated and the fresh leaves and roots were analyzed in an optical scanner coupled to the software WinRHIZO Pro v. 2002c (Régent Instruments Inc. 2004) to determine the leaf area and roots area, total length and volume. After scanning, shoots and roots were oven-dried (65 ºC) until reaching constant mass for the assessment of shoot dry mass, roots dry mass and total dry mass. The Dickson quality index- DQI (Dickson et al. 1960), was calculated as follows:

$$\text{DQI} = \frac{Total\ dry\ mass}{\left(\frac{Height\ (cm)}{Root\ collar\ diamater\ (mm)} + \frac{Roots\ dry\ mass\ (g)}{Shoots\ dry\ mass(g)}\right)}$$

The experiment was conducted in a completely randomized design with 5 treatments and 4 repetitions, using 10 plants per plot. Data was submitted to variance homogeneity analysis by the Bartlett test, variance analysis (ANOVA), and, when significant, the means were compared by the Tukey test at 5% probability level.

Results and Discussion

The types of containers significantly influenced the growth and quality of araucaria seedlings. The aboveground height was superior for seedlings grown in the plastic bags (27.6 cm) and the large TNT containers (27.02 cm) when compared to the small and large cone-tainers (21.75 and 21.78 cm, respectively) (Figure 1).

Aboveground height has always being used efficiently as an estimate of seedlings quality in nurseries and, for some species, it is a good indicator of growth and performance in the field (Gomes et al., 2002). In many nurseries, height is still the main aspect considered to establish the commercial value of forest tree seedlings (Rossa et al., 2015).

The best height for seedlings vary according to the characteristics of the species, but as a general rule, for tree species native to Brazil, heights between 20 and 35 cm indicate good quality for planting (Gonçalves et al., 2000). Taking this into account, all containers here studied allowed for satisfactory height of *A. angustifolia* seedlings. The values observed for seedlings height are similar to those reported by Rossa et al. (2011) for the same species in similar growth stage.

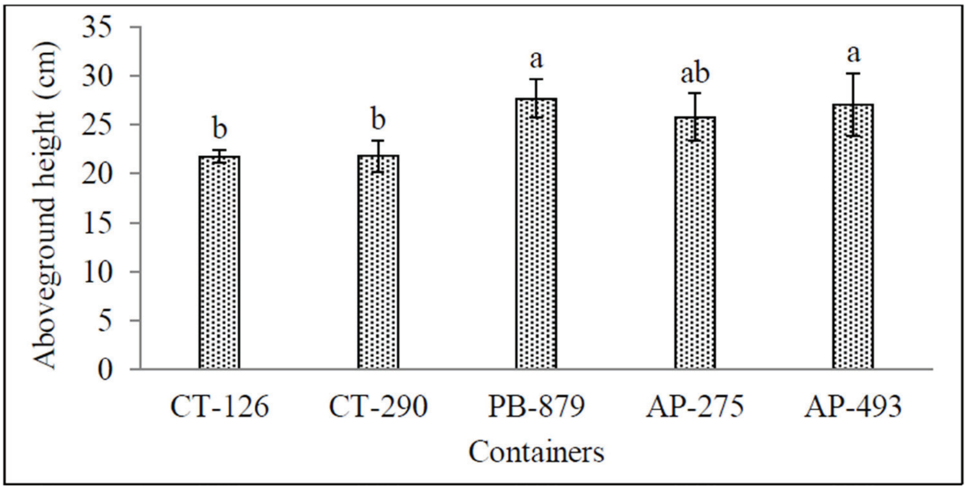

Figure 1. Aboveground height of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

According to Binotto et al. (2010), seedlings height is only effective to indicate overall quality if taken together with root collar diameter. In addition to being a simple and non-destructive assessment, the root collar diameter is one of the most appropriate indicators to predict the outplanting performance of forest species seedlings (Bayala et al., 2009; Tsakaldimi et al., 2013). Brazilian pine seedlings grown in plastic bags showed higher root collar diameter when compared to both small and large polyethylene cone-tainers and did not differ from both small and large TNT containers. Large TNT containers outperformed both polyethylene cone-tainers for this variable (Figure 2).

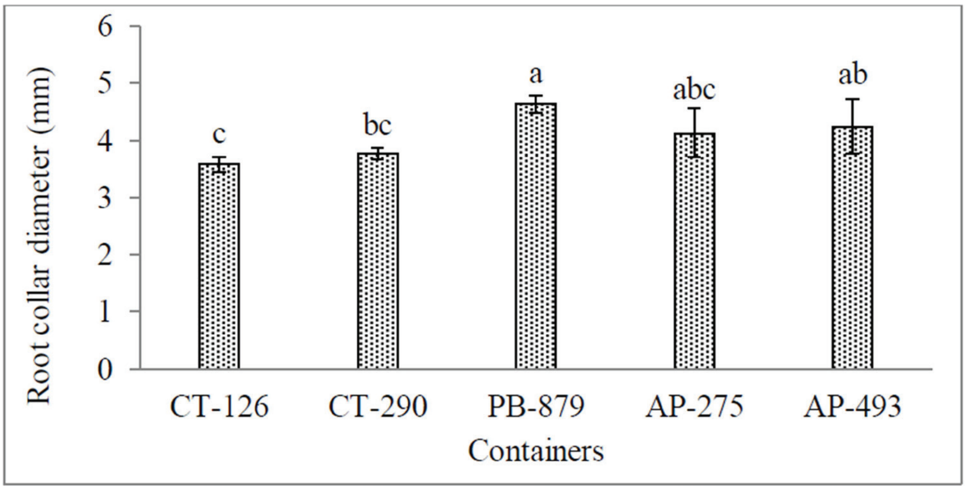

Figure 2. Root collar diameter of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

Root collar diameter of *A. angustifolia* seedlings seemed to bear a close relationship with the volume of containers rather than their shapes or composition. The higher the volume of the container, the higher was the diameter of seedlings. This relationship is probably due to a higher availability of water, nutrients and space for roots, and consequently shoots, growth, since the root collar diameter is an indicative of water/nutrients absorption and transport (Grossnickle, 2012). Similarly, *Terminalia bellirica* (Gaertn.) Roxb. seedlings presented maximum survival, height and root collar diameter when grown in 4000 ml plastic pots, rather than in smaller size containers (Bali et al., 2013).

Yet another important variable to be considered as an indicator of seedlings quality is their leaf area, which directly affects photosynthesis and transpiration, two major metabolic processes related to plant growth and development. The leaf area of araucaria tree seedlings was superior in plastic bags when compared to plants grown in small polypropylene cone-tainers. The other types of containers did not differ among themselves according to the Tukey test (Figure 3).

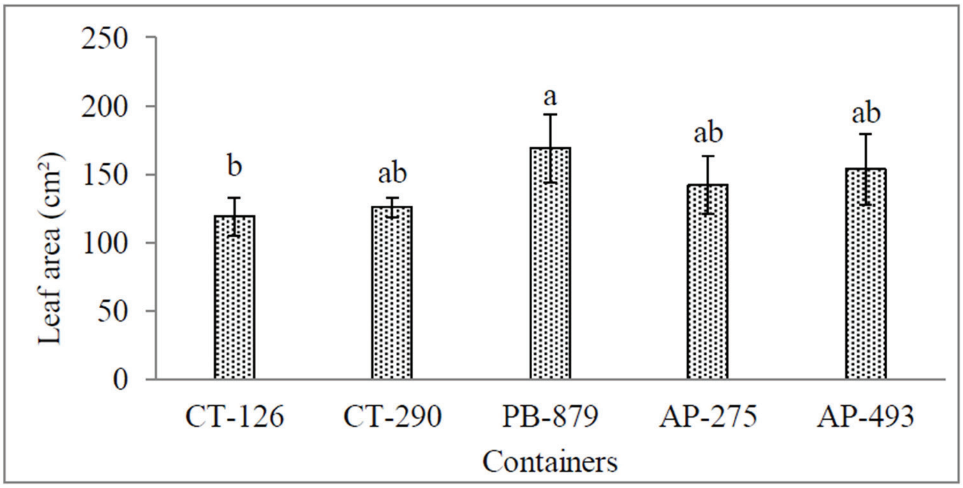

Figure 3. Leaf area of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

Superior leaf area in the larger volume container is expected due to the greater availability of water and nutrients necessary for leaf expansion, but can also be related to root space limitation in the small cone-tainer. Small volume containers can restrict water availability and impose physical limitations on root system growth (Kostopoulou et al., 2011) and, as a result, a lower leaf area may be understood as a plant adaptation to reduce transpiration rate, improving water use efficiency (Trubat et al., 2011).

As leaf area in plant species is related to photosynthesis and growth, this variable is closely related to the ability of a seedling to accumulate biomass. Accordingly, the shoot biomass of araucaria tree seedlings grown in plastic bags and both small and large TNT containers was greater than those obtained for seedlings grown in small polypropylene cone-tainers. Plastic bags also provided better results than large polypropylene cone-tainers, which, in turn, did not differ from the other treatments (Figure 4).

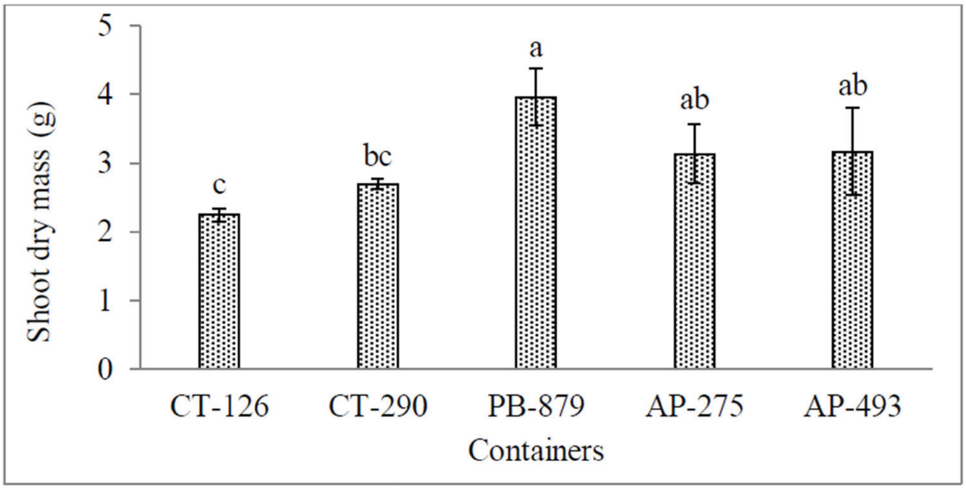

Figure 4. Shoot dry mass of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

Larger seedlings (in terms of biomass, height and area) tend to occupy a greater area within the planting area than smaller seedlings, thereby capturing more incoming solar radiation. This is a critical feature for survival after field transplanting because of the effect of competition for sunlight (Grossnickle, 2012). In agreement with the results here presented, Gomes et al. (2002) reported that larger containers promoted greater shoot biomass of *Eucalyptus grandis* W. Hill ex Maiden seedlings. According to Poorter et al. (2012), container volume has a positive linear relationship with seedling biomass and the reduced growth observed in smaller pots is caused mainly by a reduction in photosynthesis per unit leaf area, rather than by changes in leaf morphology or biomass allocation

Despite their commercial and, in some extent, physiological relevance, seedling above-ground morphology is not always an accurate indicator of out planting performance. Root system morphology, in certain cases, may provide a more accurate indication of seedling potential (Davis and Jacobs, 2005). Roots biomass of *A. angustifolia* seedlings was greater in plastic bags than in small cone-tainers and both small and larger TNT containers (Figure 5).

As for the roots area and volume, both plastic bag and large polypropylene cone-tainer promoted superior results when compared to the other treatments (Figures 6 and 7).

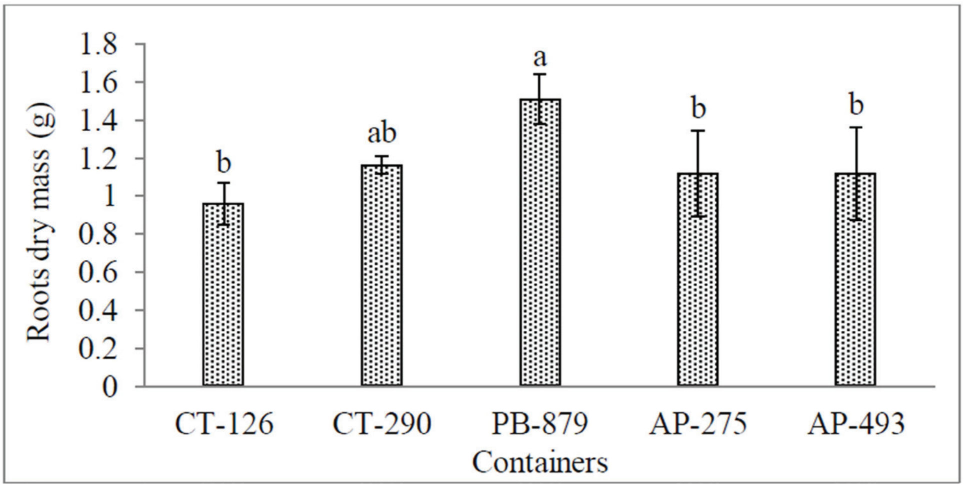

Figure 5. Roots dry mass of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

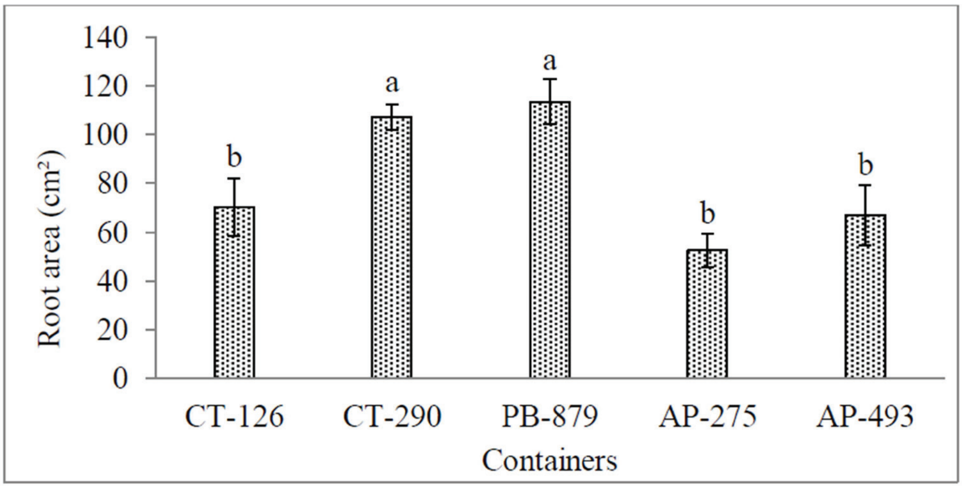

Figure 6. Root area of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

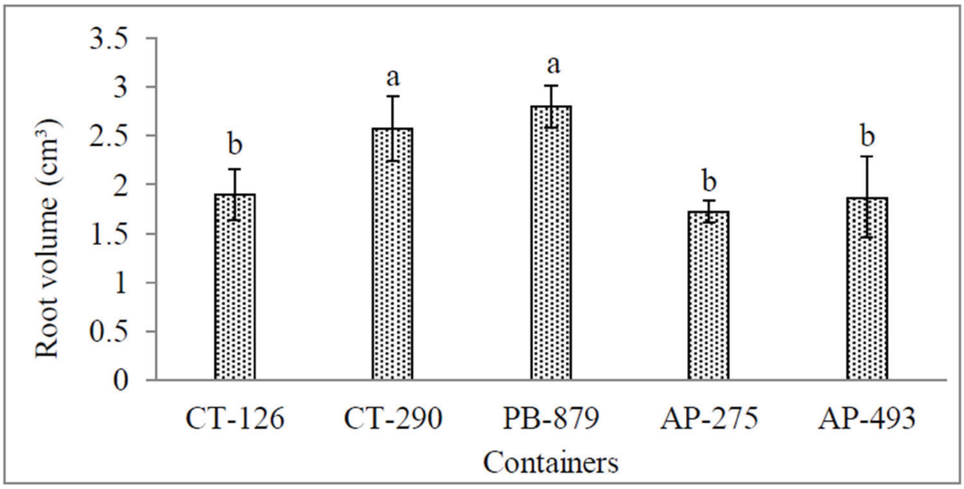

Figure 7. Root volume of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm^3 polypropylene cone-tainer; CT-290: 290 cm^3 polypropylene cone-tainer; PB-879: 879 cm^3 polyethylene black bag; AP-275: 275 cm^3 nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm^3 nonwoven fabric (TNT) Agropote® container.

Greater root mass in seedlings is an indicator of root absorptive surface, conferring a better drought avoidance capability after field planting (Grossnickle, 2012). Moreover, Successful seedling establishment is fundamentally dependent on the capacity to rapidly initiate new roots in order to mitigate the negative effects of transplant shock (Davis and Jacobs, 2005) and, since seedlings with greater biomass have a higher ability to grow new roots, this feature has a strong positive relationship with growth potential and survival (Grossnickle and McDonald, 2018).

In agreement with our results, larger container volumes have also promoted greater root biomass for seedlings of other forest tree species such as *Eucalyptus grandis, Cyclocarya paliurus* (Batal), *Mimosa caesalpiniifolia* Benth., among others (Gomes et al., 2002; Tian et al., 2017; Melo et al., 2018).

Roots area and volume provide a quantitative description of seedling root systems and in many cases have shown positive correlation with field performance and survival (Davis and Jacobs, 2005). It is worth mentioning that *A. angustifolia* seedlings grown in large TNT containers, despite having higher availability of volume for roots growth, presented lower root volume and area when compared to those seedlings grown in the large polypropylene cone-tainers (Figures 6 and 7). Similar behavior was reported for *C. paliurus* seedlings grown in TNT and black plastic containers (Tian et al., 2017). According to the authors, the superiority of the plastic container is justified by the fact that TNT containers are permeable and allow water and soluble nutrients to move laterally. Another possible explanation is that the black plastic bags would absorb more solar radiation, increasing temperature and, potentially increasing metabolic activities in the roots during early spring (Tian et al., 2017). Likewise, in the present study all containers were darker than the TNT ones. In addition, the presence of internal ribs in the polypropylene cone-tainers may have helped in directing the roots growth in a more organized manner even when less volume was available to the roots system.

In order to correctly predict the field performance of seedlings, both shoot and roots variables need to be considered. In this sense, total dry mass and Dickson quality index are important to provide an overall picture of seedlings quality when several variables are evaluated and, in addition, are some of the assessments that better correlate with seedling survival in the field for a number of forest tree species (Tsakaldimi et al., 2013). For araucaria seedlings, total dry mass was greater when using black plastic bags rather than any other container (Figure 8).

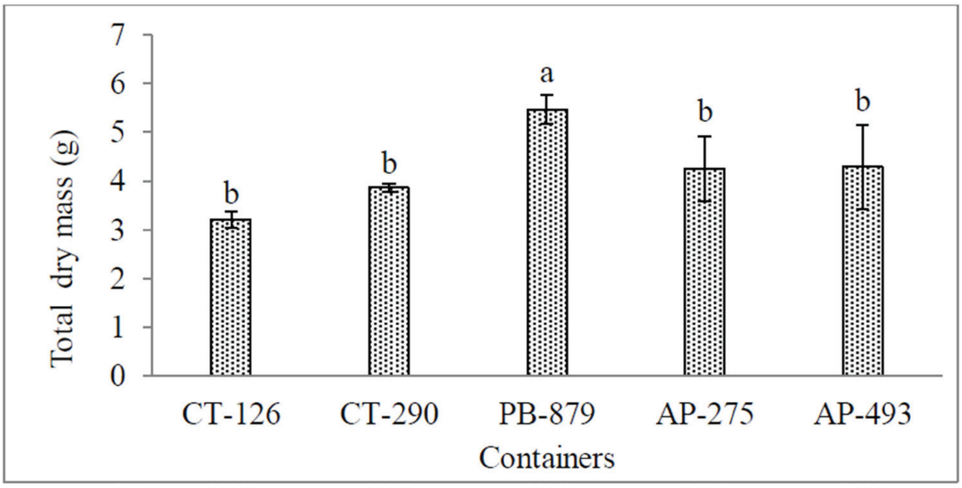

Figure 8. Total dry mass of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

A higher total mass is a consequence of higher availability of water and nutrients, leading to higher roots and shoots development. In general, the studies addressing the influence of containers on the growth of forest tree seedlings have shown that the use of larger containers results in larger seedlings due to the increased availability of nutrients (Melo et al., 2018).

Some of the most common quality indexes for seedlings, height: root collar diameter ratio and shoot mass: root mass ratio did not differ as a function of containers for araucaria seedlings, with mean values of 6.1 and 2.6, respectively. Dickson quality index, however, was statistically higher when *A. angustifolia* seedlings were grown in plastic bags in comparison to the other containers (Figure 9).

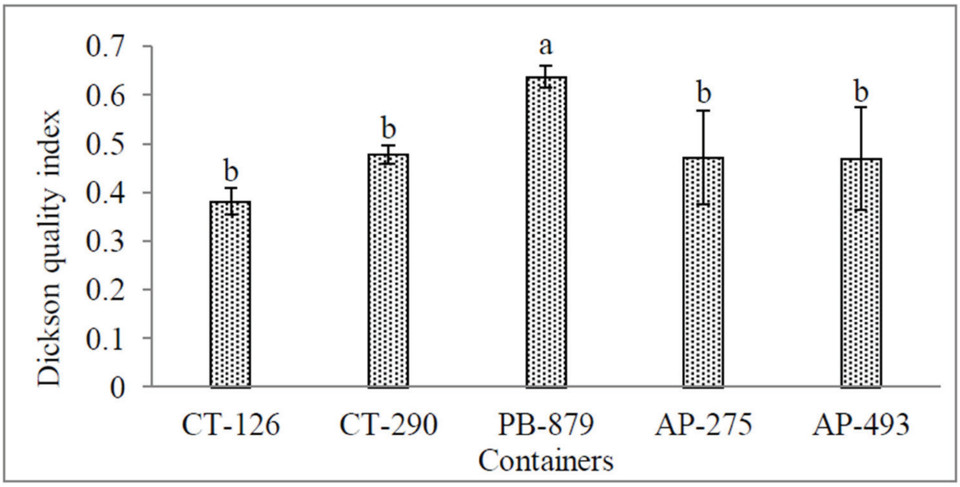

Figure 9. Dickson quality index of Brazilian pine tree (*Araucaria angustifolia*) seedlings grown in different containers. CT-126: 126 cm³ polypropylene cone-tainer; CT-290: 290 cm³ polypropylene cone-tainer; PB-879: 879 cm³ polyethylene black bag; AP-275: 275 cm³ nonwoven fabric (TNT) Agropote® container; AP-493: 493 cm³ nonwoven fabric (TNT) Agropote® container.

The Dickson quality index is an integrated seedling quality index based on several morphological features, therefore minimizing the possible errors that may be encountered by using only one or two features. This tool provides an objective basis for comparing the results of nursery management practices and is useful to practicing foresters and nurserymen in assessing the relative quality of the nursery harvest in any given year (Dickson et al., 1960). The ideal index varies according to the plant species, and no results of minimum standards of Dickson quality indexes have been found in the literature for *A. angustifolia* seedlings. Notwithstanding, Hunt et al. (1990) have established a minimum quality index of 0.20 for coniferous trees seedlings. Based on this statement, all treatments, even the smallest volume container, promoted satisfactory results for araucaria seedlings. Despite not having a specific standard for Brazilian pine seedlings, Dickson quality index reflects the plant potential for survival and growth in the field and, therefore, the higher the index, the better the quality of the plant (Mañas et al. 2009).

Taking all results in consideration, the polyethylene black bag promoted better growth and quality of Brazilian pine tree seedlings in comparison to the other containers, however, it is worth to mention that this container was considerably larger than the others, therefore demanding greater amounts of substrate. The choice of the most adequate container for *A. angustifolia* seedlings, hence, may take into account, in addition to plant responses and market prices of both seedlings and containers, the characteristics of every product. Plastic bags, besides providing the best technical performance, are easy to find and are the cheapest among all the containers here studied. TNT containers, in turn, do not need to be separated from the seedlings at the time of planting, avoiding root damages and lessening the detrimental effects of transplant shock. Finally, polypropylene cone-tainers are reusable and have internal ribs that allow for a more organized root system. Future studies should address the performance of seedlings grown in different containers after transplanting to better support growers decision in this regard.

Conclusions

Container type and size influence the growth and quality of *Araucaria angustifolia* seedlings. In general, the greater the volume, the greater the seedling growth. Seedlings grown in 879cm³ polyethylene black bags have the best technical performance regarding total biomass and Dickson quality index. Small (275 cm³) and large (493 cm³) TNT containers promote lower root area and volume when compared to large (290cm³) polyethylene cone-tainers, but allow for the same or better aboveground growth.

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Author contribution

L.M.V. 0000-0002-9336-860X Planned and performed the experiment, collected and analyzed data and reviewed the manuscript, **E.N.G.** 0000-0002-7999-070X Assisted on collection and interpretation of data and wrote the first draft of manuscript, **T.A.B.** 0000-0002-6366-1426 Assisted on data interpretation, writing and review of the manuscript's final version, **V.C.** 0000-0001-5831-2064 Planned and performed the experiment and assisted on data collection, **F.Z.** 0000-0001-5917-6711 Planned and supervised the research experiments and reviewed the manuscript.

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