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Bioactive Compounds and Initial Growth Parameters of *Jacaranda mimosifolia* Under Shading Levels and Substrate Compositions in Tropical Conditions

By Amanda Maria Frata Ferreira, Tassila Aparecida do Nascimento de Araújo, Edilson Costa, Thaise Dantas, Flávio Ferreira da Silva Binotti, Giovana Pinheiro Viana da Silva, Gustavo Haralampidou da Costa Vieira, and Eduardo Pradi Vendruscolo

Abstract. Background: This study aimed to evaluate bioactive compounds and initial growth parameters of *Jacaranda mimosifolia* seedlings under shading levels and substrate compositions. Methods: A completely randomized design arranged in a 3 × 5 factorial scheme (3 shading × 5 substrates) was used. The shading levels were 0%, 30%, and 50%. The substrates were compost made up of organomineral material (M) and vermiculite (V): 100/0 M:V, 80/20 M:V, 60/40 M:V, 40/60 M:V, and 20/80 M:V. Results: Producing *J. mimosifolia* seedlings under the full sun is not recommended in tropical conditions. The 30% and 50% shade screens reduced photosynthetically active radiation by 38% and 62%, respectively. In the 50% shading environment, the average number of leaves increased by 68%, the stem diameter by 60%, the shoot dry matter by 250%, the root dry matter by 113%, the total dry matter by 184%, and the quality of the *J. mimosifolia* seedlings by 127%. The cultivation in the 50% shading environment, on average, increased the chlorophyll *a* content by 77%, the chlorophyll b content by 56%, the total chlorophyll content by 70%, and the carotenoid content of the *J. mimosifolia* seedlings by 45%. A substrate containing 20%M for *J. mimosifolia* seedlings is not recommended. The best *J. mimosifolia* seedlings are produced in the 50% shading environment and the 100%M substrate, resulting in better biometric quality and higher chlorophyll and carotenoid contents in addition to promoting an improvement in the survival rate and acceleration in initial growth.

Keywords. Organominerals; Photosynthetic Pigments; Protected Environments; Screenhouse.

INTRODUCTION

The jacaranda (*Jacaranda mimosifolia*), known in Brazil as jacaranda mimoso, carobaguaçu, or azul, belongs to the Bignoniaceae family and is an exotic species native to Argentina, Bolivia, and Paraguay (Hills 2020). It is an ornamental tree that adapts easily to tropical and temperate regions (Alves et al. 2010). *Jacaranda mimosifolia* has antimicrobial properties (Mahran et al. 1991; Aguirre-Becerra et al. 2020), antioxidant properties (Aguirre-Becerra et al. 2020), and insecticidal properties in the control of *Acanthoscelides obtectus* in bean grains (Waweru et al. 2017). Other species from the same family, such as *J. cuspidifolia* Mart., have antibacterial properties (Arruda et al. 2011); *J. decurrens* has antioxidant and cytotoxic activity (Casagrande et al. 2014); *J. acutifolia* has antioxidant activities (Chen et al. 2006); and *J. glabra* has activity against *Plasmodium falciparum* (Gachet et al. 2010).

In addition, extracts of the leaves and flowers of *J. mimosifolia* have bioactive compounds such as fatty acids, anthocyanins, acetosides, phenylpropanoid derivatives, flavonoids, triterpenes, and quinones that have beneficial properties in the treatment of hypertension, ulcers, wounds, diarrhea, dysentery, and amoebic infections (Castillo-España et al. 2012; Naz et al. 2020), as well as influencing the production of pigments that are beneficial to human health. Bioactive compounds vary according to the quantity and quality of light in the growing environment (Silva et al. 2020).

Plant growth is largely influenced by abiotic environmental factors, with light being one of the most significant (Paradiso and Proietti 2022). It provides the energy needed for photosynthesis, and in seedlings of the Bignoniaceae family, light levels in protected environments affect morphological characteristics (Moratelli et al. 2007; da Silva Chaves et al. 2018; Souza and Freire 2018; Silveira et al. 2020). Proper selection of the protected environment and shading intensity is crucial for the growth of seedlings of *J. brasiliana* (de Freitas et al. 2017), *J. copaia* (Campos and Uchida 2002), and *J. puberula* (de Almeida et al. 2005), as well as the production of bioactive compounds. All types of screens can be used in tropical regions, while in colder regions, the exclusive use of screens is not feasible (Hickman 2018). In addition, the geographical location, micrometeorological conditions, and the interactions of the environment with substrate, container, nutrition, irrigation, and cultivars define the best environment and express the maximum potential of the species (Costa et al. 2023b).

In addition to protected environments with different covering materials, with their different shading screens, the type of substrate used, both alone and in a mixture, offers alternatives that can promote better development of the root system and more effective nutrition for seedlings of the Jacaranda genus (da Silva Chaves et al. 2018). Commercial peat based substrates provide plants with good development, as they have the physical balance and chemical characteristics to provide nutrients, retain moisture, and maintain adequate temperature (Tonetto et al. 2020; Ferraz et al. 2022).

The quality of the seedlings directly influences the development and yield of the plants, so the proper use of the substrate (Cavalcante et al. 2021; Costa et al. 2023a), the growing environment (depending on the shading levels), together with the growing region (Hickman 2018; Costa et al. 2023b) are all fundamental for the proper growth and production of bioactive compounds in your seedlings.

However, there is still insufficient information in the literature about the composition of the substrate, the growing conditions for jacaranda seedlings, and the environment/substrate interaction. It is, therefore, important to know these responses to help produce quality seedlings. This study aimed to evaluate the bioactive compounds and growth of jacaranda plants in different combinations of environments and substrates.

MATERIALS AND METHODS

The experiment to evaluate bioactive compounds and initial growth parameters of *J. mimosifolia* under different shading levels and substrates in tropical conditions was conducted from 2022 April 8 to June 28. It took place at Mato Grosso do Sul State University (UEMS), Cassilândia Campus, located in Cassilândia, Brazil (19°07’21”S, 51°43’15”W, at an altitude of 516 m).

The environment factor was evaluated at 3 shading levels (0%, 30%, and 50%), while the substrate factor was assessed at 5 levels, both in a completely randomized design arranged in a 3 × 5 factorial scheme (3 shading × 5 substrates) with 6 replications and 4 seedlings per plot. Within each cultivation environment, each substrate was composed of 24 plants, and all were used in replications, forming 6 sets of 4 plants. The environments consisted of full sun (0% shading) and 2 screenhouses, one providing 30% shading and the other 50% shading. The screenhouses measured 18.0 m × 8.0 m × 3.5 m (144 m²) and were enclosed at a 45° angle using black monofilament mesh. The air temperature (°C), relative air humidity (%), and global solar radiation (W m^{-2}) for each environment were monitored from weather stations (E4000, Irriplus Equipamentos Científicos, Viçosa, Minas Gerais, Brazil) installed inside and in the center of the environments (Table 1).

In these growing environments, 5 different substrate compositions were evaluated (S1, S2, S3, S4, and S5) using the commercial substrates Carolina Soil® (Carolina Soil Company, Kinston, NC, USA) organomineral material (M) and vermiculite (V), mixed as follows: S1 = 100%M + 0%V; S2 = 80%M + 20%V; S3 = 60%M + 40%V; S4 = 40%M + 60%V; S5 = 20%M + 80%V. The Carolina Soil® substrate is made up of sphagnum peat, vermiculite, and agroindustrial organic waste (Table 2). Vermiculite is a mineral and inert material.

The seeds were purchased commercially, and on 2022 April 8, 2 seeds were sown per polyethylene bag (15.0 cm × 25.0 cm, capacity of 1.8 liters). Emergence was verified 14 days after sowing (DAS), and thinning occurred at 28 DAS. Irrigation was conducted twice daily, morning and afternoon, according

Table 1. Air temperature, relative air humidity, and global solar radiation for each protected environment.

	Air temperature (°C)	Relative air humidity (%)	Global solar radiation (W m^{-2})
Full sun	20.81	67.00	364.00
30% shading	23.86	75.75	227.12
50% shading	21.45	72.40	139.84

Table 2. Analysis of the chemical and physical characteristics of the substrate Carolina Soil®. OM (organic matter); C/N (carbon/nitrogen ratio); WRC (water retention capacity); DD (dry density); CEC (cation exchange capacity); EC (electrical conductivity).

Characteristic	Value
N (%)	1.400
P_2O_5 (%)	0.400
K_2O (%)	1.100
Ca (%)	0.900
Mg (%)	4.200
S (%)	0.300
H65 °C (%)[§]	45.000
OM (%)	2.500
C (%)	2.700
C/N	18.800
Cu (%)	0.006
Zn (%)	0.036
Fe (%)	1.752
Mn (%)	0.240
B (%)	0.008
WRC (%)	51.000
DD (g m^{-3})	130.000
pH ($CaCl_2$)[ǂ]	6.200
CEC (mmol kg^{-1})	850.000
EC (mS cm^{-1})	0.870

[§]H65 °C = % of humidity at 65 °C
[ǂ]pH = hydrogen ion concentration

to the plant's needs (without soaking the substrate) using microsprinklers (SpinNet™ emitters with an irrigation capacity of 70 liters per hour)(Netafim, Giv'atayim, Israel). Fertilization and application of agricultural defensives were not carried out.

At 81 DAS, plant height (PH, cm), stem diameter (SD, mm), number of leaves (LN), shoot dry matter (SDM, g), and root dry matter (RDM, g) were assessed. The total dry matter (TDM, g), the plant height/stem diameter ratio (PH/SD), and the Dickson Quality Index (DQI) were determined. The height of the seedlings was measured using a graduated ruler in centimeters, measuring the distance from the base of the plant to the apex of the stem meristem. The diameter of the stem was measured with a digital caliper in millimeters. The number of leaves was determined by counting. The shoot and root dry matter was obtained after drying in a forced air circulation oven at 65 °C for 72 hours and weighed on an analytical balance with precision of 4 decimal places.

The levels of chlorophyll *a* (CLA), chlorophyll *b* (CLB), *total* chlorophyll (CLT), and carotenoids (CRT) were also determined. Chlorophyll (*a* and *b*) and carotenoid extractions were conducted following the methodology of Lichtenthaler (1987). A sample of 0.5 g of fresh plant material was weighed, 5 mL of 80% acetone was added, and the material was stored in 14-mL test tubes for 48 hours in a refrigerator at 25 °C. After this period, the test tubes were centrifuged for 15 minutes at 4,000 rpm, and then the extract supernatant was diluted in a ratio of 0.2 mL of extract to 1.8 mL of 80% acetone. Measurements were made using a spectrophotometer at 470 nm, 647 nm, 653 nm, 663 nm, and 665 nm. The ratios of chlorophyll *a*/*b* (CLA/CLB) and total chlorophyll/carotenoids (CLT/CRT) were determined.

Photosynthetically active radiation (PAR)(µmol m^{-2} s^{-1}) was monitored in the growing environments using a portable digital pyranometer (Apogee®

MQ-200 Quantum-Meter)(Apogee Instruments, Logan, UT, USA) on cloudless days at 9:30 am. The PAR data was compared in a randomized block design with 8 replications (each replication corresponded to 10 days of the experiment).

Since there were no replicates of the seedling production environments, each one was considered an experiment, and the environments were compared by joint analysis using by factorial scheme 3 × 5 (3 environments × 5 substrates)(Banzatto and Kronka 2006). In each environment, completely randomized design was used to evaluate the 5 substrate compositions, with 6 replicates of 4 plants each. The data was submitted for analysis of variance, and the means were compared using the LSD test for the environments and the Tukey test for the substrates, both at 5% probability, using the Sisvar® 5.3 statistical program (Ferreira 2019).

All the analyses were conducted using R software version 4.1.0 (R Foundation, Vienna, Austria) using the Corrplot packages for correlation. Multivariate analysis was conducted using canonical variables (Candisc package) and principal components. Principal component analysis (PCA) was conducted with the Ggfortify and Factoextra packages.

The data was also subjected to Pearson correlation analysis (R software version 4.3.3 Corrplot package) using the correlation matrix with different color gradients between the variables. The relationships were determined as follows: the closer to the blue color, the positive correlations were highlighted, while the negative correlations were highlighted in red. Correlations with 0.05% error were marked with one asterisk, correlations with 0.01% error with two asterisks, and correlations with 0.001% error with three asterisks.

RESULTS

The joint analysis, using the factorial scheme environments (E) × substrates (S), showed that there was a significant interaction (E × S) for the variables plant height (PH), number of leaves (LN), shoot dry matter (SDM), total dry matter (TDM), the plant height/stem diameter ratio (PH/SD), chlorophyll *a* (CLA), *total* chlorophyll (CLT), and carotenoids (CRT). The environments were significant for all variables (Table 3).

Under full sun, the seedlings did not develop properly, with a reduced number of plants; therefore they were not included in the statistical analysis.

All the shading screens showed significant differences in photosynthetically active radiation (PAR µmol m^{-2} s^{-1}), and the greater the shading, the lower the PAR (Figure 1). On average, the PAR of the 30% and 50% shading screens was 62% and 38% of the external PAR, respectively.

The tallest plants were found in the environment with 50% shading (S50%) in all the substrates studied.

Table 3. Analysis of variance of the joint analysis. Pr (probability); Fc (Fcalculated); PH (plant height); SD (stem diameter); LN (number of leaves); SDM (shoot dry matter); RDM (root dry matter); TDM (total dry matter); PH/SD (plant height/stem diameter ratio); DQI (Dickson quality index); CLA (chlorophyll *a*); CLB (chlorophyll *b*); CLT (*total* chlorophyll); CRT (carotenoids).

	Pr > Fc[§]					
	PH	**SD**	**LN**	**SDM**	**RDM**	**TDM**
Environments (E)	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Substrates (S)	0.0002	0.7726	0.0023	0.0000	0.3114	0.0002
E × S	0.0103	0.2942	0.0043	0.0014	0.0888	0.0244
	PH/SD	**DQI**	**CLA**	**CLB**	**CLT**	**CRT**
Environments (E)	0.0123	0.0000	0.0000	0.0000	0.0000	0.0000
Substrates (S)	0.0042	0.6086	0.0002	0.0028	0.0004	0.0041
E × S	0.0134	0.4182	0.0006	0.1123	0.0039	0.0054

[§](Pr > Fc) > 0.05, not significant; 0.05 < (Pr > Fc) < 0.01, significant at 0.05; (Pr > Fc) < 0.01, significant at 0.01. Sisvar® 5.3 statistical program (Ferreira 2019).

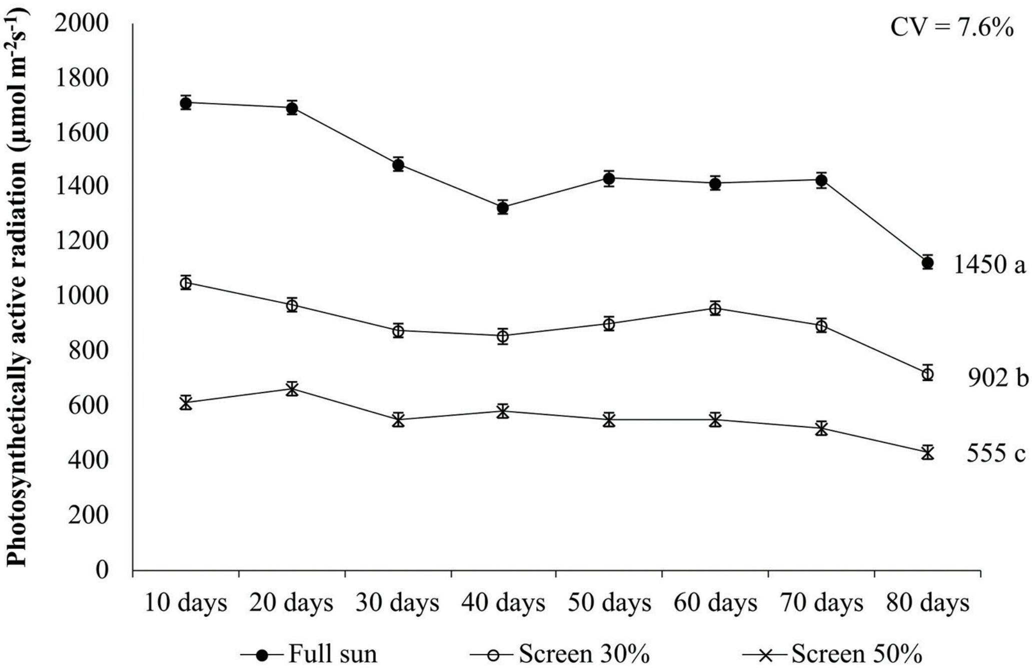

Figure 1. Photosynthetically active radiation (PAR µmol m^{-2} s^{-1}) in the different environments from 2022 April 8 to June 30. Equal letters do not differ at 5% probability by the Tukey test. CV = coefficient of variation. Vertical bars indicate the standard error.

In the 30% shading environment (S30%), the seedlings in the substrate with 100%M (S1) were taller than those in the substrate with 40%M (S4). In the S50% environment, the seedlings in the substrate with 100%M (S1), 60%M (S3), and 40%M (S4) were taller than those in the substrate with 20%M (S5) (Figure 2A).

The highest number of leaves was observed in the S50% environment across all substrates studied, with increases of 33% (S1), 42% (S2), 89% (S3), 114% (S4), and 62% (S5) compared to the S30% environment. In the S30% environment, seedlings grown in the S1 substrate had more leaves than those in the S3, S4, and S5 substrates, with increases of 42%, 57%, and 44%, respectively. Under 50% shading, plants in the S4 substrate had 22% more leaves than those in the S5 substrate (Figure 2B).

The highest shoot dry matter was observed in the S50% environment, with increases of 224% (S1), 236% (S2), 341% (S3), 309% (S4), and 138% (S5) compared to the S30% environment. In the S30% environment, no significant differences were observed in the shoot dry matter among the substrates. Under 50% shading, seedlings in the S1 substrate exhibited higher shoot dry matter than those in the S2, S3, S4, and S5 substrates, with increases of 38%, 30%, 47%, and 144%, respectively (Figure 2C).

The highest root dry matter was observed in the S50% environment, with increases of 82% (S1), 87% (S2), 120% (S3), 193% (S4), and 81% (S5) compared to the S30% environment. In the S30% environment, no significant differences were observed in the root dry matter among the substrates. Under 50% shading, the root dry matter in the S4 substrate was 38% higher than in the S5 substrate (Figure 2D).

The highest total dry matter was observed in the S50% environment, with increases of 165% (S1), 162% (S2), 232% (S3), 251% (S4), and 108% (S5) compared to the S30% environment. In the S30% environment, no significant differences were observed in the shoot dry matter among the substrates. Under 50% shading, seedlings from the S1, S2, S3, and S4 substrates, which did not differ significantly from each other, exhibited higher shoot dry matter than those from the S5 substrate, with increases of 85%, 47%, 50%, and 53%, respectively (Figure 2E).

Only in the S3 substrate did the plants under 50% shading exhibit a higher PH/SD ratio compared to those under 30% shading; in the other substrates, no differences were observed in this ratio (Figure 2F).

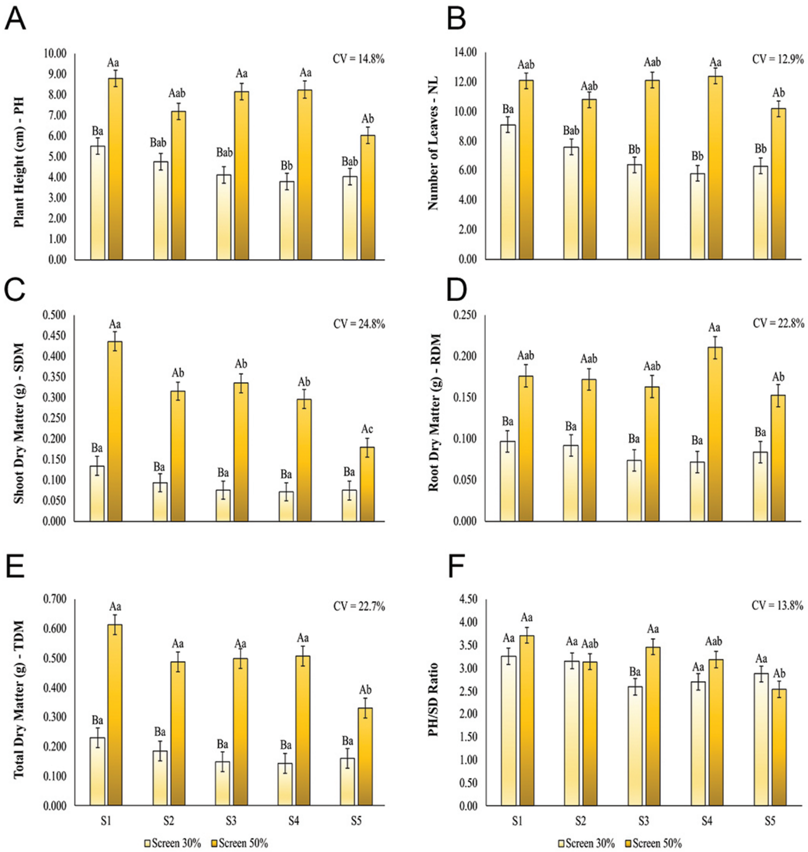

Figure 2. Plant height (A), number of leaves (B), shoot dry matter (C), root dry matter (D), total dry matter (E), and plant height/stem diameter ratio (F) of *J. mimosifolia* seedlings in different environments and substrate compositions. Equal uppercase letters for the protected environments and equal lowercase letters for the substrates do not differ at 5% probability by the LSD test and Tukey test, respectively. CV = coefficient of variation. Screen 30% = 30% shading environment; Screen 50% = 50% shading environment; S1 = 100%M + 0%V; S2 = 80%M + 20%V; S3 = 60%M + 40%V; S4 = 40%M + 60%V; S5 = 20%M + 80%V. Vertical bars indicate standard error.

The plants with the largest diameters (Figure 3A) and the highest quality (Figure 3B) were observed in the 50% shading environment, with no significant differences among the different substrates. The stem diameter and Dickson Quality Index of the plants under 50% shading were 60% and 127% higher, respectively, compared to those in the 30% shading environment.

In all substrates, chlorophyll *a*, chlorophyll *b*, *total* chlorophyll, and the total chlorophyll/carotenoid ratio were higher under 50% shading compared to 30% shading. Additionally, in substrates S1, S2, and S4, carotenoid content and the chlorophyll *a*/*b* ratio in *J. mimosifolia* seedlings were also higher under 50% shading than under 30% shading (Figure 4A to 4F).

The chlorophyll *a* contents of the plants in the S50% environment were 112% (S1), 50% (S2), 34% (S3), 138% (S4), and 52% (S5) higher than those in the S30% environment. In the S30% environment, the chlorophyll *a* contents of the plants in substrates S1, S2, and S3 were 56%, 61%, and 63% higher than in S4, respectively. In the S50% environment, the chlorophyll *a* contents of the plants in substrate S1 were 37%, 51%, 39%, and 46% higher than those in S2, S3, S4, and S5, respectively (Figure 4A).

The chlorophyll *b* contents of the plants in the S50% environment were 56% (S1), 34% (S2), 30% (S3), 105% (S4), and 52% (S5) higher than those in the S30% environment. In the S30% environment, chlorophyll *b* contents in plants from substrates S1 and S2 were 61% and 53% higher, respectively, compared to those in S4. In the S50% environment, the chlorophyll *b* contents of plants from the S1 substrate were 30% and 32% higher than those in S3 and S5, respectively (Figure 4B).

The *total* chlorophyll content of the plants in the S50% environment was 94% (S1), 45% (S2), 33%

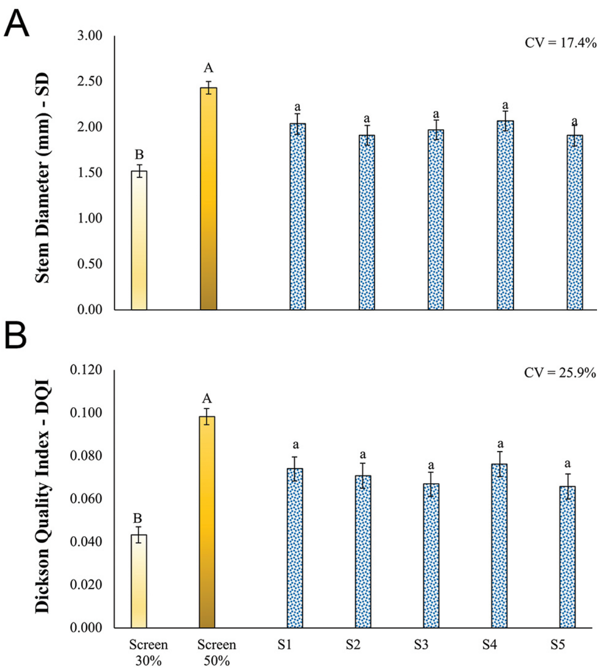

Figure 3. Stem diameter (A) and Dickson Quality Index (B) of *J. mimosifolia* seedlings in different environments and substrate compositions. Equal uppercase letters for the protected environments and equal lowercase letters for the substrates do not differ at 5% probability by the LSD test and Tukey test, respectively. CV = coefficient of variation. Screen 30% = 30% shading environment; Screen 50% = 50% shading environment; S1 = 100%M + 0%V; S2 = 80%M + 20%V; S3 = 60%M + 40%V; S4 = 40%M + 60%V; S5 = 20%M + 80%V. Vertical bars indicate standard error.

(S3), 128% (S4), and 52% (S5) higher than that in the S30% environment. In the S30% environment, the *total* chlorophyll content of the plants in substrates S1, S2, and S3 were 58%, 59%, and 58% higher, respectively, compared to those in S4. In the S50% environment, the *total* chlorophyll content of the plants in the S1 substrate was 33%, 45%, 34%, and 42% higher than in substrates S2, S3, S4, and S5, respectively (Figure 4C).

The carotenoid content of the plants in the S50% environment was 35% (S1), 24% (S2), and 77% (S4) higher than that in the S30% environment. In the S30% environment, the carotenoid content of the plants in substrates S1, S2, and S3 was 51%, 47%, and 44% higher, respectively, compared to that in S4. In the S50% environment, the carotenoid content of the plants in substrate S1 was 24% higher than that in S5 (Figure 4D).

There were differences in the number of leaves (Figure 2B), stem diameter (Figure 3A), shoot dry matter (Figure 2C), root dry matter (Figure 2D), total dry matter (Figure 2E), seedling quality (Figure 3B), chlorophyll *a* (Figure 4A), chlorophyll *b* (Figure 4B), *total* chlorophyll (Figure 4C), and carotenoids (Figure 4D) in *J. mimosifolia* seedlings in relation to the cultivation environment and substrates, with the greenhouse with 50% shading and using 100% organomineral substrate allowing better biometric quality and increased chlorophyll and carotenoids in the seedlings (Figure 5).

Pearson correlation, which assesses the level of interrelation between variables (Figure 6), showed that the growth variables and photosynthetic pigment variables of *J. mimosifolia* seedlings have a strong positive correlation between them, which means that the plants with the best biometric growth quality were those with the highest contents of chlorophylls and carotenoids.

The principal component analysis, where the first component explained 98.85% of the data variability and the second component explained 0.77% (Figure 7), reveals the formation of 2 similarity groups (clusters): one formed by the 50% shading environment and the other by the 30% shading environment. It can be observed that the highest levels of chlorophyll *a* and *total* chlorophyll were found in the group corresponding to the 50% shading environment (Figure 7), as confirmed by the LSD test (Figure 4).

The analysis of canonical variables showed that the treatments in the 50% shading environment were closer to the growth vectors and photosynthetic pigments of *J. mimosifolia* seedlings, resulting in seedlings of better quality. In this environment, substrate S1 led to greater growth and higher photosynthetic pigment content (Figure 8), as confirmed by the LSD test (Figures 2 and 4).

DISCUSSION

Jacaranda mimosifolia does not tolerate full sunlight (Croce et al. 2022), requiring shading for adequate growth as seen in this study with the formation of seedlings of this species under 50% and 30% shading. This was also found with *Schizolobium parahyba* (Caron et al. 2010), *Euterpe edulis* (Guimarães et al. 2018), and *E. oleracea* (Dapont et al. 2016). However, other studies have reported better initial growth of *J. mimosifoli* under full sun rather than in a protected environment (greenhouse)(de Oliveira et al. 2018) due to the region of production, its micrometeorological conditions, and the time of year (Hickman

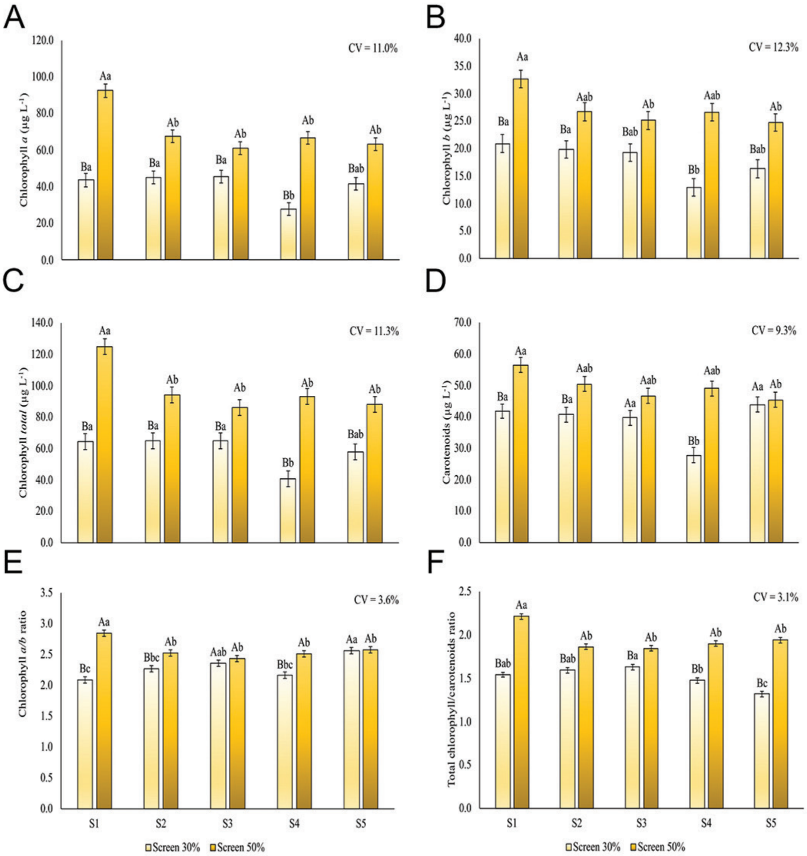

Figure 4. Chlorophyll *a* (A), chlorophyll *b* (B), *total* chlorophyll (C), carotenoids (D), chlorophyll *a*/*b* ratio (E), and total chlorophyll/carotenoid ratio (F) of *J. mimosifolia* seedlings in different environments and substrate compositions. Equal uppercase letters for the protected environments and equal lowercase letters for the substrates do not differ at 5% probability by the LSD test and Tukey test, respectively. CV = coefficient of variation. Screen 30% = 30% shading environment; Screen 50% = 50% shading environment; S1 = 100%M + 0%V; S2 = 80%M + 20%V; S3 = 60%M + 40%V; S4 = 40%M + 60%V; S5 = 20%M + 80%V. Vertical bars indicate standard error.

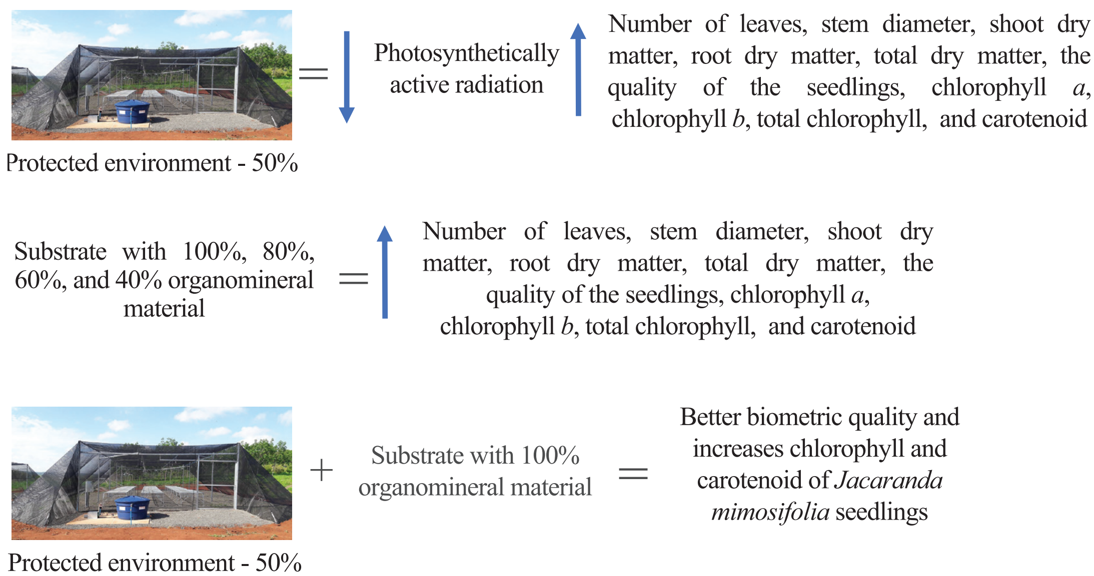

Figure 5. Main results of jacaranda seedlings in terms of shade levels and substrate composition.

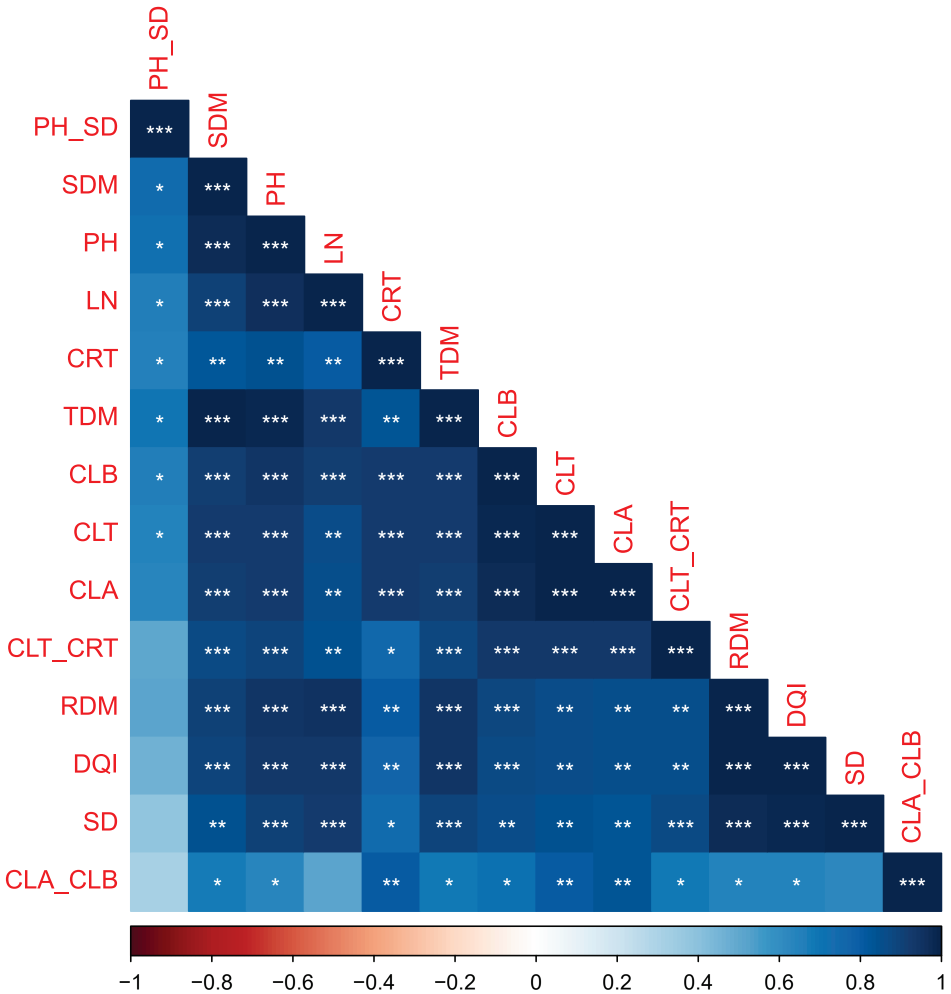

Figure 6. Pearson correlation for the variables shoot dry matter (SDM), plant height (PH), number of leaves (LN), total carotenoids (CRT), total dry matter (TDM), plant height/stem diameter ratio (PH_SD), chlorophyll *b* (CLB), total chlorophyll (CLT), chlorophyll *a* (CLA), total chlorophyll/carotenoids ratio (CLT_CRT), root dry matter (RDM), Dickson Quality Index (DQI), stem diameter (SD), and chlorophyll *a*/*b* ratio (CLA_CLB) of *J. mimosifolia* seedlings in different environments and substrate compositions. *Indicates significant relationship at *P* < 0.05. **Indicates significant relationship at *P* < 0.01. ***Indicates significant relationship *P* < 0.001.

2018; Costa et al. 2023b). In our study, shading regulated leaf temperature and plant water status, providing improved turgor and photosynthetic activity, which are essential for seedling growth (Dapont et al. 2016).

The availability of photosynthetically active radiation is essential for growth, but the *J. mimosifolia* seedlings did not evolve under the full sun due to the high radiation (Figure 1) which exceeded the plants' capacity to use it, causing an imbalance in the photosynthetic apparatus and photoinhibition (de Souza et al. 2016; Taiz et al. 2017), which in turn impacted the physiological, biochemical, and morphological properties and compromised the development of the seedling (Taiz et al. 2017). This was in line with what was observed in *Tocoyena formosa* seedlings (Bonamigo et al. 2016) and *S. amazonicum* Huber ex Ducke seedlings (de Oliveira Bastos et al. 2023). This process, promoted by the high irradiance, damaged the integrity of the chloroplasts, reducing photosynthetic efficiency (de Oliveira Bastos et al. 2023). Therefore, it is essential to determine the degree of tolerance of the species to light intensity and to evaluate the influence of environments with and/or without shading on plant growth (de Souza et al. 2016).

The average values of air temperature (°C), relative humidity (%), and global solar radiation (W m^{-2}) may have influenced the increase in biometric characteristics and photosynthetic pigments of jacaranda

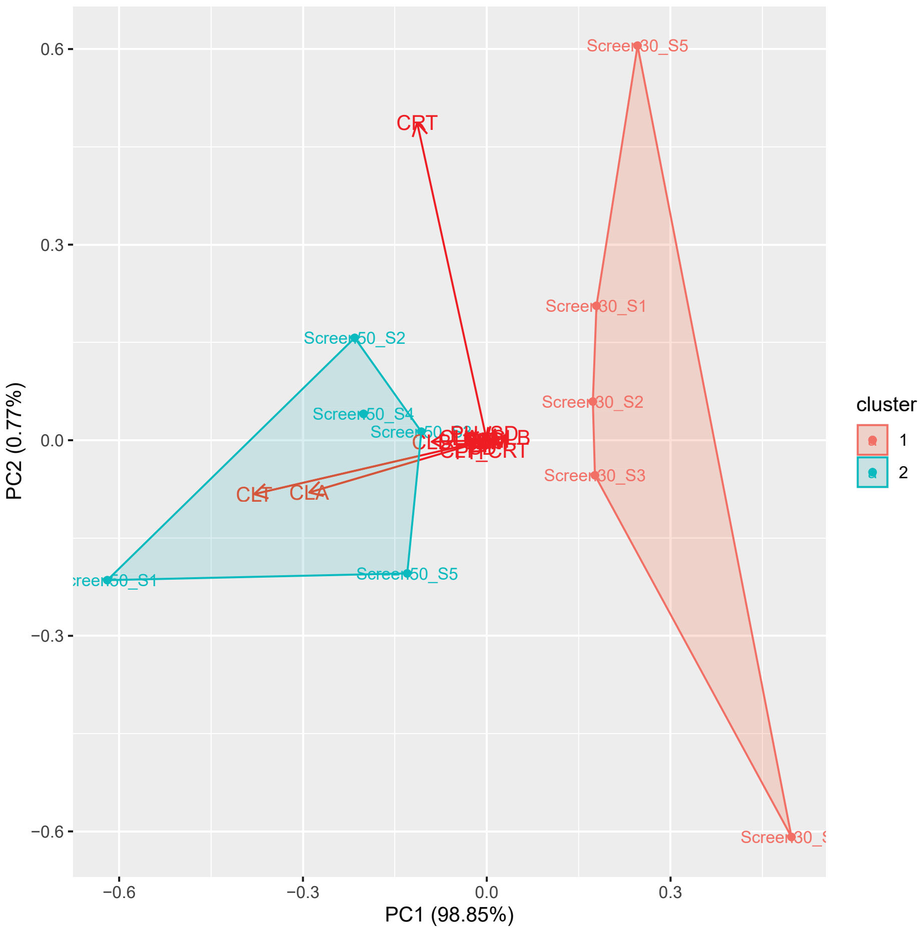

Figure 7. Principal component analysis of the variables plant height (PH), number of leaves (LN), stem diameter (SD), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), plant height/stem diameter ratio (PH_SD), chlorophyll *a* (CLA), chlorophyll *b* (CLB), *total* chlorophyll (CLT), total carotenoids (CRT), chlorophyll *a*/*b* ratio (CLA_CLB), and total chlorophyll/carotenoids ratio (CLT_CRT) of *J. mimosifolia* seedlings in different environments and substrate compositions. Screen 30% = 30% shading environment; Screen 50% = 50% shading environment; S1 = 100%M + 0%V; S2 = 80%M + 20%V; S3 = 60%M + 40%V; S4 = 40%M + 60%V; S5 = 20%M + 80%V.

seedlings in the 50% shaded environment. These characteristics influenced the increase in photosynthesis and, consequently, the production of photoassimilates (Taiz et al. 2017; Nagel et al. 2024), since the environment that promotes conditions that favor metabolic activities consists of the environment suitable for the development of the species.

Plants exposed to lower PAR (50% shading) convert light more efficiently into shoot dry matter (Alves et al. 2021); however, in substrates S2, S3, and S5, there was no significant difference compared to the environment with 30% shading. Other studies have examined the growth of *E. precatoria* under different shading levels and found similar results, with the shadier environment providing the best growth due to the lower PAR radiation (de Almeida et al. 2018). These studies reinforce the conclusion that shading can be an important tool to enable photosynthetic efficiency and improve the growth of seedlings of some plant species, leading to an improvement in the use of PAR by the plant for conversion into dry matter (Figure 2).

The plants with the highest numbers of leaves and Dickson Quality Index were found in the environment with 50% shading in all the substrates studied. It is important to note that *J. mimosifolia* plants show greater photosynthetic efficiency under shaded conditions, requiring greater nutrient absorption to maintain plant growth and development. The reduction in the number of leaves of jacaranda seedlings when

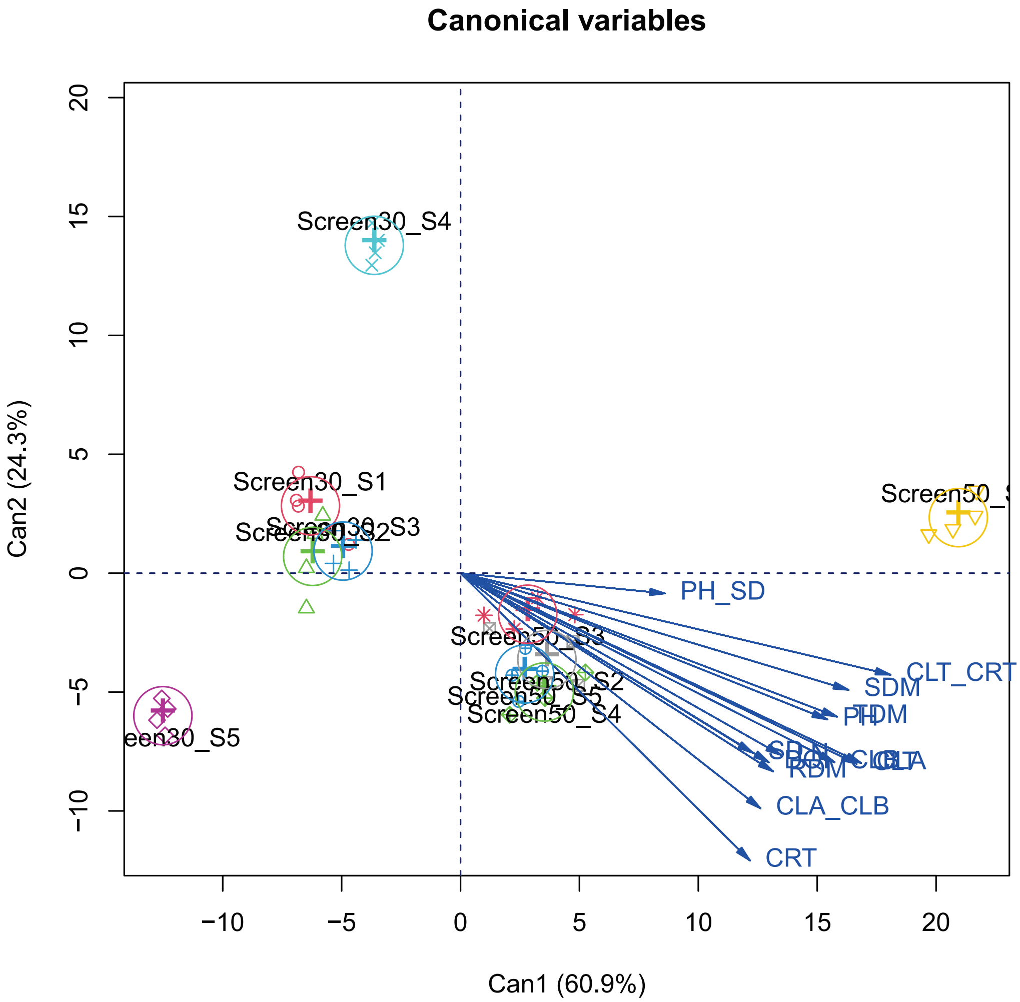

Figure 8. Graphical representation of the canonical correlation analysis on plant height (PH), number of leaves (LN), stem diameter (SD), shoot dry matter (SDM), root dry matter (RDM), total dry matter (TDM), plant height/stem diameter ratio (PH_SD), chlorophyll *a* (CLA), chlorophyll *b* (CLB), *total* chlorophyll (CLT), total carotenoids (CRT), chlorophyll *a*/*b* ratio (CLA_CLB), and total chlorophyll/carotenoids ratio (CLT_CRT) of *J. mimosifolia* seedlings in different environments and substrate compositions. Screen 30% = 30% shading environment; Screen 50% = 50% shading environment; S1 = 100%M + 0%V; S2 = 80%M + 20%V; S3 = 60%M + 40%V; S4 = 40%M + 60%V; S5 = 20%M + 80%V.

subjected to high light levels may be related to the acceleration of leaf senescence caused mainly by the increase in respiratory rates, which occurs due to increased transpiration in brighter environments, and this behavior is considered a mechanism of adaptation to the environment (Taiz et al. 2017). In agreement with our studies, *S. parahyba* seedlings had a greater number of leaves in shaded environments (de Oliveira Bastos et al. 2023).

The shading levels (environments) and substrates interact according to the different light conditions and nutrient percentages to produce the best *J. mimosifolia* seedlings. In the most shaded environment, a substrate with a higher percentage of nutrition was required, while in a less shaded environment, a substrate with a lower percentage of nutrients was needed. Because plants accumulate more dry matter in conditions of greater shading (Pan et al. 2016), they need substrates with greater nutrition, as observed for *J. mimosifolia* seedlings at 50% shading levels.

It is worth noting that the S3 substrate (60%M + 40%V) provided 18.6% more leaves than the S5 substrate (20%M + 80%V) due to the greater availability of nutrients in the organomineral material, especially macronutrients. On the other hand, substrate S5, with a higher proportion of vermiculite (80%), has a lower capacity for retaining and making nutrients available, resulting in lower dry matter production. Substrates with a higher organic matter content increase the availability of essential nutrients, resulting in greater plant growth (Prato et al. 2020), as well as highlighting the importance of adequate nutrition in the formation of chlorophyll and photosynthetic efficiency, corroborating the results observed with substrate S3.

In *J. mimosifolia* seedlings, adequate shading (50% shading) increases dry matter (Dapont et al. 2016) (Figures 2 and 7) and photosynthetic efficiency since light plays an essential role in plant development and is mainly influenced by the quantity and quality of available light energy (Barros et al. 2019).

The ratio of chlorophyll *a*/*b* and *total* chlorophyll/carotenoids is indicative of plant adaptation to light conditions; due to shading, the changes not only increase photosynthesis but also improve energy conversion efficiency, resulting in more vigorous growth.

The interaction between shading and substrate nutrition is fundamental in the production of *J. mimosifolia* seedlings, and the results presented show that shading directly influences the production of photosynthetic pigments, such as chlorophyll *a* and *total* chlorophyll (Figure 6) and carotenoids (Epifanio et al. 2022). In environments with moderate shading, seedlings tend to have higher levels of *total* chlorophyll and carotenoids and a favorable chlorophyll *a*/*b* ratio, reducing the ideal balance between the different types of chlorophyll.

The physiological mechanisms affected by the nutrition of *J. mimosifolia* seedlings in different substrates and shading levels are related to the production of photosynthetic pigments such as chlorophyll *a*, chlorophyll *b*, *total* chlorophyll, and carotenoids. The greater availability of nutrients in substrates with a higher proportion of organomineral material (S1, S2, and S4) favors the synthesis of chlorophyll and carotenoids, which optimizes light absorption and photosynthesis. In environments with 50% shading, these levels were significantly higher than those with 30% shading, indicating that moderate shading favors the accumulation of pigments essential for growth.

Adequate shading, combined with balanced nutrition, maximizes photosynthetic efficiency, allowing better conversion of light into dry matter, suggesting that substrates richer in the organic matter were necessary for environments with greater shading, highlighting the importance of nutritional balance for pigment production and plant development (Dapont et al. 2016; Prato et al. 2020) (Figure 7).

Considering the results observed in this study, it can be assured that the differences in light and substrate conditions promoted changes in the bioactive compounds of chlorophyll and carotenoids, as well as in the biometric aspects of plant height; stem diameter; dry matter of shoot, root, and total; and the Dickson Quality Index of *J. mimosifolia* seedlings.

CONCLUSION

Producing *J. mimosifolia* seedlings under the full sun is not recommended in tropical conditions.

In the 50% shading environment, on average, there was an increase of 68% in the number of leaves, 60% in the stem diameter, 250% in the shoot dry matter, 113% in root dry matter, 184% in total dry matter, and 127% in the quality of *J. mimosifolia* seedlings.

Under 50% shading, the *J. mimosifolia* seedlings exhibited, on average, a 77% increase in chlorophyll *a* content, a 56% increase in chlorophyll *b* content, a 70% increase in *total* chlorophyll content, and a 45% increase in carotenoid content.

The superior seedlings, with the best biometric characteristics and highest contents of photosynthetic pigments, can be obtained with a substrate composed of 100% organomineral material, but percentages of 80%, 60%, and 40% can also be used. The substrate containing 20% organomineral material is not recommended for *J. mimosifolia* seedling production.

The best *J. mimosifolia* seedlings are produced in a 50% shading environment with the substrate composed of 100% organomineral material, resulting in the best biometric quality and highest chlorophyll and carotenoid contents.

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Amanda Maria Frata Ferreira
University of State of Mato Grosso do Sul
Department of Agronomy
Cassilândia, Mato Grosso do Sul, Brazil

Tassila Aparecida do Nascimento de Araújo
Federal University of Pelotas
Department of Agronomy
Pelotas, Rio Grande do Sul, Brazil

Edilson Costa (corresponding author)
University of State of Mato Grosso do Sul
Department of Agronomy
Cassilândia, Mato Grosso do Sul, Brazil
edilson.costa@uems.br

Thaise Dantas
Federal University of Grande Dourados
Department of Agronomy
Dourados, Mato Grosso do Sul, Brazil

Flávio Ferreira da Silva Binotti
University of State of Mato Grosso do Sul
Department of Agronomy
Cassilândia, Mato Grosso do Sul, Brazil

Giovana Pinheiro Viana da Silva
University of State of Mato Grosso do Sul
Department of Agronomy
Cassilândia, Mato Grosso do Sul, Brazil

Gustavo Haralampidou da Costa Vieira
University of State of Mato Grosso do Sul
Department of Agronomy
Cassilândia, Mato Grosso do Sul, Brazil

Eduardo Pradi Vendruscolo
University of State of Mato Grosso do Sul
Department of Agronomy
Cassilândia, Mato Grosso do Sul, Brazil

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Résumé. Contexte: Cette recherche visait à évaluer les composés bioactifs et les paramètres de croissance initiale de semis de *Jacaranda mimosifolia* en fonction des niveaux d'ombrage et de la composition du substrat. Méthodes: Un plan complètement aléatoire organisé selon un schéma factoriel 3 × 5 (3 niveaux d'ombrage × 5 substrats) a été utilisé. Les niveaux d'ombrage étaient de 0%, 30% et 50%. Les substrats étaient des composts composés de matières organiques (M) et de vermiculite (V): 100/0 M:V, 80/20 M:V, 60/40 M:V, 40/60 M:V, et 20/80 M:V. Résultats: La production de semis de *J. mimosifolia* en plein soleil n'est pas recommandée sous les conditions tropicales. Les écrans d'ombrage de 30% et 50% ont réduit le rayonnement photosynthétiquement actif de 38% et 62%, respectivement. Dans l'environnement ombragé à 50%, le nombre moyen de feuilles a augmenté de 68%, le diamètre des tiges de 60%, la matière sèche des pousses de 250%, la matière sèche des racines de 113%, la matière sèche totale de 184% et la qualité des plants de *J. mimosifolia* de 127%. La culture dans un milieu ombragé à 50% a augmenté en moyenne la teneur en chlorophylle A de 77%, la teneur en chlorophylle B de 56%, la teneur en chlorophylle totale de 70% et la teneur en caroténoïdes des plantules de *J. mimosifolia* de 45%. Un substrat contenant 20% de M pour les semis de *J. mimosifolia* n'est pas recommandé. Les meilleurs semis de *J. mimosifolia* sont produits dans un milieu ombragé à 50% et dans un substrat contenant 100% de M, ce qui se traduit par une meilleure qualité biométrique et des teneurs en chlorophylle et en caroténoïdes plus élevées, en plus de favoriser une amélioration du taux de survie et une accélération de la croissance initiale.

Zusammenfassung. Hintergrund: Ziel dieser Studie war es, bioaktive Verbindungen und anfängliche Wachstumsparameter von *Jacaranda mimosifolia*-Sämlingen unter verschiedenen Beschattungsgraden und Substratzusammensetzungen zu bewerten. Methoden: Es wurde ein vollständig randomisiertes Design in einem 3 × 5-Faktorschema (3 Beschattungsgrade × 5 Substrate) verwendet. Die Beschattungsgrade betragen 0%, 30% und 50%. Die Substrate bestanden aus Kompost aus organisch-mineralischem Material (M) und Vermiculit (V): 100/0 M:V, 80/20 M:V, 60/40 M:V, 40/60 M:V und 20/80 M:V. Ergebnisse: Die Produktion von *J. mimosifolia*-Sämlingen unter voller Sonneneinstrahlung wird unter tropischen Bedingungen nicht empfohlen. Die 30%- und 50%-Schattensiebe reduzierten die photosynthetisch aktive Strahlung um 38% bzw. 62%. In der Umgebung mit 50% Beschattung stieg die durchschnittliche Anzahl der Blätter um 68%, der Stammdurchmesser um 60%, die Trockenmasse der Triebe um 250%, die Trockenmasse der Wurzeln um 113%, die Gesamttrockenmasse um 184% und die Qualität der *J. mimosifolia*-Sämlinge um 127%. Der Anbau in der Umgebung mit 50% Beschattung erhöhte im Durchschnitt den Chlorophyll-a-Gehalt um 77%, den Chlorophyll-b-Gehalt um 56%, den Gesamtchlorophyllgehalt um 70% und den Carotinoidgehalt der *J. mimosifolia*-Sämlinge um 45%. Ein Substrat mit 20% M für *J. mimosifolia*-Sämlinge wird nicht empfohlen. Die besten *J. mimosifolia*-Sämlinge werden in einer Umgebung mit 50% Beschattung und einem Substrat mit 100% M produziert, was zu einer besseren biometrischen Qualität und einem höheren Chlorophyll- und Carotinoidgehalt führt und zusätzlich eine Verbesserung der Überlebensrate und eine Beschleunigung des anfänglichen Wachstums fördert.

Resumen. Antecedentes: Este estudio tuvo como objetivo evaluar compuestos bioactivos y parámetros iniciales de crecimiento de plántulas de *Jacaranda mimosifolia* bajo niveles de sombreado y composiciones de sustrato. Métodos: Fue utilizado un diseño totalmente aleatorizado configurado en un esquema factorial 3 × 5 (3 sombreados × 5 sustratos). Los niveles de sombreado fueron 0%, 30%, y 50%. La composición de los sustratos estuvo compuesta de material organo-mineral (M) y vermiculita (V): 100/0 M:V, 80/20 M:V, 60/40 M:V, 40/60 M:V, and 20/80 M:V. Resultados: Producir plántulas de *J. mimosifolia* a la luz del sol directa no se recomienda en condiciones tropicales. Las pantallas de sombra del 30% y 50% redujeron la radiación fotosintéticamente activa en un 38% y 62%, respectivamente. En el ambiente sombreado al 50%, el número promedio de hojas aumentó en un 68%, el diámetro del tallo en un 60%, la materia seca del brote en un 250%, la materia seca de la raíz en un 113%, la materia seca total en un 184% y la calidad de las plántulas de *J. mimosifolia* en un 127%. El cultivo en el ambiente sombreado al 50%, en promedio, aumentó el contenido de clorofila a en un 77%, el contenido de clorofila B en un 56%, el contenido total de clorofila en un 70% y el contenido de carotenoides de las plántulas de *J. mimosifolia* en un 45%. No se recomienda un sustrato que contenga 20% (M) para las plántulas de *J. mimosifolia*. Las mejores plántulas de *J. mimosifolia* se producen en el ambiente sombreado al 50% y el sustrato al 100% (M), lo que resulta en una mejor calidad biométrica y mayores contenidos de clorofila y carotenoides, además de promover una mejora en la tasa de supervivencia y la aceleración del crecimiento inicial.