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RESEARCH ARTICLE

Growth of tamarind seedlings in different levels of shadowing and substrate composition

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ABSTRACT

Tamarind (*Tamarindus indica* L.) is a species with promising potential for commercial production; therefore, studies involving practices of conducting culture in the initial stage are essential. The present study aimed to evaluate different shading levels and substrate compositions in the seedling production of tamarind. The experimental design was completely randomized in a 4×4 factorial scheme, four levels of shading (0%, 18%, 30%, and 50%) and four substrates (pine bark-based substrate pure and mixed with 50% vermiculite, and sphagnum peat-based substrate pure and mixed with 50% vermiculite), with four replicates of four seedlings. Growth and biometric relationships were evaluated at 40 and 98 d after transplantation (DAT). The results reported that seedlings formed on the sphagnum peat-based substrate on pure or associated with vermiculite at 98 DAT had a height greater than 35 cm and a total 8.5 g DM. In contrast, seedlings produced in pine bark-based substrate did not reach 20 cm in height and had less than 3 g total DM. The condition of 30% and 50% shading promoted greater growth in height, reaching an average height greater than 40 cm, while in the full sun environment, seedlings showed an average of less than 35 cm; however, for the other variables, full sun environment did not differ from 30% shading, producing good quality seedlings. Thus, the cultivation of seedlings in an environment with 0% or 30% shading, associated with the sphagnum peat-based substrate pure or mixed with 50% vermiculite promoted the production of tamarind seedlings with vigorous growth. In the best environments, the best substrates increased, on average, 41.3% number of leaves, 80.5% shoot dry mass, 56.8% root dry mass, and 71.0% total dry mass. In the best substrates, the best environments increased, on average, 18.0% number of leaves, 20.7% shoot dry mass, 8.7% root dry mass, and 14.3% total dry mass.

Key words: Photosynthetically active radiation, pine bark, sphagnum peat, *Tamarindus indica*, vermiculite.

INTRODUCTION

The Brazilian Cerrado region has a vast variety of fruit species, among these exotic and native ones. Exotic species have a promising potential for commercial cultivation, featuring a new segment for Brazilian fruit growing due to the preference for consumption of a specific market niche.

Among the species introduced in the Brazilian Cerrado, tamarind (*Tamarindus indica* L.) stands out, a species originally from South Africa which exhibits a high capacity to adapt to local edaphoclimatic conditions. Due to its resistance to drought and its well-developed and deep root system, it is recommended for cultivation in semi-arid regions, emphasizing wood supply, landscaping, and fruit production (Pereira et al., 2016).

However, the formation of seedlings is a primary step, as their quality will reflect in all subsequent stages of production, so adequate techniques are essential. In this sense, the plant environment is characterized as the set of micrometeorological conditions of the production area, which aim to provide adequate growing conditions, so the study to determine the appropriate cultivation environment for producing quality seedlings is extremely important (Costa et al., 2012).

For the production of high-quality tamarind seedlings, several techniques can be used, such as the use of shading, through the use of covering meshes, provided that the essential amount of light is provided, as this plays a fundamental role in plant development, being able to control processes that are related to DM accumulation, stem development, height, and leaf area (Mendonça et al., 2008; Costa et al., 2012). Good quality tamarind seedlings are also formed under full sun (Mendonça et al., 2008; Anil et al., 2022), which shows great adaptability of the species in different environmental conditions (El-Siddig et al., 2006; Mendonça et al., 2008).

The use of protected environments provides the plant with protection against direct incident radiation, rain, and strong winds, in addition to allowing greater phytosanitary control and production at different times of the year, thus providing better development throughout the crop cycle (Salles et al., 2019). However, despite the advantages of the protected environment, the study of shading levels involving production under full sun is necessary, as the light intensity can promote morphological changes in characteristics of the seedlings to reduce possible losses in the photosynthesis process and the excess or lack of photosynthetic radiation can be limiting for plant development (Taiz et al., 2014).

In addition to the environment, it is observed that the substrate is fundamental for adequate seedling development. It must have physical and chemical properties that provide adequate growth and development of the root and shoot of the seedlings, being formulated with a single material or by combining with different components in a way that retains moisture and promotes the availability of nutrients, meeting the plant's needs. For the growth of tamarind seedlings, substrates composed of 80% soil + 20% organic compost being commercial material composed of wastes from slaughterhouse, sugarcane bagasse, fruits, vegetables, cereals, among others (Costa et al., 2012), goat manure and organic compound (Pereira et al., 2016), sphagnum + 500 mg L^{-1} indolebutyric acid (Ferreira et al., 2017), soil + bovine manure and soil + goat manure (Gomes et al., 2019), cattle manure + buriti (*Mauritia flexuosa* L.f.) wood (Amaral et al., 2020) and organic substances and plant growth regulators (Khushboo Tandon et al., 2021), are suitable, because in addition to providing adequate nutrition and physical properties, which highlights the importance of the organic matter in the formulation of the substrate.

In addition, it is essential to determine the appropriate material for formulating substrates to establish a cultivation environment that favors the production of good quality seedlings, which varies among the species. Although the formulation of substrates by the producers themselves is advantageous, there are many difficulties in preparing homogeneous products, which results in high labor costs, so the acquisition of commercial substrates can favor production. These can present different constitutions, being important for the study to verify the compatibility of the substrate with the chemical and physical requirements of the species.

Considering the importance of the plant environment and the use of suitable substrates for the formation of seedlings of good quality fruit forest species, and the potential use of tamarind (*Tamarindus indica* L.) in Brazil, this study aimed to analyze different levels of shading and compositions of substrates in the formation of tamarind seedlings.

MATERIAL AND METHODS

The experiments with production of tamarind (*Tamarindus indica* L.) seedlings were conducted at the State University of Mato Grosso do Sul (UEMS), at the University Unit of Cassilândia (UUC), in Cassilândia (19º07'21" S, 51º43'15" W; 516 m a.s.l.), Mato Grosso do Sul, Brazil. According to the Köppen climate classification, it presents a rainy tropical climate (Aw-type) with rainy summer and dry winter.

A completely randomized experimental design (CRD) was adopted in a 4×4 factorial scheme. Four shading levels and four substrate compositions were evaluated. The four shading levels consisted of an open-air environment 0% shading, and full sun (FS) with three different shading percentages: 18%, 30%, and 50% (S18%, S30%, and S50%, respectively), given by three screen houses 18.0 m long × 8.0 m wide (144 m^2) and 3.5 m in height, closing at 45 degrees of inclination, with black monofilament screen (Sombrite, Group Equipesca, Campinas, São Paulo, Brazil).

In these cultivation environments, four different substrate compositions were also evaluated, derived from two commercial substrates: Sphagnum peat, vermiculite, dolomitic limestone, gypsum, and NPK fertilizer (Carolina Soil, Carolina Soil Company, Santa Cruz do Sul, Rio Grande do Sul, Brazil) and pine bark, charcoal, simple superphosphate, and vermiculite (TropStrato Tubete Citrus, Group Provaso-Vida Verde, Mogi Mirim, São Paulo, Brazil), pure or mixed with medium-sized vermiculite. The substrates were: 100% pine bark-based substrate (S1), 100% sphagnum peat-based substrate (S2), 50% pine bark-based substrate and 50% vermiculite (S3), and 50% sphagnum peat-based substrate and 50% vermiculite (S4), with four replicates of four seedlings each.

Tamarind fruits were collected in Cassilândia, on a farm, and propagation was conducted by seeds after removing the skin and pulp under running water.

Sowing was conducted in 128 cell trays on 28 September 2018, with only one seed per cell, containing 70% of the substrate based on pine bark and 30% medium vermiculite, with emergence being verified 7 d after sowing (DAS), after the stabilization of the emergence, the transplant was performed on 5 November 2018. The seedlings were transplanted into 1.8 L polyethylene bags (15.0 × 25.0 cm) with different substrate compositions and distributed in different growing environments.

The seedlings were watered using a watering can, keeping the humidity close to field capacity. Supplementary fertilization was not conducted, and insecticides and fungicides were unnecessary.

At 40 and 98 d after transplantation (DAT), data were collected on plant height (PH), stem diameter (SD), and number of leaves (NL). For these evaluations, four seedlings of each replicate were used. The height of the seedlings was measured with a graduated ruler, measuring the distance from the stem of the plant to the apex of the meristem of the stem, number of leaves was measured by counting, and diameter of the stem was measured with a digital caliper (mm). At 98 DAT, shoot DM (SDM) (g), root DM (RDM) (g), and total DM (TDM) (g) were determined, which were obtained after drying the root and shoot in an air-forced circulation oven at 65 °C until they reach the constant matter and measured on an analytical balance. The TDM (g) was obtained by adding the shoot and root DM. The absolute growth rate (AGR) was obtained through the relationship between height analysis according to the period between evaluations. The Dickson quality index (DQI) was calculated using the proposed formula: DQI = [TDM/(PH/SD) + (SDM/RDM)].

In the cultivation environments, the photosynthetically active radiation (PAR) (μmol m^{-2} s^{-1}) was monitored with a portable digital pyranometer (Apogee Instruments, Logan, Utah, USA), measured on days without clouds, always at the same time, at 10:00 h (GMT -4). Temperature (°C) and relative air humidity (RH%) were also monitored from weather stations (E4000, Irriplus Equipamentos Científicos, Viçosa, Minas Gerais, Brazil) installed inside and in the center of the screen houses with 18% and 30% shading and on the screen with 50% shading data was collected by the DataLogger device (InstruTemp Instrumentos de Medição Ltda., Vila Diva, São Paulo, Brazil). The temperature, relative humidity, and global solar radiation values were acquired from the automatic data collection station of Cassilândia (A742, INMET-SONABRA, Cassilândia, Mato grosso do Sul, Brazil) for the external environment. Data were recorded from November to February. Environmental data were compared in a randomized block design with five replicates (each replicate was a month of collection, from November to February). The precipitation was 343.20 mm (November), 153.00 mm (December), 108.40 mm (January), and 3.2 mm (February), with a total accumulated of 607.8 mm (INMET-SONABRA).

The data were submitted to ANOVA (F test) and means were compared by the Tukey test at 5% probability. The Pearson correlation |rij| was carried out through the network of correlations between the study variables. When present, positive relationships were highlighted in green, and negative relationships in red. The determination of line thickness followed the cutoff value of 0.7, corresponding to 70% reliability.

The canonical variables were also determined for the growth variables and biometric relationships existing between shading levels and substrates for tamarind seedlings. These analyzes were carried out with the R software v.4.0.3, using the Qgraph and Candisc packages (2022; R core team, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

By monitoring the micrometeorological data collected at different shading levels during the production of tamarind seedlings, it is observed that the air temperature and relative air humidity (Figures 1A and 1B), regardless of the month of collection in the different shadings, are equivalent. While the photosynthetically active radiation (PAR) (Figure 1C) showed great variation depending on the shading level used.

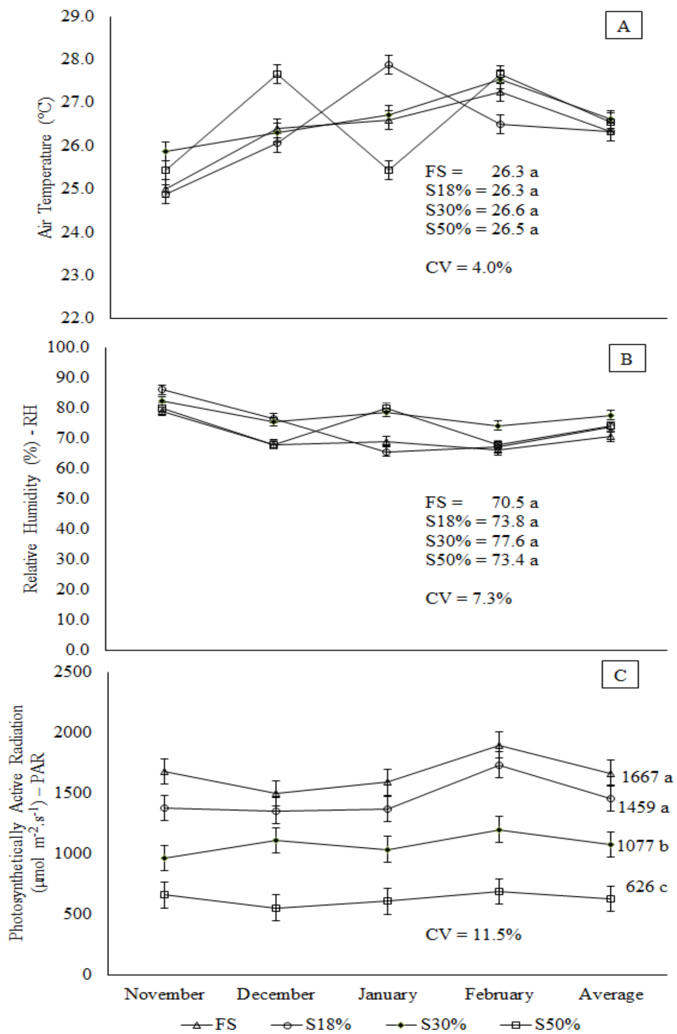

Figure 1. Air temperature (A), relative air humidity (B), and photosynthetically active radiation (C) in the different growing environments of tamarind seedlings. Means followed by the same lowercase letter for each variable do not differ by the Tukey test at 5% probability. CV: Coefficient of variation; FS: full sun; S18%: 18% shading; S30%: 30% shading; S50%: 50% shading. Vertical bars indicate standard error.

The substrate based on pine bark is indicated for producing coffee, flowers, citrus, and vegetables, as described by the company. It consists of pine bark, charcoal, simple superphosphate, and vermiculite. This product contains 25 kg with a density of 460 kg m^{-3} (wet base), corresponding to 54 L packaging (data provided by the manufacturer). The substrate based on sphagnum peat consists of sphagnum peat, expanded vermiculite, dolomitic limestone, gypsum, and NPK fertilizer, suitable for coffee, forest, fruit, desert rose, and vegetable seedlings; each 8 kg package corresponds to 45 L substrate. These were chemically analyzed (Table 1).

Table 1. Chemical characteristics of substrates used in the composition of the four substrates evaluated in the production of tamarind seedlings. *N, Ca, Mg, S, Cu, Fe, Mn, Zn, B, and Mo – Total contents. OM: Organic matter; CEC: cation exchange capacity.

Characteristics	Sphagnum peat-based substrate	Pine bark-based substrate
Nitrogen, g kg^{-1}	14.00	12.00
Phosphorus (P_2O_5), g kg^{-1}	3.60	4.00
Potassium (K_2O), g kg^{-1}	11.00	2.00
Calcium, g kg^{-1}	9.10	13.00
Magnesium, g kg^{-1}	42.00	22.00
Sulfur, g kg^{-1}	3.00	2.20
Copper, g kg^{-1}	0.06	0.04
Iron, g kg^{-1}	17.52	10.40
Manganese, g kg^{-1}	2.40	1.80
Zinc, g kg^{-1}	0.36	0.34
Boron, g kg^{-1}	0.08	0.00
Organic matter, g kg^{-1}	250.00	420.00
Moisture, g kg^{-1}	45.00	36.00
Mineral matter, g kg^{-1}	300.00	220.00
pH (in water)	6.15	5.12
C:N ratio	18.80	31.70
OM (DM), %	45.50	65.60
CEC, mmol kg^{-1}	850.00	890.00
Electrical conductivity, mS cm^{-1}	0.87	0.83

Substrate based on sphagnum peat (S2) had higher levels of nutrients such as N, K, Mg, S, Cu, Fe, Mn, and Zn, with B in its composition. At the same time, substrate based on pine bark did not contain it (Table 1). The substrate based on pine bark (S1) showed a C:N ratio of 31.70; this high ratio and the lower availability of N caused the immobilization of N, being reflected in the lower growth of seedlings than substrates S2 and S4 (50% substrate based on sphagnum peat+50% vermiculite) with a C:N ratio of 18.80 (Table 1).

The screen houses with 50%, 30%, and 18% shading allowed the passage of 37.5%, 64.6%, and 87.5% PAR concerning the full sun environment (100%) (Figure 1C). Thus, in this study on the plant environment, PAR was among the micrometeorological factors that most influenced growth conditions of seedlings.

There was an interaction between Shading levels × Substrates (A × S) for the variables, plant height at 40 DAT (PH1), plant height at 98 DAT (PH2), stem diameter at 40 DAT (SD1), stem diameter at 98 (SD2), number of leaves at 40 DAT (NLF1), number of leaves at 98 DAT (NL2), shoot DM (SDM), Dickson quality index (DQI), and absolute growth rate (AGR). There was no interaction between factors for the other variables, RDM and TDM; however, the influence of both factors was found on these variables (Table 2).

The different shading levels influenced seedling height at 40 DAT. The largest seedlings of substrate S2 were verified in 18%, 30% and 50% shadings. The largest seedlings of substrate S4 were observed in 18% and 30% shadings (Table 3).

Table 2. Summary of ANOVA of plant height at 40 (PH1) and 98 d after transplantation (DAT) (PH2), stem diameter at 40 (SD1) and 98 DAT (SD2), number of leaves at 40 (NLF1) and 98 DAT (NLF2), shoot DM (SDM), root DM (RDM), total DM (TDM), absolute growth rate (AGR), and Dickson quality index (DQI). *Significant at 5% probability; **significant at 1% probability; ^{ns}: nonsignificant; CV: coefficient of variation.

Treatments	PH1	SD1	NL1	PH2	SD2	NL2
Shading levels (SL)	**	**	**	**	**	**
Substrates (S)	**	**	**	**	**	**
SL × S	**	**	**	*	**	**
CV, %	7.0	6.2	15.7	9.3	8.7	26.7
Treatments	SDM	RDM	TDM	AGR	DQI	
Shading levels (SL)	*	ns	*	**	*	
Substrates (S)	**	**	**	**	**	
SL × S	*	ns	ns	**	*	
CV, %	24.5	28.1	23.1	23.7	27.8	

Table 3. Plant height at 40 (PH1) and 98 d after transplantation (DAT) (PH2), stem diameter at 40 (SD1) and 98 DAT (SD2), number of leaves at 40 (NL1) and 98 DAT (NL2), shoot DM at 98 DAT, and absolute growth rate of tamarind seedlings in different shading levels and substrates. Means followed by the same lowercase letter in the row and uppercase in the column, for each variable, do not differ by the Tukey test at 5% probability. CV: Coefficient of variation; S: substrate, S1: 100% substrate based on pine bark; S2: 100% substrate based on sphagnum peat; S3: 50% substrate based on pine bark + 50% vermiculite; S4: 50% substrate based on sphagnum peat + 50% vermiculite; FS: full sun; S18%: 18% shading; S30%: 30% shading; S50%: 50% shading.

	FS	S18%	S30%	S50%	FS	S18%	S30%	S50%
	Plant height at 40 DAT (cm) – PH1				Plant height at 98 DAT (cm)- PH2			
S1	15.8^{aB}	17.0^{aB}	18.2^{aB}	18.2^{aB}	17.7^{aB}	18.5^{aB}	18.9^{aB}	19.5^{aC}
S2	19.9^{bA}	25.0^{aA}	23.5^{aA}	20.0^{bB}	37.0^{bA}	38.0^{bA}	43.8^{aA}	39.7^{abA}
S3	16.6^{aB}	16.8^{aB}	15.9^{aB}	17.9^{aB}	17.7^{aB}	18.0^{aB}	16.8^{aB}	19.6^{aC}
S4	21.8^{bA}	23.5^{abA}	23.7^{abA}	24.9^{aA}	32.2^{cA}	40.2^{bA}	43.1^{abA}	47.1^{aB}
	Stem diameter at 40 DAT (mm) – SD1				Stem diameter at 98 DAT (mm)- SD2			
S1	2.49^{bA}	1.26^{cC}	2.80^{aAB}	2.74^{abA}	3.23^{aB}	3.16^{aB}	3.48^{aB}	3.26^{aB}
S2	2.53^{bA}	2.98^{aA}	2.88^{aAB}	2.46^{bA}	5.10^{aA}	5.11^{aA}	5.36^{aA}	4.22^{bA}
S3	2.49^{aA}	2.49^{aB}	2.58^{aB}	2.58^{aA}	3.30^{aB}	3.21^{aB}	3.16^{aB}	3.31^{aB}
S4	2.73^{aA}	2.97^{aA}	2.96^{aA}	2.69^{aA}	5.25^{aA}	4.65^{aA}	5.14^{aA}	4.59^{aA}
	Number of leaves at 40 DAT– NL1				Number of leaves at 98 DAT - NL2			
S1	9.0^{aB}	9.9^{aB}	10.9^{aB}	8.9^{aB}	11.2^{aB}	11.8^{aB}	12.3^{aB}	10.8^{aB}
S2	16.4^{aA}	17.5^{aA}	17.3^{aA}	10.9^{bB}	49.8^{aA}	38.9^{aA}	49.9^{aA}	22.2^{bA}
S3	9.7^{aB}	8.3^{aB}	8.6^{aB}	9.6^{aB}	11.1^{AB}	15.4^{aB}	9.6^{AB}	11.4^{AB}
S4	14.7^{aA}	10.3^{bB}	16.8^{aA}	14.8^{aA}	43.0^{abA}	31.7^{bA}	46.3^{abA}	40.0^{aB}
	Shoot dry matter at 98 DAT – SDM (g)				Absolute growth rate – AGR (cm d^{-1})			
S1	1.29^{aB}	1.37^{aB}	1.58^{aB}	1.53^{aC}	0.03^{aC}	0.03^{aB}	0.01^{aB}	0.02^{aB}
S2	6.20^{aA}	6.00^{aA}	6.77^{aA}	6.24^{aA}	0.29^{abA}	0.21^{bA}	0.34^{aA}	0.32^{aA}
S3	1.13^{aB}	1.15^{aB}	1.34^{aB}	1.55^{aC}	0.02^{aC}	0.02^{aB}	0.02^{aB}	0.03^{aB}
S4	6.68^{aA}	4.82^{bA}	7.70^{aA}	4.43^{bB}	0.17^{cB}	0.27^{bA}	0.32^{abA}	0.37^{aA}

The largest seedlings at 98 DAT were found on substrate S2 in environments with 30% and 50% shading; on substrates S1 and S3 (50% substrate based on pine bark+50% vermiculite), there was no difference depending on the cultivation environment, whereas, in S4, they were formed in the environment with 18%, 30% and 50% shading. Thus, it was observed that in substrate S2, the smallest seedlings occurred in the environment with 0% and 18% and in S4 with 0% shading (Table 3).

Regarding the substrates at 40 and 98 DAT, seedlings showed a similar response, since in environments with 0%, 18%, and 30% shading, seedlings with a higher height were formed on substrates consisting of pure substrate based on sphagnum peat or associated with vermiculite (S2 and S4). In the environment with 50% shading, at 40 DAT, seedlings were higher in height on S4 substrates, and at 98 DAT, the largest seedlings were found on substrate S2 followed by S4 (Table 3, Figure 2a). In the substrates S2 and S4, it was verified that the lowest heights occurred in the seedlings cultivated in environments with a higher intensity of solar radiation (Table 3, Figure 2b).

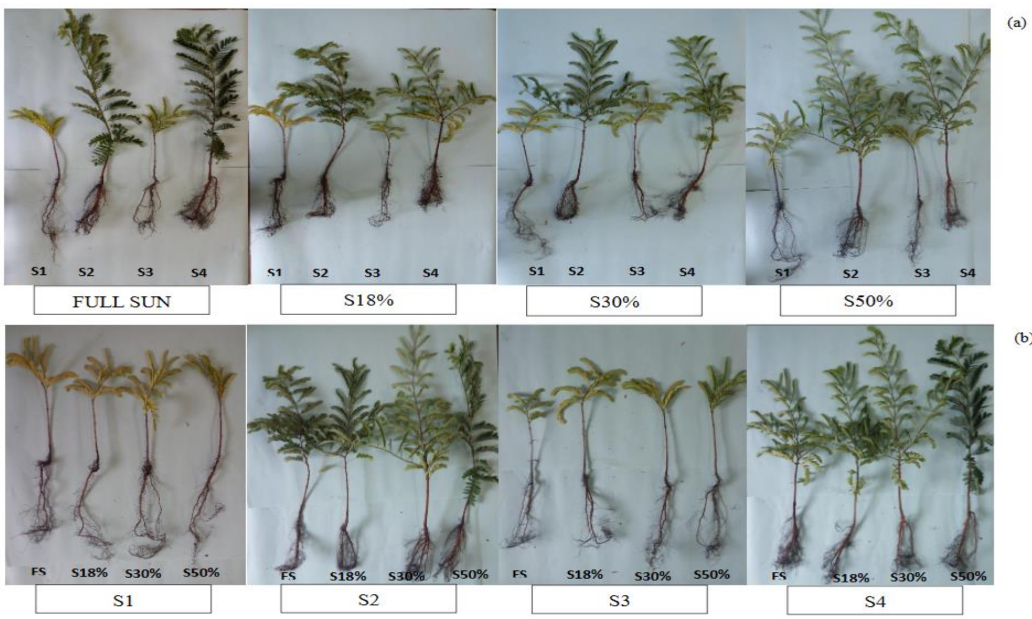

Figure 2. Comparison of tamarind seedlings according to the substrates within each cultivation environment (a) and Comparison of tamarind seedlings formed at different shading levels on each substrate used (b). Cassilândia-MS, 2019. S1: 100% Substrate based on pine bark; S2: 100% substrate based on sphagnum peat; S3: 50% substrate based on pine bark + 50% vermiculite; S4: 50% substrate based on sphagnum peat + 50% vermiculite; FS: full sun; S18%: screen 18%; S30%: screen 30%; S50%: screen 50%.

The seedlings formed in 0% and 50% shading environments at 40 DAT did not differ in diameter due to the different substrate compositions. However, in the environment with 18% shading, seedlings with larger diameters were formed on the substrate based on sphagnum peat (S2 and S4). In the environment with 30% shading, the largest diameters occurred in the seedlings from the substrates S4, however, did not differ from substrates S1 and S2 (Table 3).

At 98 DAT, the growth response in diameter of seedlings was more punctual as to the determination of the substrate that provided conditions that favored the growth of stem thickness because regardless of the cultivation environment, seedlings that presented the largest diameters were produced with substrates S2 (100% substrate based on sphagnum peat) and S4 (50% substrate based on sphagnum peat + 50% vermiculite) (Table 3).

Different shading levels promoted a difference in seedling diameter at 40 DAT, seedlings conducted on substrate S1 had the largest diameters in the environment with 30% shading, not differing from the environment with 50% shading, S2 substrate diameters were obtained from seedlings produced in environments with 18% and 30% shading. In the substrates S3 and S4, there was no influence of different shading levels (Table 3).

While at 98 DAT, there was a difference only in the substrates. For the variables plant height and stem diameter, the substrates composed of the commercial substrate based on sphagnum peat, presented chemical and physical conditions that favored the growth of the seedlings, which developed well both in the substrate S2 with 100% substrate based on sphagnum peat as in S4, containing 50% vermiculite (Table 3).

For the number of leaves at 40 DAT, there were no differences in the seedlings conducted on the substrates S1, S2, and S3 depending on the growing environments; however, on S4, the environments with 18% and 50% shading produced seedlings with the lowest number of leaves (Table 3).

At 98 DAT, it is possible to observe the increase in number of leaves, and in environments with 0%, 18%, and 30% shading, substrates S2 and S4 highlighted providing conditions that favored growth. While in the environment with 50% shading, seedlings with the highest number of leaves were obtained on S2, and S4 did not differ from S1 and S3 (Table 3).

And as observed in this study at 98 DAT, seedlings in the substrate S2 and S4 in the environment with 30% shading presented a number of leaves greater than 45, while in the substrate based on pine bark (S1 and S3), it ranged from 9.62 to 12.25 (Table 3). It demonstrated the greatest growth and development of seedlings in the same growing period, depending on the substrate.

The seedlings grown on the peat-based substrates had a greater number of leaves and showed more vivid colors, with an intensity of green color, while seedlings conducted on the substrate based on pine bark showed less intense color (Figure 2).

Through the absolute growth rate (AGR), it is possible to verify the growth according to the period of seedling production. The seedlings conducted in S1 and S3 showed no difference due to the different shading levels, presenting a daily growth in height ranging between 0.01 and 0.03 cm d^{-1} (Table 3).

The seedlings conducted on substrates S2 had greater daily growth in 30% and 50% shading environments; however, they did not differ from the full sun environment, and the latter did not differ from the environment with 18% shading. In the substrate S4, the highest growth rate was observed in the environment with 50% shading (0.36 cm d^{-1}), but it did not differ from the environment with 30% shading (0.32 cm d^{-1}) (Table 3).

Thus, it was observed that in environments with 50% and 30% shading, featuring the highest shading levels, between November and February, the radiation conditions (PAR) to which the seedlings were conducted, with averages of 626.0 and 1077.4 µmol m^{-2} s^{-1} (Figure 1C), respectively, constituted a favorable radiation range for the greatest daily increase in seedling height.

For the SDM variable, there was no difference between the cultivation environments for seedlings conducted on substrates S1, S2, and S3, while seedlings conducted on substrate S4 showed greater DM accumulation in environments with 0% and 30% shading. The substrates that favored the greatest DM accumulation of the seedlings were those constituted by substrate based on sphagnum peat (S2 and S4) (Table 3).

In the full sun environment, despite the high intensity of solar radiation, shoot DM of the seedlings did not differ from the environment with 30% shading. While in the environment with 18% shading, the level of radiation was high, the seedlings reaching about 87.5% of the external radiation (Figure 1C). Due to the structure of the screen, the ventilation inside is reduced; so, there was greater thermal discomfort compared to the full sun environment due to the higher temperature in January (Figure 1B).

For the variables RDM and TDM, there was no interaction between the environmental factors and substrates. According to the individual analysis of the factors, it was observed that both for the RDM and TDM, the substrates constituted by substrate based on sphagnum peat favored greater DM accumulations; therefore, these substrates containing sphagnum peat promoted adequate seedling growth (Table 4).

Table 4. Root DM and total DM of the tamarind seedlings according to the shading levels and substrates. Means followed by the same letter in the column for each variable do not differ by the Tukey test at 5% probability. CV: Coefficient of variation. S1: 100% substrate based on pine bark, S2: 100% substrate based on sphagnum peat, S3: 50% substrate based on pine bark + 50% vermiculite, S4: 50% substrate based on sphagnum peat + 50% vermiculite.

Substrates	Root DM (g)	Total DM (g)
S1	1.28^{b}	2.72^{b}
S2	3.02^{a}	9.32^{a}
S3	1.16^{b}	2.46^{b}
S4	2.63^{a}	8.53^{a}
Environments	Root DM (g)	Total DM (g)
Full sun	1.93^{a}	5.76^{ab}
Screen 18%	1.92^{a}	5.25^{b}
Screen 30%	2.30^{a}	6.65^{a}
Screen 50%	1.94^{a}	5.38^{b}

Regarding the cultivation environments, for the root system, there was no difference due to the intensity of photosynthetically active radiation (Figure 1C) received by the seedlings. However, the shading levels reflected an effect on the total dry matter, in which the greatest accumulation of matter occurred in seedlings grown in the environment with 30% shading, but this did not differ from the full sun conditions, which did not differ from 18% and 50% shading with the lowest TDM values (Table 4).

The Dickson quality index is one of the methods that present greater reliability; the higher the means, the higher the quality of seedlings, and this was observed in this study because seedlings in all shading levels showed higher quality when cultivated in the substrates 100% substrate based on sphagnum peat (S2) and 50% substrate based on sphagnum peat + 50% vermiculite (S4), therefore, these substrates formed seedlings with higher quality than the seedlings in the substrates containing substrate based on pine bark (Figure 3).

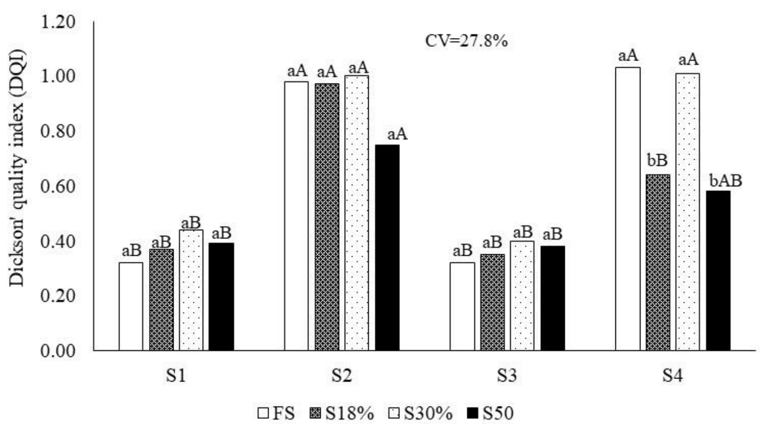

Figure 3. Dickson quality index (DQI) of tamarind seedlings according to the shading levels and substrates. CV: Coefficient of variation. Means followed by the same lowercase letter indicate no difference among environments within each substrate, and means followed by the same uppercase letter indicate no difference among substrates within each environment, both by the Tukey test at 5% significance. S1: 100% Substrate based on pine bark; S2: 100% substrate based on sphagnum peat; S3: 50% substrate based on pine bark + 50% vermiculite; S4: 50% substrate based on sphagnum peat + 50% vermiculite; FS: full sun; S18%: screen 18%; S30%: screen 30%; S50%: screen 50%.

On average, the tamarind seedlings on substrates based on sphagnum peat showed DM distribution of 68% for SDM and 32% for RDM, and on substrates based on pine bark, they presented 53% SDM and 47% RDM (Figure 4). Based on the correlation between the seedling quality with the distribution of shoot and root DM, it can be inferred that a high-quality tamarind seedling, on average, allocates close to 2/3 DM in the shoot and 1/3 DM in the root. In this way, treatments with suitable substrates, applied to the plant environment, practically maintain a ratio 2:1 in the distribution of DM between the shoot and root of the seedlings; that is, the allocation of DM in the shoot is twice the root (Figure 4).

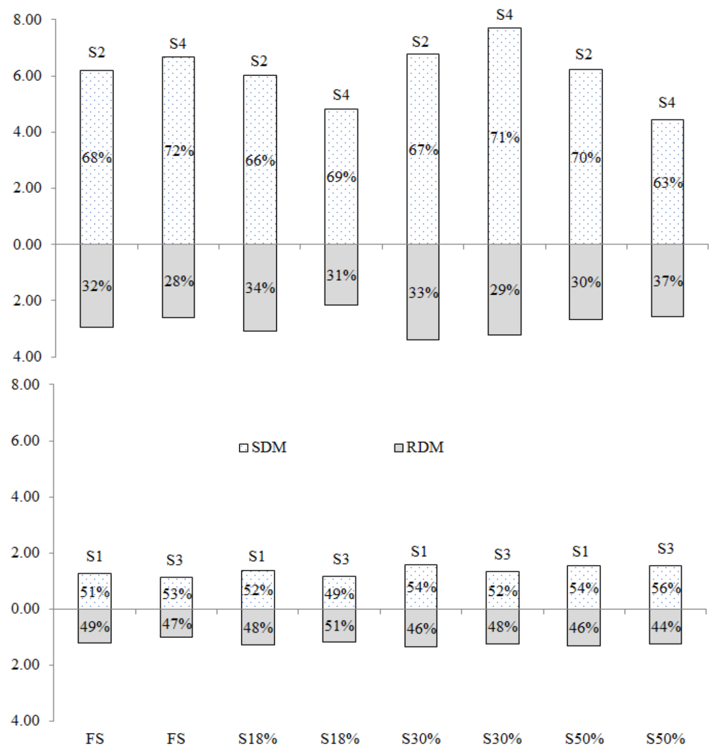

Figure 4. Distribution of DM between shoot (SDM) and root (RDM) in tamarind seedlings according to the shading levels and substrates. S1: 100% Substrate based on pine bark; S2: 100% substrate based on sphagnum peat; S3: 50% substrate based on pine bark + 50% vermiculite; S4: 50% substrate based on sphagnum peat + 50% vermiculite; FS: full sun; S18%: screen 18%; S30%: screen 30%; S50%: screen 50%.

According to the statistics of the multivariate analysis, canonical variables, all the variables analyzed demonstrate an indication of effect for all paired treatments. In this case, the even treatments correspond to those containing the main composition of substrate based on sphagnum peat (Figure 5). The presented result emphasizes all the data in the study on the efficiency of the substrate used for the growth and development of the tamarind seedlings. Likewise, it is observed that the variables tended towards treatments 30% shading level + substrate based on sphagnum peat (10), 30% shading level + 50% substrate based on sphagnum peat and 50% vermiculite (12), and 50% shading level + substrate based on sphagnum peat (14). With the result obtained, we can infer that using an environment with 30% shading associated with a substrate consisting of 50% substrate based on sphagnum peat + 50% vermiculite characterizes a viable alternative to produce tamarind seedlings in a protected environment.

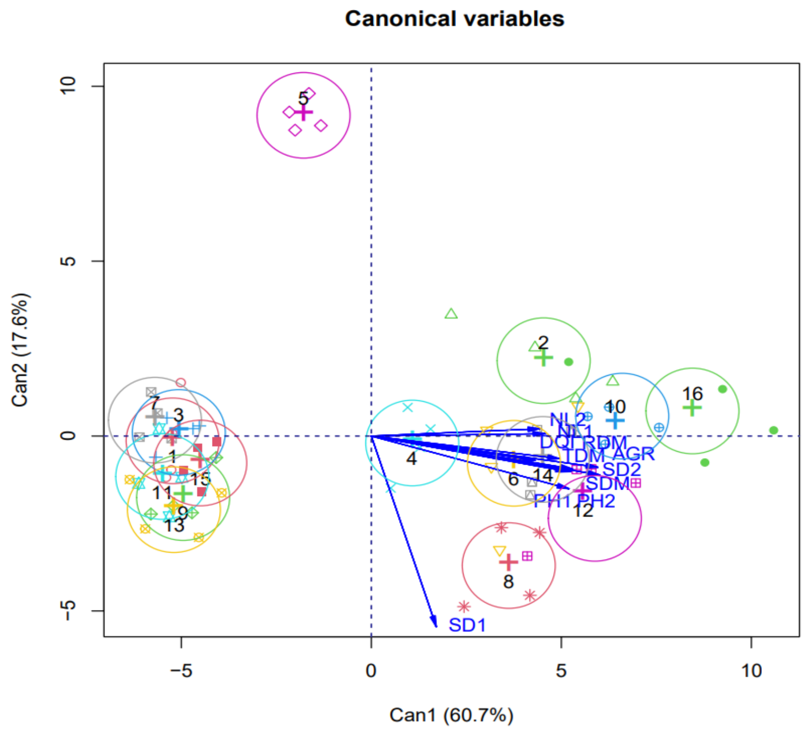

Figure 5. Multivariate analysis of canonical variables referring to the analyzed variables of tamarind seedlings according to the shading levels and substrates. Cassilândia, 2019. FS: Full sun; S18%: screen 18%; S30%: screen 30%; S50%: screen 50%; S1: 100% substrate based on pine bark; S2: 100% substrate based on sphagnum peat; S3: 50% substrate based on pine bark + 50% vermiculite; S4: 50% substrate based on sphagnum peat + 50% vermiculite; FS: full sun; S18%: screen 18%; S30%: screen 30%; S50%: screen 50%. Then, 1: FS+S1; 2: FS+S2; 3: FS+S3; 4: FS+S4; 5: S18%+S1; 6: S18%+S2; 7: S18%+S3; 8: S18%+S4; 9: S30%+S1; 10: S30%+S2; 11: S30%+S3; 12: S30%+S4; 13: S50%+S1; 14: S50%+S2; 15: S50%+S3; 16: S50%+S4.

In addition to the results analyzed for canonical variables, the correlation between the study variables shows that except for the stem diameter (SD1), which only showed interaction with PH1 and SD2, all the others were highly correlated (Figure 6).

According to the results obtained, due to the positive correlation observed between all the variables, represented by the green color, it is understood that due to the positive correlation, as there was an increase in one variable, there was an increase in the others. In this way, the substrates that promoted greater growth in height, number of leaves, and diameter, reflected in a higher daily growth rate, with seedlings with higher DM and quality, that is, tamarind seedlings with growth in height and leaves, become more exuberant in size and conformation, obtaining vigorous seedlings, with adequate development of shoots and root system (Figure 6).

Generally, for all the variables analyzed, the positive effect of using substrate based on sphagnum peat on the composition of the substrates S2 and S4 was observed. This substrate has raw material with greater added value when compared to the substrate based on pine bark. Thus, as the substrate based on sphagnum peat + 50% vermiculite promotes the same growth pattern for the seedlings, the use of vermiculite can cause a reduction in production costs.

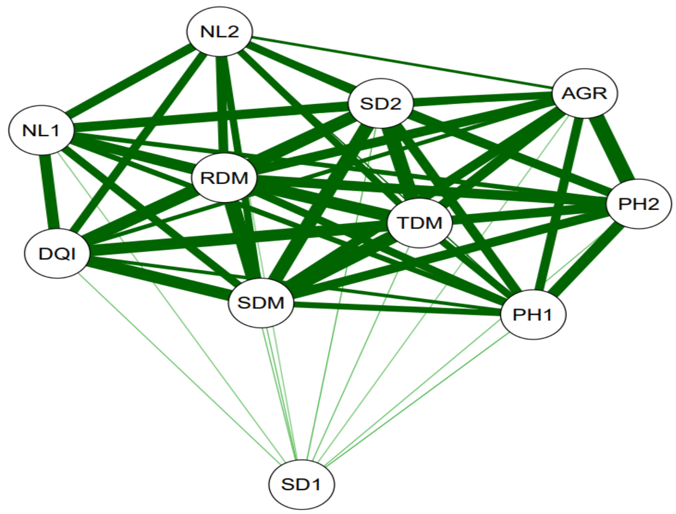

Figure 6. Pearson correlation between the analyzed variables of tamarind seedlings according to the shading levels and substrates. Cassilândia, 2019. Plant height at 40 (PH1) and 98 d after transplantation (DAT) (PH2), stem diameter at 40 (SD1) and 98 DAT (SD2), number of leaves at 40 (NL1) and 98 DAT (NL2), shoot DM (SDM), root DM (RDM), total DM (TDM), absolute growth rate (AGR), and Dickson quality index (DQI).

DISCUSSION

Tamarind, *Tamarindus indica* L., seedlings, due to their characteristics of origin from tropical climate regions (India/Africa), are very demanding in light (El-Siddig et al., 2006) and adapted better to full sun (Mendonça et al., 2008) and in a 30% shaded environment. Because it adapts to large variations in temperature (9.5 to 37 ºC), altitude (0 to 2000 m), soil types (El-Siddig et al., 2006), as well as tolerating adverse weather conditions (Mendonça et al., 2008), the seedlings developed properly in all environments, which had similar temperatures, but very different luminosities, due to shading screens.

Tamarind seedlings can be produced in full sun (Mendonça et al., 2008), in a greenhouse (Costa et al., 2012), or black screen with 50% shading (Mendonça et al., 2008; Soares et al., 2017). The seedlings in the 50% shading environment developed less than those in full sun and 30% shading environment; however, in this type of environment, seedlings have higher levels of chlorophyll *a*, chlorophyll *b*, total chlorophyll, and the chlorophyll *a*/*b* ratio, comparing the blue, red, and white screens, all with 50% shading (Soares et al., 2017), present adequate quality index when using substrate containing 60% of organic compound (Costa et al., 2012) or with Osmocote (15-10-10) at a dose of up to 6.0 kg m^{-3} (Mendonça et al., 2008).

In full sun, the seedlings receive a higher rate of photosynthetic radiation and are more apt to receive green grafting (Anil et al., 2022), with a higher quality index (Mendonça et al., 2008); however, due to exposure to high direct radiation, the seedlings do not have high height, because in the photomorphogenic process, plants under high irradiance can inhibit the extension of the hypocotyl and stem growth (Taiz et al., 2014).

In conditions of lower light intensity, the level of phytochrome in the form of far-red absorption is low, inhibiting the sensitivity of the hypocotyl to endogenous gibberellin and promoting greater cell elongation of the hypocotyl (Taiz et al., 2014), promoting plants with taller height. The shading aims to reduce thermal stress, relating temperature and solar radiation, requiring specific studies because inadequate shading can reduce photosynthesis and, consequently, delay plant growth (Wu et al., 2018).

The beneficial effect of substrate based on sphagnum peat on seedling growth is a function of the chemical and physical characteristics of the substrate. Among micronutrients, it appears that the lack of B results in more frequent deficiency compared to nutrients in this same category, and the lack of this essential element can significantly affect plant development, resulting in rapid inhibition of seedling growth. Boron participates in a series of physiological processes, including the formation and stabilization of the cell wall, integrity of the plasma membranes, lignification, and differentiation of the xylem, so when there is a deficiency, growth is affected by the failure to develop new shoots and roots (Hänsch and Mendel, 2009).

These chemical characteristics of substrate based on sphagnum peat that presented higher amounts of macro and micronutrients, pH, and adequate C:N ratio promoted the nutritional supply that favored the fast and adequate growth of seedlings, and in addition, it presented an adequate structure for the removal of the seedlings to conduct the transplant. Substrates with a C:N ratio greater than 25 (substrate based on pine bark) present strong N immobilization and slow decomposition of the plant material when inferior that they allow high mineralization of N (substrate based on sphagnum peat). In addition to the yellowing of the leaves, one of the symptoms of nutritional N deficiency is leaf chlorosis (Taiz et al., 2014).

The vermiculite acted as a conditioner, which, associated with the substrate based on sphagnum peat, favored the growth of seedlings; despite being an inert material, which does not aggregate with nutrient supply, it is a compound that promotes the physical property of the substrate (Kim and Kim, 2011), as it guarantees greater porosity, and aeration capacity, adding water retention. Seedlings produced with the substrate based on pine bark would need additional fertilization and a longer conduction period to obtain growth similar to substrate based on sphagnum peat.

The use of substrate containing organic matter (Costa et al., 2012; Pereira et al., 2016; Ferreira et al., 2017; Gomes et al., 2019; Amaral et al., 2020) promotes an increase in the translocation of nutrients which generates vigorous development in height, stem diameter, and DM accumulation, and presents an adequate nutritional balance that reflects in higher growth. Substrates based on sphagnum peat promote seedlings with a greater DM accumulation, height, and number of leaves, as it promotes porosity, nutrition, and adequate structuring conditions (Melo et al., 2019). In this study, the positive effect of the substrate based on sphagnum peat was also observed, which presents organic matter, sphagnum peat, and chemical characteristics, such as the presence of the micronutrient B and greater availability of N that were fundamental for the quality of the seedlings.

In the substrates that formed the seedlings with higher quality, those that contained substrate based on sphagnum peat, due to adequate nutrition, the plants invested more in the shoot and less in the root system, which favored greater production of photoassimilates. Thus, it is evident that the scarcity of nutrients reduces the production of photoassimilates as the plants become smaller. The distribution of DM between shoot and root tends to become equal, as the root system tends to become deeper in search of nutrients. This energy expenditure causes the shoot to become reduced, as observed in the seedlings formed on the substrates containing substrate based on pine bark.

Based on the correlation between quality of the seedling and distribution of DM between shoot and root, it can be inferred that a high-quality seedling of tamarind tree, on average, accumulate close to 2/3 DM in the shoot, and 1/3 DM in the root. In this way, treatments with suitable substrates, applied to the plant environment, practically maintain a ratio of 2:1 in the DM distribution between the shoot and root of the seedlings; the shoot is twice the root part.

The correlation in multivariate analysis is a tool important to infer the effect of management on the behavior of cultivated plants. It is worth noting that the Pearson correlation demonstrates the connection between the variables, which can contribute to the understanding of growth and development throughout the seedlings and their final conformation (Pedó et al., 2021), as verified in the present study, which the positive correlations between the variables demonstrate greater security in the results obtained.

Excess solar radiation and temperature can negatively affect production for several crops, especially in the summer. In regions with high average irradiance values, manipulation with the use of shading screens is an option to optimize agricultural production sustainably, as they promote thermal comfort for plant development. Regarding the cultivation environments, considering all the variables analyzed in the present study, it was observed that tamarind, being a rustic species with greater tolerance to harmful weather, developed well in the full sun environment. However, considering the ergonomics of the worker, the shading environment with 30% promotes greater thermal comfort during the execution of activities.

CONCLUSIONS

The use of sphagnum peat-based substrate, pure or mixed with 50% medium vermiculite, produced the best tamarind seedlings. The environments with 30% shading and full sun promote the formation of high-quality tamarind seedlings.

Author contribution

Conceptualization: J.S.S., F.F.S.B., E.C. Methodology: J.S.S., F.F.S.B., E.C. Investigation: J.S.S, A.H.F.L., E.C. Resources: G.H.C.V., E.C. Data curation: J.S.S., F.F.S.B., A.H.F.L., and E.C. Writing-original draft: J.S.S., F.F.S.B., E.C. Writing-review & editing: J.S.S., F.F.S.B., E.C., G.H.C.V., W.S.G.J., and E.J.S.J. Project administration: F.F.S.B., E.C., G.H.C.V. Funding acquisition: F.F.S.B., E.C., G.H.C.V. All co-authors reviewed the final version and approved the manuscript before submission.

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