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Production of *Nephelium lappaceum* Seedlings using Different Volumes of Tubes and Cultivation Densities

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ABSTRACT

Rambutan (*Nephelium lappaceum*) fruit is a potential non-timber forest product in tropical countries such as Indonesia due to its high economic potential. However, it is necessary to know the silvicultural aspects of the species in order to produce high-quality seedlings. The volume of the tube used and the spacing between seedlings can influence the quality of the seedlings. Thus, this work aimed to evaluate the production of seedlings of *N. lappaceum* through different densities of seedlings per tray and volumes of tubes. The experiment was installed in the nursery of the Technology Foundation of the state of Acre in Rio Branco. A completely randomized design with two factors (2 × 3) was adopted, considering two volumes of tubes, 110 cm^3 and 180 cm^3, and three seedling densities per tray, 1/3, 2/3, and 3/3. After 120 days, it was observed that the seedlings produced in tubes with a volume of 180 cm3 had greater aerial length and stem diameter in relation to the density of seedlings per tray, seedlings produced in less dense trays (1/3) had a higher Dickson quality index. Therefore, it is inferred that seedlings of *N. lappaceum* are favored when tubes with a volume of 180 cm^3 and a density per tray of 1/3 are used.

1. Introduction

Nephelium comprises 22 species, among which 9 have edible fruits, with *N. lappaceum* being the most-known species (Windarsih and Efendi 2019), being popularly named rambutan. It is an exotic tree of Malay origin that belongs to the Sapindaceae family (Sukmandari et al. 2017). The term '*rambutan*' derives from '*rambut'*, a Malay-Indonesian word meaning hairy (Mahmood et al. 2018). The fruit of the species has a reddish shell that contains flexible structures in the shape of thorns. A white aril covers the seed, and it is noted that in addition to having an edible fruit, which can be consumed in nature or in the form of juices or jellies (Chai et al. 2019; Jahurul et al. 2020), the species is also used in folk medicine, as it has pharmacological and healing properties present in its bark, seed, pulp, and leaves (Hernández-Hernández et al. 2019; Perumal et al. 2021; Sukmandari et al. 2017).

Due to the high economic potential of the species, the cultivation of rambutan is considered an option to raise the income of producers, so it is essential to produce seedlings of good quality. For this, it is essential to use good nursery cultivation practices, increasing the chances of survival in the field (Moreira et al. 2016), since healthy seedlings, with high vegetative vigor, are more resistant to the adverse conditions that are found in the field (Lima Filho et al. 2019). To determine the quality of seedlings, morphological variables such as shoot length and stem diameter are commonly used, or physiological variables such as the biomass of vegetative compartments (Grossnickle and Macdonald 2018). However, assessing the quality of seedlings considering only one variable is not recommended because it can result in erroneous evaluations, so it is recommended to use relationships between variables, for example, the relationship between shoot length and stem diameter (Ribeiro et al. 2021).

The Dickson quality index is also widely used since it includes in its equation variables, such as the height and diameter of the seedling, in addition to the accumulated biomass (Dickson et al. 1960). Among the factors that can affect the quality of seedlings produced in the nursery are the volume of the container used and the spacing between the seedlings in the tray (Fernandes et al. 2019; Moreira et al. 2016). The volume of the container is a key point for the production of quality seedlings because it influences the amount of substrate, fertilizer, and water to be used during planting and in the determination of the area to be occupied in the nursery, consequently impacting the cost of production of the seedling (Dias et al. 2016; Lima Filho et al. 2019), in addition, the size of the tube influences the development of the root and air axis of plants (Cruz et al. 2016; Gonzaga et al. 2016).

The spacing between seedlings in the tray can increase competition for light and aeration, impacting seedling growth (Massad et al. 2018; Sampaio et al. 2018). In addition to influencing morphological issues, this factor also implies economic issues since the more spaced the seedlings are, the greater the need for physical space in the nursery, in addition to a greater number of trays for allocation of the tubes (Azevedo et al. 2016; Massad et al. 2018). In the literature, there is still a lack of information on the ideal conditions for producing rambutan seedlings in a nursery, which may limit the establishment of plantations of the species. Thus, this study aimed to evaluate the growth of seedlings of *Nephelium lappaceum* as a function of the volume of the tubes and the density of seedlings per tray.

2. Materials and Methods

2.1. Place of Study

The experiment was conducted in the forest nursery of the Technology Foundation of the State of Acre – FUNTAC, located in Rio Branco, AC, Brazil, between May and September 2021. The local climate, according to Koppen's classification, is of the Am type, tropical monsoon (Alvares et al. 2013), with annual rainfall ranging from 1,800 mm to 2,500 mm annually and an average temperature of around 24.5ºC (Amaral and Gonçalves 2021).

2.2. Experimental Design and Treatments

A completely randomized experimental design was adopted with two factors (factorial scheme 2 x 3) and 10 replications. The first factor corresponds to two volumes of conical tubes, 110 and 180 cm³, with a diameter of 63 mm and heights of 13 and 19 cm, respectively, and the second factor, to three levels of density of seedlings in the tray, being 1/3; 2/3 and 3/3 depending on the volumetry.

The treatments differed in the variation of the volume of the tubes (capacity in cm^3) and in the density of planting in the growth of the seedlings, being considered the following: Treatment 1 – tubes of 110 cm^3 with a density of 32 seedlings per tray; treatment 2 – tubes of 110 cm^3 with a density of 64 seedlings per tray; treatment 3 – tubes of 110 cm^3 with a density of 96 seedlings per tray; treatment 4 – tubes of 180 cm^3 with a density of 18 seedlings per tray; treatment 5 – tubes of 180 cm^3 with a density of 36 seedlings per tray and treatment 6 – tubes of 180 cm^3 with a density of 54 seedlings per tray.

2.3. Sowing and Storage in the Nursery

Rambutan seeds from a commercial plantation belonging to the Reca Project – Dense Consortium Economic Reforestation, located in the District of Nova California, Porto Velho – RO, Brazil, were used. The fruits were pulped, the seeds washed, and because they were recalcitrant materials, they were immediately put to germinate in tubes, according to each treatment. The tubes, made of black nontoxic polypropylene, were placed in appropriate trays on the bench, suspended at 1.0 m high; these were stored in the nursery for 120 days in a covered environment with monofilamentous mesh capable of filtering 50% of the incident light, being irrigated daily for 10 minutes.

2.4. Substrate Used

In the tubes, the seeds were sown in a commercial substrate composed of bio-stabilized pine bark, vermiculite, charcoal mill, and phenolic foam, to which was added 6.0 kg m^{-3} of controlled release fertilizer (6 months) of formulation 14-14-14 (N-P-K) + Micronutrients.

2.5. Measurement of the Analyzed Variables

Shoot length and seedling harvest diameter were measured every 30 days, and 4 post-sowing measurements were made. On the 120th day after sowing, 10 seedlings of each treatment were randomly selected and submitted for biometric evaluation. The aerial part length (APL), with the aid of a graduated ruler, and the collar diameter using a digital caliper were analyzed.

The leaf area (LA) (cm) of the seedlings was measured with the aid of the Easy Leaf Area Free software. The aerial axis was separated from the root axis, and then the samples were inserted in Kraft paper packages and stored in a forced ventilation oven (60°C) until they reached constant mass. Subsequently, the total dry mass (TDM), aerial dry mass (ADR), and root mass (RM) of the samples were determined using a semi-analytical balance (0.01 g). After that, the Dickson quality index (DQI) was calculated according to the Equation 1 (Dickson et al. 1960).

$$DQI = \frac{TDM}{\frac{SL}{CD} + \frac{ADR}{RDM}} \quad (1)$$

where DQI is the Dickson quality index, SL is shoot length (cm), CD is collar diameter (mm), ADR is aerial dry mass (g), RDM is root dry mass (g), and TDM is total dry mass (g).

2.6. Statistical Analysis

The data obtained were submitted to the verification of the presence of outliers by the Grubbs test (1969), to the normality of the residues by the Shapiro-Wilk test (1965), and to the homogeneity of the variances by the Bartlett test (1937). After verification of the assumptions, analysis of variance was performed by the F test to verify the effects of the treatments and note differences. The qualitative data were compared following the Scott-Knott test (1974) at 5% probability.

3. Results and Discussion

The largest volume of the tube (180 cm^3), associated with the densities of 18 or 36 plants per tray, provided seedlings with a larger stem diameter after 120 days. In addition, the highest heights were obtained in the three densities in the tube of 180 cm^3 at 90 and 120 days (**Fig. 1**).

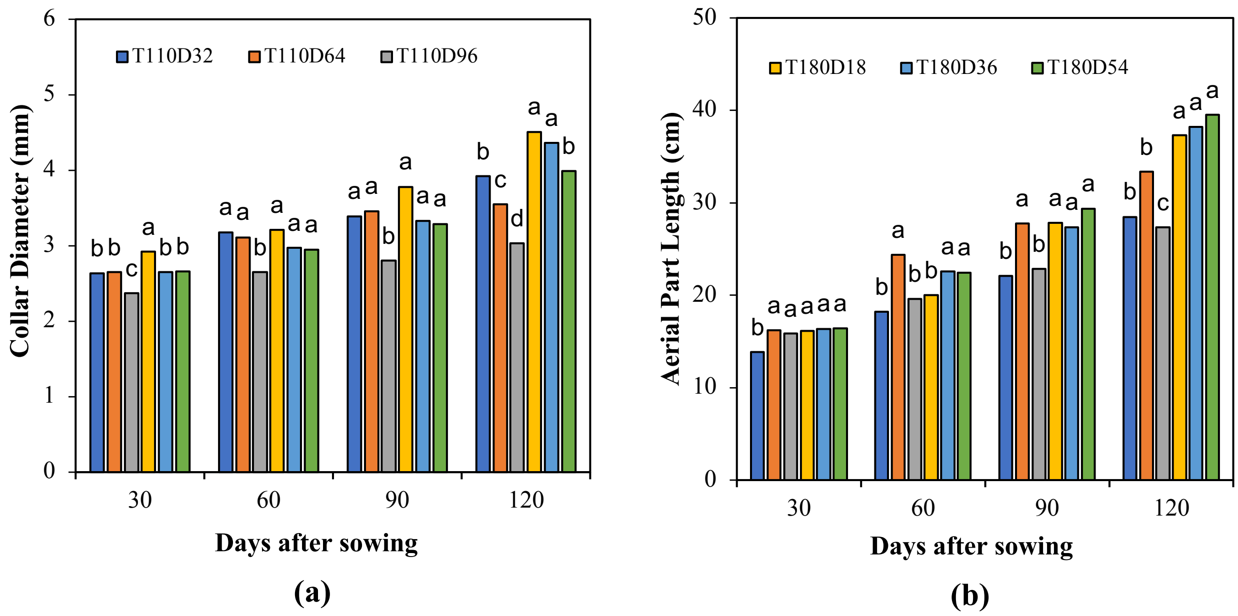


Fig. 1. (a) Stem growth in diameter and (b) plant height of *Nephelium lappaceum* seedlings after 30, 60, 90, and 120 days. Different letters indicate a significant difference by the Scott-Knott test ($p < 0.05$).

Seedlings produced in the tube with a lower volume (110 cm^3) showed a negative response to the variables shoot length and stem diameter compared to plants produced in the tube with a volume of 180 cm^3. From the 60th day on, the significant difference between the treatments became more evident, and the worst performance for the variables mentioned was obtained in those from the 110 cm^3 tube with 96 cells per tray. On the other hand, seedlings produced in tubes with greater volume exhibited greater height and diameter after 120 days (**Fig. 1**). The cultivation densities studied suggest that the denser the seedlings, the lower their growth in stem diameter when compared to the treatments with lower density (**Fig. 1a**) within 120 days. In contrast, it was verified that in the 180 cm^3 tube, the height was satisfactory in any density (**Fig. 1b**) at the last measurement.

Until the 90th day, the diameter of the stem is statistically equal in all seedlings produced in tubes with a volume of 180 cm^3. However, at 120 days, the treatment with 54 seedlings per tray presents a reduction in the increase of the diameter of the plant collection, probably due to the competition for light since there is a greater number of individuals per space, where plants prioritize growth in height to increase the area of solar energy capture when the competition for luminosity increases (Massad et al. 2018; Sampaio et al. 2018).

The development of the diameter of the collar and the length of the aerial part observed in this study, in relation to the volume of the substrates, corroborates the results found by Lima Filho et al. (2019), who noted that seedlings of *Ceiba speciosa* showed more intense growth in larger containers compared to smaller volume containers, and the difference in development increases over time, since smaller compartments tend to restrict expansion in length and diameter of the plant. Considering the density of the seedlings, an intervention is recommended after 90 days because even if the height of the plants is elevated alone, this is not a good indicator of quality. It is suggested that this variable be analyzed in conjunction with other indicators, such as the diameter of the stem since the height of the seedling is an indication of initial growth but not of survival after planting (Melo et al. 2018). Although in the treatment with greater volume and greater density, the seedlings present greater length, the expansion of the diameter of the stem was limited, resulting in thinner plants. It is noteworthy that the diameter of the stem is an indication of the potential for survival of the plant in the field, and individuals with smaller diameters are more likely to suffer tipping after transplantation since they have less resistance to environmental weather (Lima Filho et al. 2019; Vieira et al. 2019).

The diameter of the collar and the length of the shoot are two morphometric variables that complement each other, analyzing such variables together makes it possible to understand whether plant growth is occurring in a balanced way, and in the literature, it is recommended to use a relationship between APL and CD which should present a value between 5.1 and 8.1, it should be noted that very high values for this ratio may indicate the susceptibility of the plant to suffer damping off (Ribeiro et al. 2021). For the nurseryman, the intervention is interesting only from the 90 days for economic reasons, since by adopting the higher density, the plants start to occupy less space in the nursery. In addition, to prevent a negative impact on the quality of the seedlings due to the reduction of the expansion of the diameter of the stem, it is recommended to alternate the density of the seedlings 3/3 to 2/3, which statistically would be equal to 1/3.

It is observed that there was a significant effect for volume (V) and density (D) in the variables described in the summary of the statistical analysis after 120 days (**Table 1**). However, there was no interaction between V x D on the total dry mass (TSM) and Dickson quality index (DQI).

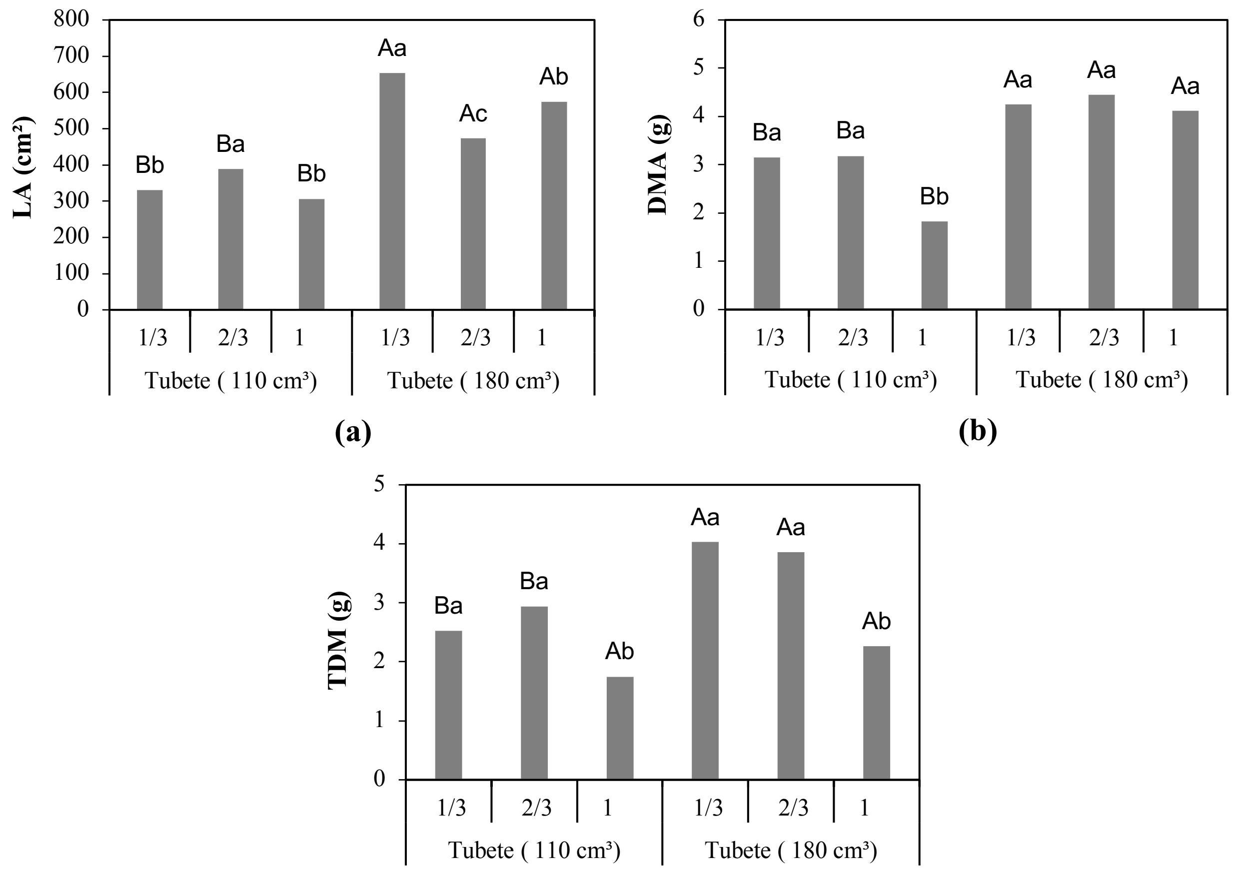
Table 1. Summary of the statistical analysis of the measurement at 120 days on the leaf area (LA), dry mass of aerial part (DMA), dry mass of root (DMR), total dry mass (TDM), and Dickson quality index (DQI) of *Nephelium lappaceum* in different densities and tube volume

Source of Variation	**GL**	**LA**	**DMA (g)**	**DMR (g)**	**TDM (g)**	**DQI**
		Mean square				
Volume (V)	1	761354*	36,33*	14,27*	96,17*	0,73*
Density (D)	2	21219*	4,13*	11,87*	30,01*	0,59*
VxD	2	78951*	2,10*	1,26*	0.50ns	0.004ns
Residue	54	859	0,17*	0,32*	0,49	0,01
CV (%)		6,45	11,81	19,67	11,02	15,53
Overall average		454,36	3,49	2,89	6,39	0,64

Notes: means accompanied by ns are not significant; * are significant at 5% probability. CV = coefficient of variation.

The 180 cm³ tube provided seedlings with positive responses to the variables AF, MSPA, and MSR after 120 days, than those produced in the tube with lower volume (**Fig. 2**), emphasizing that this is the favorable volume to be adopted for the production of seedlings of this species. Other authors also reported that adopting containers with this volume benefits plant growth (Butzke et al. 2018; Freitas et al. 2021; Gasparin et al. 2015). The results suggest that the smaller volume of the container limits the space for root expansion, in addition to reducing the availability of water, nutrients, and organic matter for seedling development, compromising their growth, both in the root axis and the aerial axis (Aguilar et al. 2020; Cruz et al. 2016; Dias et al. 2016). The lower biomass accumulation, both in the shoot and the roots, evidence this fact. Lima Filho et al. (2019) mentioned that a reduced root system makes plants more susceptible to water stress since they cannot absorb a sufficient amount of water to replace evapotranspiration losses. It is observed that even occupying less space in the nursery, the production of seedlings in tubes of smaller volume implies plants with a greater need for intervention since the volume of substrate contained will not supply the spatial demand necessary for root development compared to the larger tubes.

In the treatment with higher volume and lower density, the seedlings presented a larger leaf area (**Fig. 2A**) and, consequently, greater accumulation of dry biomass in the air compartment (**Fig. 2B**). This result was already predicted because the larger the area of solar energy capture for photosynthesis, the more the development of seedlings is benefited (Leal et al. 2015; Trautenmüller et al. 2017), also leading to a greater accumulation of dry matter in the root.



(c)

Fig. 2. (a) Mean leaf area, (b) shoot dry mass, and (c) root dry mass of *Nephelium lappaceum* due to the interaction between different densities and tube volume at 120 days. Means accompanied by the same letter, capital in volume and lowercase in density, within each factor do not differ according to the Scott-Knott test ($p > 0.05$).

The leaf area reflects the plant's ability to capture solar rays and perform the gas exchange and may be indicative of the production quality of a crop (Carmo et al. 2018), given that the larger the area of interception of light energy, the more balanced is the relationship between the distribution of biomass accumulation in the shoot and the root, due to the ability to convert this energy into carbohydrates necessary for plant growth (Watthier et al. 2016).

Seedlings produced in treatments with tubes with a volume of 180 cm³ and density of 1/3 presented the highest means of total dry mass and Dickson quality index (**Table 2**). Those produced in treatments with a density of 2/3 also presented a high total biomass accumulation. It may be attractive for the producer to adopt this density because it reduces costs and the area used for production, and the Dickson quality index, although it differed significantly in absolute terms, was close to that of seedlings produced in lower-density trays.

Table 2. Mean total dry mass (TSM) and Dickson quality index (DQI) of *Nephelium lappaceum* at different densities and tube volume at 120 days

Source of variation		**TDM (g)**	**DQI**
		Medium	
Volume	110	5.12 b	0.53 b
	180	7.65 a	0.75 a
Density	1/3	6.97 a	0.77 a
	2/3	7.21 a	0.71 b
	3/3	4.98 b	0.45 c

Notes: means accompanied by the same letter within each factor do not differ from each other by the Scott-Knott test ($p > 0.05$).

The Dickson quality index is an efficient indicator of seedlings' quality since it includes multiple morphophysiological variables. It is emphasized that the higher the index value, the more vigorous the seedling is (Aguilar et al. 2020). Some authors mention that the minimum value for this index would be 0.2. However, Caldeira et al. (2013) stated that this value can vary according to the time of the seedling in the nursery and the cultivated species. Based on the exposed results, it is emphasized that for the production of *N. lappaceum* under the conditions adopted in this experiment, the use of containers with greater volume (180 cm^3) and with a density of 54 seedlings per tray, with subsequent change to 36 seedlings, can result in more vigorous seedlings, making them more resistant to attack by pathogens, as well as increasing their production, resulting in lower planting maintenance costs and greater economic profitability (Lima Filho et al. 2019).

4. Conclusions

The cultivation of *Nephelium lappaceum* seedlings in nurseries was significantly enhanced by utilizing 180 cm^3 tubes. This method, in particular, demonstrates its superiority in the initial 90-day period post-sowing, where the tubes can be arranged with an impressive density of 54 seedlings per tray. This innovation improves cultivation efficiency and optimizes the use of space in the nursery. As the cultivation process advances beyond the initial 90-day period, a shift in strategy is recommended. This tendency involves a prudent reduction in the density of seedlings per tray from 54 to 36, ensuring the seedlings' continued health and growth. This innovative approach, anchored in scientific observation and practical application, presents a promising avenue for enhancing nursery productivity and sustainability while offering a blueprint for the improved cultivation of *N. lappaceum* seedlings.

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