

Cassava Wastewater Biofertilizer Application Strategies Affect the Quality of Sabiá (*Mimosa Caesalpiniiifolia* Benth.) Seedlings in the Brazilian Semiarid Region

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CASSAVA WASTEWATER BIOFERTILIZER APPLICATION STRATEGIES AFFECT THE QUALITY OF SABIÁ (*Mimosa Caesalpiniiifolia* Benth.) SEEDLINGS IN THE BRAZILIAN SEMIARID REGION

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Abstract

Climate change is increasing the frequency and intensity of extreme weather events, which are further exacerbated by anthropogenic activities, particularly in semiarid regions, where the temporal and spatial variability of rainfall limits water availability and, consequently, the establishment and development of forest species. This study aimed to evaluate the quality of *Mimosa caesalpiniiifolia* Benth. seedlings grown in soil fertilized with treated cassava wastewater biofertilizer as a potassium source under different soil application strategies. The experiment was conducted under protected conditions at the Academic Unit of Agricultural Engineering, Federal University of Campina Grande, Campina Grande, Paraíba, Brazil. Treatments were arranged in a randomized complete block design using a 6×2 factorial scheme, consisting of six concentrations of treated cassava wastewater biofertilizer (CB: C1 = 20%, C2 = 40%, C3 = 60%, C4 = 80%, C5 = 100%, and C6 = 120% of the recommended fertilization rate) and two application strategies for basal fertilization (F1: application of the total recommended volume; and F2: split application, with 50% of the total recommended volume applied initially and the remaining 50% applied seven days later), using a 1:1 (v/v) dilution ratio and five replicates. Applying the biofertilizer as a single dose resulted in the highest Dickson Quality Index (DQI) values at concentrations C2, C4, C5, and C6, with values of 3.16, 2.87, 3.14, and 2.71, respectively, whereas split application resulted in higher DQI values at concentrations C1 and C3, with values of 2.64 and 2.50, respectively. Split and single-dose application strategies of treated cassava wastewater biofertilizer affected all morphometric and seedling production variables of *Mimosa caesalpiniiifolia* Benth.

Keywords Biofertilizer · Fertilization · Ecosanitation · Caatinga · Water resources

Introduction

The production of native forest species seedlings is an essential step in the restoration of degraded areas and the implementation of Environmental Degradation Recovery Plans (PRADs), particularly in semiarid regions, where environmental degradation threatens the conservation of natural resources and biodiversity. In addition to the direct impacts of anthropogenic activities, these ecosystems are strongly influenced by intrinsic climatic characteristics, including high spatial and temporal variability in rainfall and elevated evapotranspiration rates. In this context, identifying sustainable alternatives for producing high-quality seedlings is critical to the success of ecological restoration initiatives.

In 2020, the United Nations (UN) declared 2021–2030 the UN Decade on Ecosystem Restoration, establishing a global political, scientific, and financial call to scale up efforts to restore deforested and

degraded landscapes worldwide. Achieving this goal, however, requires the adoption of effective and efficient restoration strategies at large scales, as well as the development of techniques adapted to different ecosystem contexts, thereby promoting synergistic effects among ecosystem services (Meli et al. 2017; Zavistanovicz, 2025).

Among forest species with potential for the restoration of degraded areas, *Mimosa caesalpiniiifolia* Benth., commonly known as Sabiá, is a native species of the Caatinga biome belonging to the Fabaceae family and widely distributed throughout the Brazilian semiarid region. This species has considerable potential for nutrient cycling, energy production, timber supply, pharmaceutical applications, and the restoration of degraded areas. Moreover, it represents an important source of fiber and protein for livestock feed (Braga et al. 2024; Santos et al. 2025).

Given the growing demand for seedlings of native forest species for degraded-area restoration and forest biomass production, it is essential to consider the factors governing plant growth and development, including climatic and environmental conditions. Among environmental factors, soil nutrient availability is particularly important for ensuring adequate seedling establishment and development.

Brazil is currently facing market instability and fluctuations in agricultural input prices, partly due to its substantial dependence on imported fertilizers from countries affected by geopolitical instability, such as Russia. This scenario highlights the need for alternative technologies capable of reducing dependence on international fertilizer markets. Among these alternatives, the use of treated wastewater as a source of plant nutrients has emerged as a promising strategy.

Within the framework of ecosanitation, the reuse of treated cassava wastewater (manipueira) as a fertilizer source to partially or fully replace conventional potassium fertilization in agricultural and forestry systems has been increasingly recognized as an economically and environmentally viable alternative (Agbogidi et al. 2023; Torres et al. 2024; Atojunere, 2026; Ramos et al. 2026). In addition to supplying essential nutrients, this liquid biofertilizer can contribute to more efficient water use, thereby integrating nutrient recovery and water reuse into sustainable production systems.

Therefore, this study aimed to evaluate the quality of *Mimosa caesalpiniiifolia* Benth. seedlings grown in soil receiving basal fertilization with treated cassava wastewater biofertilizer as a potassium source under different soil application strategies.

Materials and Methods

Experimental site and experimental conditions

The experiment was conducted from April to July 2026 under greenhouse conditions at the Academic Unit of Agricultural Engineering (UAEA), Federal University of Campina Grande (UFCG), Campina Grande, Paraíba, Brazil, at 7°15'18" S, 35°52'28" W and an elevation of 550 m above sea level. According to the Köppen–Geiger climate classification, the region has an As climate, characterized as tropical with a dry summer (Alvares et al. 2013). During the experimental period, mean air temperatures ranged from 21.77 to 28.40 °C, while relative humidity ranged from 69.0 to 99.1%, as recorded using a digital thermo-hygrometer (Figure 1).

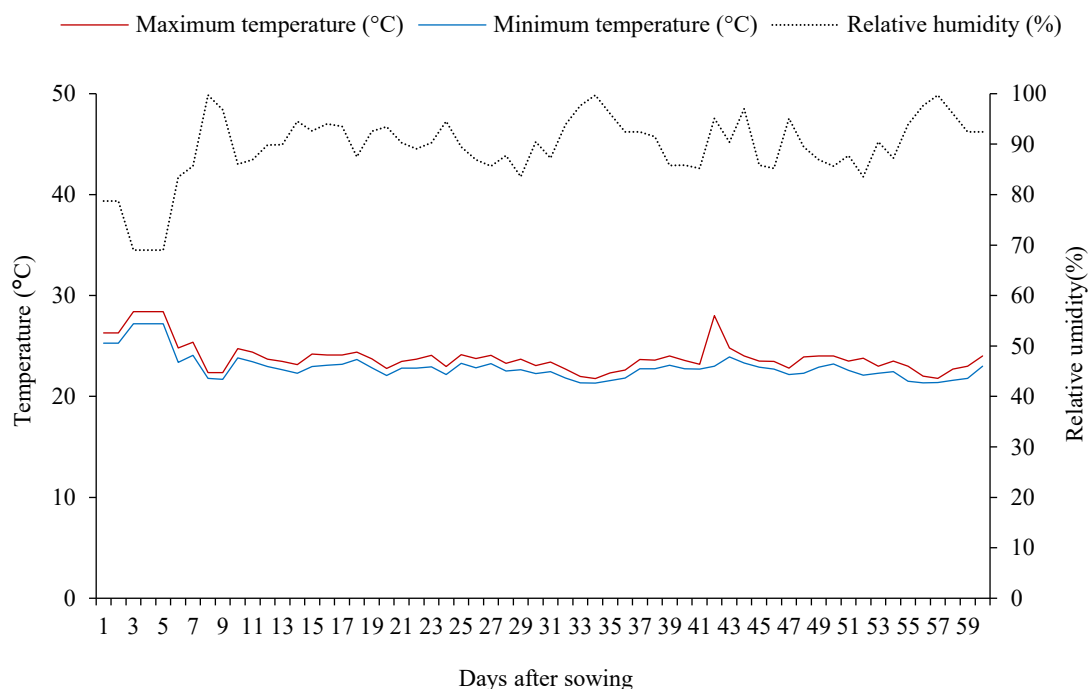


Fig.1 Climatic conditions during the experimental period: maximum and minimum air temperatures and mean relative humidity.

Experimental design and treatment description

The treatments were arranged in a randomized complete block design using a 6×2 factorial scheme, consisting of six concentrations of treated cassava wastewater biofertilizer (CB: 20, 40, 60, 80, 100, and 120% of the recommended fertilization rate) and two application strategies for basal fertilization with treated cassava wastewater biofertilizer (F1: application of the total recommended volume; and F2: split application, with 50% of the total recommended volume applied initially and the remaining 50% applied seven days after the first application), with five replicates. In all treatments, the biofertilizer was diluted 1:1 (v/v) with tap water. Sowing was performed seven days after treatment application. The volumes of biofertilizer applied were calculated based on its potassium concentration and expressed as g L^{-1} (Table 1). The experiment comprised 60 experimental plots, each containing two plants.

Tab.1 Description of the treatments evaluated.

Application strategy (AS)	Treated cassava wastewater biofertilizer concentration					
	20%	40%	60%	80%	100%	120%
Complete basal application (100%) – F1	F1C1	F1C2	F1C3	F1C4	F1C5	F1C6
Split basal application (50%–50%) – F2	F2C1	F2C2	F2C3	F2C4	F2C5	F2C6

Synthetic fertilizer was applied according to the recommendations of Costa et al. (2008), using monoammonium phosphate (MAP; 12% N and 50% P_2O_5) as the phosphorus source. Nitrogen fertilization was performed using urea (45% N). No dilution was used for the synthetic fertilizer treatment, whereas

potassium was supplied through the cassava wastewater-based biofertilizer, following the methodology proposed by Novais et al. (1991).

In addition, foliar fertilization was performed every 15 days using a commercial Dripsol® solution at a concentration of 1.0 g L⁻¹, containing Mg (1.2%), B (0.85%), Fe (3.4%), Zn (4.2%), Mn (3.2%), Cu (0.5%), and Mo (0.06%). The solution was applied to both the adaxial and abaxial leaf surfaces using a backpack sprayer.

Seedling production and characterization of the soil and treated cassava wastewater biofertilizer

To produce the seedlings, five Sabiá (*Mimosa caesalpiniiifolia* Benth.) seeds were sown in 3-L seedling bags, evenly spaced at a depth of 2 cm. The seeds of *Mimosa caesalpiniiifolia* used in the experiment were obtained from a local commercial establishment. *Mimosa caesalpiniiifolia* is a perennial leguminous tree native to the Brazilian Caatinga, characterized by rapid growth, high adaptability to semiarid conditions, and potential for use in agroforestry systems, restoration of degraded areas, and forage production. The soil was collected in the municipality of Alagoa Nova, Paraíba, Brazil. A soil sample was transported to the Laboratory of Irrigation and Salinity at the Federal University of Campina Grande for physicochemical characterization according to the methodology proposed by Teixeira et al. (2017).

The soil chemical properties were as follows: pH = 5.07; organic matter (OM) = 7.95 g dm⁻³; phosphorus (P) = 9.20 mg dm⁻³; potassium (K) = 0.36 mg dm⁻³; sodium (Na) = 0.01 cmolc kg⁻¹; calcium (Ca²⁺) = 1.24 cmolc kg⁻¹; and magnesium (Mg²⁺) = 2.39 cmolc kg⁻¹. The soil acidity-related properties were aluminum (Al³⁺) = 0.60 cmolc kg⁻¹ and potential acidity (H⁺ + Al³⁺) = 3.71 cmolc kg⁻¹. Regarding physical properties, the soil consisted of 727 g kg⁻¹ sand, 211 g kg⁻¹ silt, and 62 g kg⁻¹ clay. The soil also exhibited an electrical conductivity of the saturation extract (ECe) of 0.09 dS m⁻¹ and a cation exchange capacity (CEC) of 7.57 cmolc kg⁻¹.

Cassava wastewater (manipueira) was collected from a small-scale cassava starch-processing facility in the municipality of Puxinanã, Paraíba, Brazil, and subjected to anaerobic digestion. A total volume of 85 L of wastewater was collected and stored in a hermetically sealed container equipped with a gas outlet system to allow the gases generated during digestion to escape. The outlet tubing connected the headspace of the primary container to a second 500-mL container partially filled with water to the level corresponding to the effluent outlet (Figure 2), as described by Souza et al. (2014).

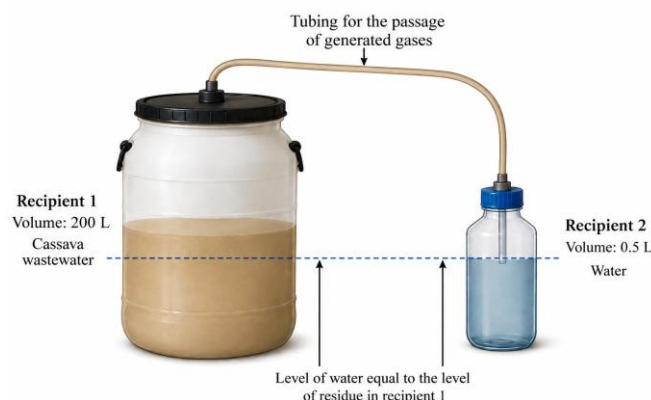


Fig. 2 Anaerobic digestion process for the treatment of cassava wastewater and production of treated cassava wastewater biofertilizer.

The cassava wastewater was subjected to anaerobic digestion for 60 days. Ten days before the treatments were applied, a sample of the cassava wastewater-based biofertilizer was collected for physicochemical characterization (Table 2). The analyses were performed by the SENAI Institute of Technology for Operational Efficiency, Quality Control Laboratory—Water and Effluent Division, following the methodology described in the *Standard Methods for the Examination of Water and Wastewater* (APHA, 2005). The resulting physicochemical characteristics are presented in Table 2.

Table 2. Physicochemical characteristics of the treated cassava wastewater biofertilizer.

Parameter	Unit	Value
Electrical conductivity	CE (mS cm ⁻¹)	9.14
Chloride	mgCl ₁ L ⁻¹	1252
Total hardness	mgCaCO ₃ L ⁻¹	6274
Hydrogen ion potential (pH)	-	4.30
Apparent color	mg Pt-Co L ⁻¹	1000
Calcium	mg Ca L ⁻¹	94
Magnesium	mg Mg L ⁻¹	1474
Aluminum	mg Al ³⁺ L ⁻¹	1.75
Potassium	mg K ⁺ L ⁻¹	2050
Sodium	mg Na ⁺ L ⁻¹	177
Total phosphorus	mg L ⁻¹	303.46
Ammoniacal nitrogen	mg N-NH ₃ L ⁻¹	300
Nitrite	mg N-NO ₂ ⁻ L ⁻¹	1.45
Chemical oxygen demand (COD)	mgO ₂ /L	55161

Variables analyzed

Two growth assessments were performed by measuring plant height and stem collar diameter at 30 and 60 days after sowing (DAS). Absolute and relative growth rates were calculated based on plant height measurements.

Seedling vigor was assessed using the Emergence Speed Index (ESI) up to 7 DAS, and the Dickson Quality Index (DQI) was also determined. At 60 DAS, fresh leaf and stem biomass and dry leaf, stem, and root biomass were determined. Relative water content (RWC) and electrolyte leakage from the leaf blade were also assessed, along with photosynthetic pigment contents, including chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoids.

Plant height was measured at 30 and 60 DAS using a graduated measuring tape, whereas stem collar diameter was measured at the soil surface using a digital caliper.

Absolute growth rate (AGR) and relative growth rate (RGR) for plant height were calculated according to the methodology proposed by Benincasa (2003), using Equations 1 and 2:

$$AGR = \frac{(PH_2 - PH_1)}{(t_2 - t_1)} \quad (1)$$

$$RGR = \frac{(\ln PH_2 - \ln PH_1)}{(t_2 - t_1)} \quad (2)$$

Where:

A₂ - plant height at time t₂ (cm);

A₁ - plant height at time t₁ (cm);

$t_2 - t_1$ - time interval between measurements; and

$\ln$ – natural logarithm.

The ESI was estimated according to the methodology proposed by Maguire (1962). Based on the biometric measurements, the Dickson Quality Index (DQI) was calculated according to Dickson (1960), using Equation 3.

$$DQI = \frac{\frac{TDM}{H} - \frac{SDM}{SD}}{\frac{SDM}{SD} + \frac{RDM}{RDM}} \quad (3)$$

Where:

H – shoot height (cm);

SD – stem collar diameter (mm);

TDM – total dry mass (g);

SDM – shoot dry mass (g);

RDM – root dry mass (g).

Fresh and dry masses of the shoot and roots were determined using a precision balance with a resolution of 0.01 g. For dry mass determination, the plant material was placed in a forced-air circulation oven at 70 °C for 72 h.

To obtain the values of relative water content (RWC), leaves were collected to obtain 5 leaf discs from each plant (113 mm² of area). Immediately after collection, the discs were weighed, avoiding moisture losses, generating the fresh mass (FM) values, subsequently, these samples were placed in beakers, immersed in 50 mL of distilled water and kept for 24 hours. After this period, excess water was removed with paper towels, obtaining the turgid mass (TM) of the samples, which were then taken to an oven (temperature $\cong 65 \pm 3$ °C, until constant weight) to obtain the dry mass (DM) of the samples. The RWC was determined according to Equation 4.

$$RWC = \frac{FM - DM}{TM - DM} \times 100 \quad (4)$$

Where:

RWC – Relative water content (%);

FM – Fresh leaf mass (g);

TM – Turgid mass (g); and

DM – Dry mass (g).

Electrolyte leakage in the cell membrane under salinity stress conditions was evaluated by the membrane disruption capacity. Five leaf discs with an area of 113 mm² were collected, washed with distilled water to remove other electrolytes adhered to the leaves. Subsequently, they were placed in beakers containing 50 mL of bidistilled water and hermetically sealed with aluminum foil. The beakers were kept at a temperature of 25 °C for 24 hours, and the initial electrical conductivity (C_i) was measured. Soon after, the beakers were kept in an oven with forced air ventilation at a constant temperature of 80 °C for 150

minutes. At the end of this process, the final electrical conductivity (C_f) was measured again. Thus, electrolyte leakage in the cell membrane was obtained according to Scotti-Campos et al. (2013), according to Equation 5.

$$EL = \frac{C_i}{C_f} \times 100 \quad (5)$$

Em que:

EL – Electrolyte leakage (%);

C_i – Initial electrical conductivity at 25 °C (dS m^{-1}); and

C_f – Final electrical conductivity at 25 °C (dS m^{-1});

Photosynthetic pigment contents were determined at 60 DAS. Leaf samples were collected from the middle third of the shoot and subsequently transported to the Plant Physiology Laboratory at the Federal University of Campina Grande, Campina Grande campus, for determination of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl total), and carotenoid (Car) contents. Photosynthetic pigments were extracted using dimethyl sulfoxide (DMSO) according to the methodology described by Wellburn (1994). One leaf disc of known mass and an area of 113 mm² was placed in a container containing 5 mL of DMSO. Each container was wrapped in aluminum foil to prevent pigment degradation and maintained in the dark for 48 h. The extracts were then analyzed using a spectrophotometer at absorbance wavelengths of 665, 649, and 480 nm for the determination of chlorophyll *a*, chlorophyll *b*, and carotenoids. The pigment contents were calculated using Equations 6, 7, 8, and 9.

$$\text{Chl}_a = [(11.65 \times \text{ABS}_{665}) - (3.45 \times \text{ABS}_{649})] \quad (6)$$

$$\text{Chl}_b = [(21.99 \times \text{ABS}_{649}) - (5.32 \times \text{ABS}_{665})] \quad (7)$$

$$\text{Chl}_t = [(17.3 \times \text{ABS}_{649}) + (7.18 \times \text{ABS}_{665})] \quad (8)$$

$$\text{Car} = [(1000 \times \text{ABS}_{480}) - (2.14 \times \text{Chl}_a - (70.16 \times \text{Chl}_b))] / 220 \quad (9)$$

The chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoid (Car) contents obtained from the plants were expressed in $\mu\text{g mL}^{-1}$.

Statistical analysis

The experimental data were subjected to preliminary procedures to assess the underlying statistical assumptions. Initially, the observed values for each variable were organized according to the experimental treatments and examined for outliers and inconsistencies. Subsequently, the normality of the residuals was assessed using the Shapiro–Wilk test, while homogeneity of variances (homoscedasticity) among treatments was evaluated using Levene’s test.

Following these procedures, the data were subjected to multivariate analysis using Principal Component Analysis (PCA), which reduced the dimensionality of the original dataset while retaining the most relevant information through linear combinations of variables. Principal components were selected based on eigenvalues ($\lambda \geq 1.0$) from the correlation matrix, if they explained more than 10% of the total variance (Govaerts et al. 2007). Variables with correlation coefficients below 0.60 were subsequently subjected to analysis of variance (ANOVA) and the F-test ($p \leq 0.05$). Means for the biofertilizer application strategies were compared using the Scott–Knott test ($p \leq 0.05$), whereas linear and quadratic polynomial

regression analyses were performed to evaluate the effects of treated cassava wastewater biofertilizer concentrations. Pearson's correlation analysis was subsequently performed at $p \leq 0.05$. All statistical analyses were conducted using R software.

Results

As shown in the analysis of variance summary (Table 3), significant effects were observed for the Emergence Speed Index (ESI) at 7 DAS, absolute growth rate of plant height (AGRph), relative growth rate of plant height (RGRph), number of leaves (NL), and stem collar diameter (SD) of Sabiá (*Mimosa caesalpinifolia* Benth. seedlings at 60 days after sowing, as a function of treated cassava wastewater biofertilizer concentrations and application strategies.

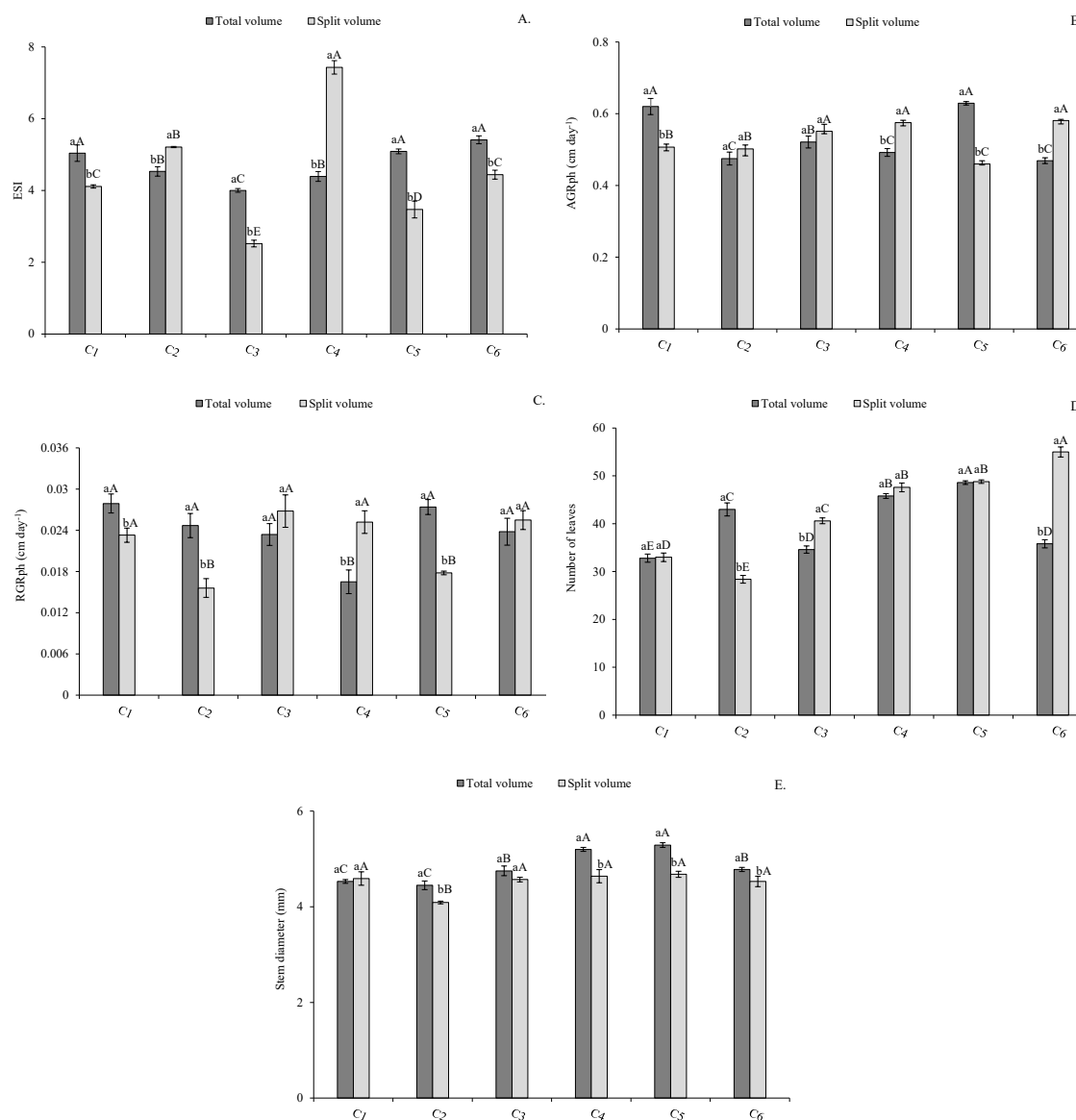
Table 3. Analysis of variance summary for the Emergence Speed Index (ESI) at 7 DAS, absolute and relative growth rates of plant height (AGRph and RGRph), number of leaves (NL), and stem collar diameter (SD) of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings at 60 days after sowing, as affected by treated cassava wastewater biofertilizer concentrations and application strategies.

Source of variation	DF	Mean squares				
		ESI	AGRph	RGRph	NL	SD
Implementation strategy (IS)	1	7.60***	3.8×10^{-5} *	3.74×10^{-5} *	69.28***	1.47***
Biofertilizer concentrations (BC)	5	12.70***	6.1×10^{-3} ***	5.35×10^{-5} ***	432.46***	0.66***
Interação (IS×BC)	5	9.09**	0.03***	1.34×10^{-5} ***	296.90***	0.16***
Residue		0.091	8×10^{-4}	1.13×10^{-5}	3.39	0.03
CV (%)		6.21	5.36	14.57	4.48	4.05

DF – degrees of freedom; CV – coefficient of variation; * ** and *** – significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$, respectively.

For the Emergence Speed Index (ESI) (Figure 3A), when the treated cassava wastewater biofertilizer was applied as a single dose, the highest values were observed at concentrations C1, C5, and C6, reaching 5.04, 5.09, and 5.41, respectively. Under split application, the highest ESI value (7.43) was recorded at concentration C4, which differed significantly from the other concentrations (C1, C2, C3, C5, and C6).

Significant differences were observed between application strategies at all concentrations evaluated. Single-dose application resulted in higher ESI values at concentrations C1, C3, C5, and C6, whereas split application increased ESI at concentrations C2 and C4, reaching values of 5.21 and 7.43, respectively. These values represented increases of 15.01 and 69.25%, respectively, compared with the corresponding single-dose applications of the same biofertilizer volumes, indicating that ESI responses to the application strategy depended on the biofertilizer concentration.



X and Y represent the treated cassava wastewater biofertilizer concentration (C1 = 36.6 mL; C2 = 73.2 mL; C3 = 109.8 mL; C4 = 146.4 mL; C5 = 183.0 mL; and C6 = 219.6 mL) and the variable evaluated, respectively. For the same biofertilizer concentration, means followed by different letters indicate significant differences between single-dose and split applications. Lowercase letters indicate significant differences among application strategies, whereas uppercase letters indicate significant differences among biofertilizer concentrations (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error of the mean (n = 5).

Fig. 3 Emergence Speed Index at 7 days after sowing – ESI (DAS) (A), absolute growth rate of plant height – AGRph (B), relative growth rate of plant height – RGRph (C), number of leaves – NL (D), and stem collar diameter – SD (E) of Sabiá (*Mimosa caesalpiniiifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 DAS.

For the absolute growth rate of plant height (AGRph) (Figure 3B), single-dose application resulted in the highest values at concentrations C1 and C5, reaching 0.62 and 0.63, respectively. Under split application, significantly higher AGRph values were observed at concentrations C3, C5, and C6. The

interaction between application strategy and biofertilizer concentration revealed significant differences at C1, C4, C5, and C6.

At C1 and C5, single-dose application resulted in higher AGRph values (0.62 and 0.63, respectively). In contrast, split application resulted in higher values at C4 and C6, reaching 0.57 and 0.58, respectively, corresponding to increases of 19.28 and 23.88% compared with the respective single-dose applications of the same biofertilizer volumes. No significant differences were observed between application strategies at C2 and C3.

For the relative growth rate of plant height (RGRph), single-dose application resulted in a significant difference only at C4 (Figure 3C), where the lowest value of 0.0165 cm day⁻¹ was recorded. Under split application, significantly higher RGRph values were observed at C3, C4, and C6. The interaction between application strategy and biofertilizer concentration showed significant differences at C1, C2, C4, and C5. Higher values were recorded under single-dose application at C1, C2, and C5, with values of 0.0279, 0.0247, and 0.0274 cm day⁻¹, respectively. Under split application, the highest value (0.0268 cm day⁻¹) was recorded at C3.

Regarding the number of leaves (NL) (Figure 3D), single-dose application resulted in the highest value (48.80 leaves) at C5. Under split application, the highest value (55 leaves) was recorded at C6. The interaction between application strategy and biofertilizer concentration was significant at C2, C3, and C6. At C2, single-dose application resulted in a significantly higher NL, whereas at C3 and C6, split application resulted in significantly higher values.

For stem collar diameter (SD) (Figure 2E), seedlings receiving the biofertilizer as a single dose showed the highest values at C4 and C5. Under split application, C2 resulted in the lowest SD value (4.09 mm) compared with the other concentrations. The interaction between application strategy and biofertilizer concentration was significant at C2, C4, C5, and C6. At these concentrations, single-dose application resulted in higher SD values of 4.45, 5.20, 5.29, and 4.70 mm, respectively, corresponding to increases of 8.08, 10.19, 11.53, and 5.23% compared with split application.

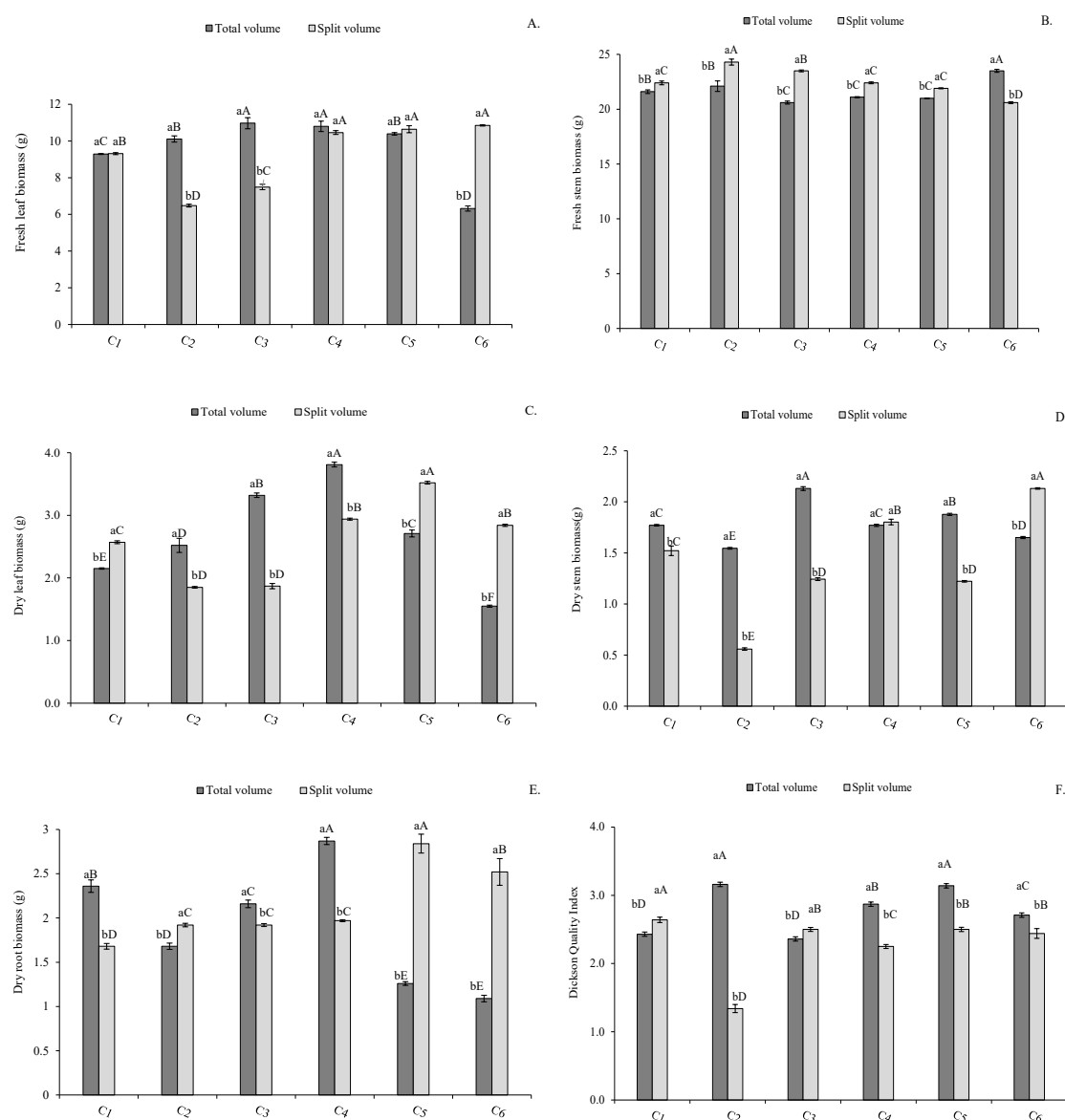
According to the analysis of variance summary (Table 4), significant effects were observed for fresh leaf biomass (FLB), fresh stem biomass (FSB), dry leaf biomass (DLB), dry stem biomass (DSB), dry root biomass (DRB), and Dickson Quality Index (DQI) of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 DAS.

Table 4. Analysis of variance summary for fresh leaf biomass (FLB), fresh stem biomass (FSB), dry leaf biomass (DLB), dry stem biomass (DSB), dry root biomass (DRB), and Dickson Quality Index (DQI) of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 DAS.

Source of variation	DF	Mean squares					
		FLB	FSB	DLB	DSB	DRB	DQI
Implementation strategy (IS)	1	2.93***	11.05***	0.096***	1.97***	0.85***	3.75***
Biofertilizer concentrations (BC)	5	9.37***	3.46***	2.49***	0.97***	0.51***	0.35***
Interação (IS×BC)	5	22.38***	10.23***	2.87***	0.77***	2.80**	1.37***
Residue		0.12	0.19	0.009	0.001	0.020	8.8x10 ⁻³
CV (%)		3.68	1.98	3.61	2.66	7.16	3.72

DF – degrees of freedom; CV – coefficient of variation; ** and *** – significant at $p \leq 0.01$ and $p \leq 0.001$, respectively.

Regarding fresh leaf biomass (Figure 4A), single-dose application of the treated cassava wastewater biofertilizer resulted in the highest values at concentrations C3 and C4. Under split application, the highest values were observed at C4, C5, and C6, which differed significantly from the other concentrations. The interaction between application strategy and biofertilizer concentration revealed significant differences only at C2, C3, and C6. At C2 and C3, single-dose application resulted in higher fresh leaf biomass values (10.11 and 10.97 g, respectively). In contrast, at the highest concentration evaluated (C6), split application resulted in the highest value (10.85 g), indicating that Sabiá seedlings respond differently to the application strategy depending on the treated cassava wastewater biofertilizer concentration.



X and Y represent the treated cassava wastewater biofertilizer concentration (C1 = 36.6 mL; C2 = 73.2 mL; C3 = 109.8 mL; C4 = 146.4 mL; C5 = 183.0 mL; and C6 = 219.6 mL) and the variable evaluated, respectively. For the same biofertilizer concentration, means followed by different letters indicate significant differences between single-dose and

split applications. Lowercase letters indicate significant differences among application strategies, whereas uppercase letters indicate significant differences among biofertilizer concentrations (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error of the mean ($n = 5$).

Fig. 4. Fresh leaf biomass – FLB (A), fresh stem biomass – FSB (B), dry leaf biomass – DLB (C), dry stem biomass – DSB (D), dry root biomass – DRB (E), and Dickson Quality Index – DQI (F) of *Sabiá* (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 days after sowing.

Regarding fresh stem biomass (Figure 4B), *Sabiá* seedlings receiving the treated cassava wastewater biofertilizer as a single dose showed the highest value (23.5 g) at C6 (219.6 mL of biofertilizer). Under split application, the highest FSB value (24.3 g) was observed at C2 (73.2 mL), which differed significantly from the other concentrations. When application strategies were compared within each biofertilizer concentration, significant differences were observed at all concentrations. Single-dose application resulted in significantly higher FSB only at C6, whereas split application resulted in higher values at C1, C2, C3, C4, and C5.

For dry leaf biomass (Figure 4C), single-dose application resulted in the highest value (3.81 g) at C4 (146.4 mL). Under split application, the highest DLB value was observed at C5 (183.0 mL), reaching 3.52 g, which differed by 7.16% from the value obtained at C4 under single-dose application. The interaction between application strategy and biofertilizer concentration was significant at all concentrations. Single-dose application resulted in higher DLB values of 2.52, 3.32, and 3.81 g at C2, C3, and C4, respectively, whereas split application resulted in higher values at C1, C5, and C6, reaching 2.57, 3.52, and 2.84 g, respectively.

For dry stem biomass (Figure 4D), seedlings receiving the biofertilizer as a single dose showed the highest value (2.13 g) at C3. Under split application, the highest value was also 2.13 g, recorded at C6, which differed significantly from the other concentrations. Single-dose application resulted in significantly higher DSB values than split application at C1, C2, C3, and C5. Under split application, the lowest DSB value was observed at C2 (73.2 mL). No significant difference between application strategies was observed at C4.

For dry root biomass (Figure 4E), single-dose application of the treated cassava wastewater biofertilizer resulted in the highest value (2.87 g) at C4, which differed significantly from the other concentrations. Under split application, the highest DRB value (2.84 g) was observed at C5, differing significantly from the other concentrations. The interaction between application strategy and biofertilizer concentration showed significant differences at all concentrations. Single-dose application resulted in significantly higher DRB values at C1, C3, and C4, whereas split application resulted in higher values at C2, C5, and C6.

For the Dickson Quality Index (Figure 4F), single-dose application of the treated cassava wastewater biofertilizer resulted in the highest values at C2 and C5, reaching 3.16 and 3.14, respectively. Under split application, the highest DQI value (2.64) was observed at C1. The interaction between application strategy and biofertilizer concentration was significant at all concentrations evaluated. Single-dose application resulted in higher DQI values at C2, C4, C5, and C6, with values of 3.16, 2.87, 3.14, and

2.71, respectively, whereas split application resulted in higher values at C1 and C3, reaching 2.64 and 2.50, respectively.

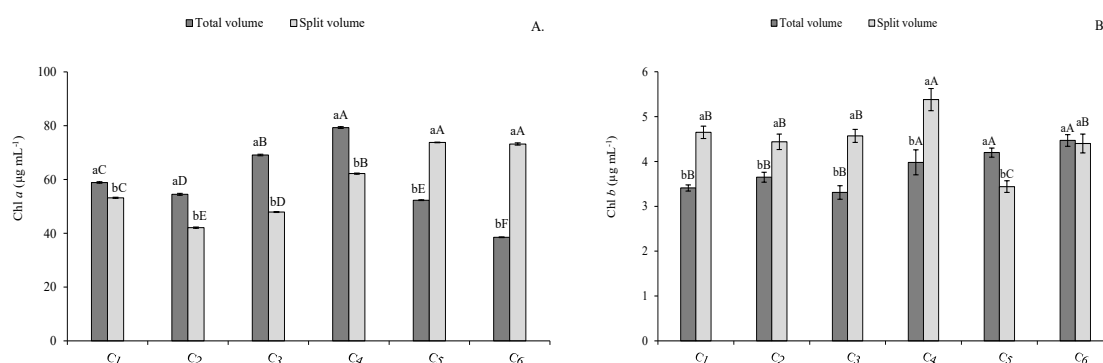
The analysis of variance summary indicated significant effects for all photosynthetic pigment variables evaluated (Table 5).

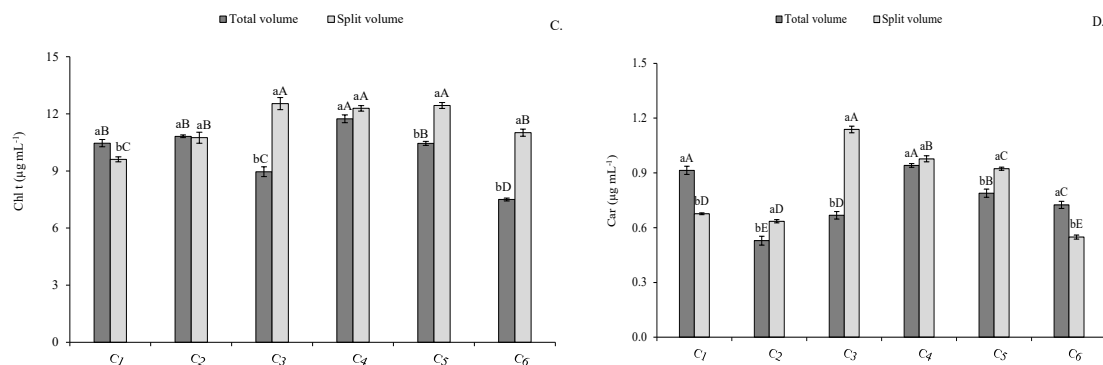
Table 5. Analysis of variance summary for chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), total chlorophyll (Chl *t*), and carotenoid (Car) contents of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 days after sowing.

Source of variation	DF	Mean squares			
		Chl <i>a</i>	Chl <i>b</i>	Chl <i>t</i>	Car
Implementation strategy (IS)	1	0.34 ^{ns}	6.15 ^{***}	31.64 ^{***}	0.046 ^{***}
Biofertilizer concentrations (BC)	5	574.8 ^{***}	1.09 ^{***}	9.65 ^{***}	157.35 ^{***}
Interação (IS×BC)	5	0.379 ^{***}	1.90 ^{***}	8.71 ^{***}	0.16 ^{***}
Residue		0.303	0.12	0.19	0.001
CV (%)		0.98	8.64	4.11	4.79

DF – degrees of freedom; CV – coefficient of variation; *** and ^{ns} – significant at $p \leq 0.001$ and not significant, respectively.

For chlorophyll *a* content (Figure 5A), seedlings receiving the treated cassava wastewater biofertilizer as a single dose showed the highest value ($79.3 \mu\text{g mL}^{-1}$) at C4. Under split application, the highest chl *a* contents were observed at C5 and C6, reaching 73.8 and $73.2 \mu\text{g mL}^{-1}$, respectively, which differed significantly from the other concentrations. The interaction between application strategy and biofertilizer concentration revealed that single-dose application resulted in significantly higher values at C1, C2, C3, and C4. In contrast, at the highest biofertilizer concentrations (C5 and C6), split application resulted in significantly higher chl *a*, with increases of 47.40% and 90.13%, respectively, compared with seedlings receiving the same biofertilizer concentrations under single-dose application.





X and Y represent the treated cassava wastewater biofertilizer concentration (C₁ = 36.6 mL; C₂ = 73.2 mL; C₃ = 109.8 mL; C₄ = 146.4 mL; C₅ = 183.0 mL; and C₆ = 219.6 mL) and the variable evaluated, respectively. For the same biofertilizer concentration, means followed by different letters indicate significant differences between single-dose and split applications. Lowercase letters indicate significant differences among application strategies, whereas uppercase letters indicate significant differences among biofertilizer concentrations (Scott–Knott test, $p \leq 0.05$). Vertical bars represent the standard error of the mean ($n = 5$).

Fig. 5 Chlorophyll *a* (Chl *a*) (A), chlorophyll *b* (Chl *b*) (B), total chlorophyll (Chl *t*) (C), and carotenoid (Car) contents (D) of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 days after sowing.

For chlorophyll *b* content (Figure 4B), seedlings receiving the treated cassava wastewater biofertilizer as a single dose showed the highest values at C₅ and C₆, reaching 4.20 and 4.47 $\mu\text{g mL}^{-1}$, respectively. Under split application, the highest chlorophyll *b* content was observed at C₄ (5.38 $\mu\text{g mL}^{-1}$), which differed significantly from the other concentrations. The interaction between application strategy and biofertilizer concentration revealed no significant difference only at C₆. At C₁, C₂, C₃, and C₄, split application resulted in significantly higher chlorophyll *b* contents than single-dose application. In contrast, at C₅, single-dose application resulted in the highest chlorophyll *b* content.

For total chlorophyll content (Figure 5C), single-dose application resulted in the highest value (11.74 $\mu\text{g mL}^{-1}$) at C₄. Under split application, the highest values were observed at C₃, C₄, and C₅, reaching 12.54, 12.29, and 12.44 $\mu\text{g mL}^{-1}$, respectively. When application strategies were compared within each biofertilizer concentration, no significant differences were observed at C₂ and C₄. In contrast, single-dose application resulted in a significantly higher value only at C₁, whereas split application resulted in significantly higher values at C₃, C₅, and C₆.

For carotenoid content (Car) (Figure 5D), seedlings receiving the treated cassava wastewater biofertilizer as a single dose showed the highest value (0.941 $\mu\text{g mL}^{-1}$) at C₄ (146.4 mL). Under split application, the highest carotenoid content was observed at C₃, reaching 1.138 $\mu\text{g mL}^{-1}$. The interaction between application strategy and biofertilizer concentration revealed that single-dose application resulted in significantly higher values only at C₁ and C₆, whereas split application resulted in higher values at C₂, C₃, and C₅. No significant difference between application strategies was observed at C₄.

The analysis of variance summary indicated significant effects for all relative water content and electrolyte leakage variables evaluated in Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings (Table 6).

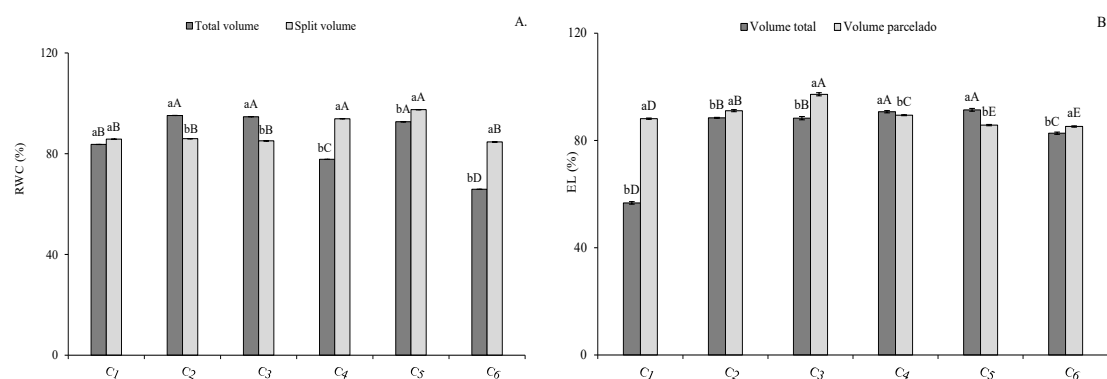
Table 6. Analysis of variance summary for relative water content (RWC) and electrolyte leakage (EL) of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 days after sowing.

Source of variation	DF	Mean squares
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		TRA	EE
Implementation strategy (IS)	1	0.02**	619.33***
Biofertilizer concentrations (BC)	5	0.05***	41.81***
Interação (IS×BC)	5	0.04***	434.53***
Residue		0.001	0.73
CV (%)		4.04	0.99

DF – degrees of freedom; CV – coefficient of variation; *** and ns – significant at $p \leq 0.001$ and not significant, respectively.

For relative water content (RWC), Sabiá seedlings receiving the treated cassava wastewater biofertilizer as a single dose showed the highest values at C2, C3, and C5, reaching 95.20%, 94.70%, and 92.70%, respectively (Figure 6A). Under split application, the highest RWC values were observed at C4 and C5, with 93.9% and 97.50%, respectively. The interaction between application strategy and biofertilizer concentration revealed no significant difference only at C1. Single-dose application resulted in higher RWC values at C2 and C3, whereas split application resulted in higher RWC values at C4, C5, and C6, reaching 93.6%, 97.5%, and 84.7%, respectively.



X and Y represent the treated cassava wastewater biofertilizer concentration (C1 = 36.6 mL; C2 = 73.2 mL; C3 = 109.8 mL; C4 = 146.4 mL; C5 = 183.0 mL; and C6 = 219.6 mL) and the variable evaluated, respectively. For the same biofertilizer concentration, means followed by different letters indicate significant differences between single-dose and split applications. Lowercase letters indicate significant differences among application strategies, whereas uppercase letters indicate significant differences among biofertilizer concentrations (Scott-Knott test, $p \leq 0.05$). Vertical bars represent the standard error of the mean ($n = 5$).

Fig. 6 Relative water content (RWC) (A) and electrolyte leakage (EL) (B) of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings as affected by treated cassava wastewater biofertilizer concentrations and application strategies at 60 days after sowing.

For electrolyte leakage (EL) (Figure 6B), when application strategies were evaluated separately, single-dose application of the treated cassava wastewater biofertilizer resulted in the lowest value (56.7%) at C1 (36.6 mL), followed by C2 (88.4%), C3 (88.3%), and C6 (82.7%). In contrast, under split application, the lowest EL values were observed at C4 (89.4%), C5 (85.7%), and C6 (85.2%), which differed significantly among the evaluated concentrations within each application strategy. The interaction between application strategy and biofertilizer concentration revealed significant differences between application strategies at all concentrations evaluated. At C1, C2, C3, and C6, single-dose application resulted in lower

EL values than split application, whereas at C4 and C5, split application resulted in lower EL values than single-dose application.

Only variables with correlation coefficients greater than $|r| > 0.60$ were retained for the principal component analysis (PCA). PCA revealed associations among the evaluated variables and characterized the responses of Sabiá seedlings to treated cassava wastewater biofertilizer concentrations and application strategies, indicating an interaction between these sources of variation. The first two principal components (PC1 and PC2) explained 71.5% of the total variance, with PC1 accounting for 46.5% and PC2 for 25.0%. PC1 comprised nine variables, whereas PC2 was associated exclusively with FSB (Figure 7).

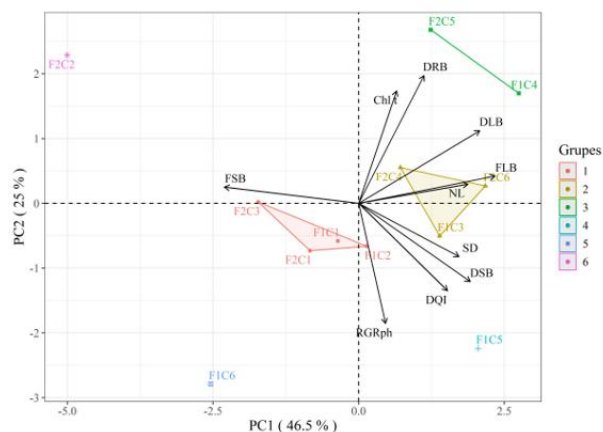


Fig. 7 Two-dimensional projection of the principal components derived from treated cassava wastewater biofertilizer concentrations (DM) and application strategies (EA) on principal components PC1 and PC2.

The variables included in the PCA were RGRph, NL, SD, DQI, FLB, FSB, DLB, DRB, and total chlorophyll (Chl t). Negative correlations were observed for RGRph, DLB, Chl t, and DQI, with coefficients of -0.0071 , -0.0361 , -0.0011 , -0.0084 , and -0.0036 , respectively. Group 4 showed the lowest statistical relevance and comprised treatments F1C1, F1C2, F2C1, and F2C3. In contrast, Groups 2 (F2C1, F1C3, and F2C6), 3 (F2C5 and F1C4), showed greater statistical relevance, indicating better seedling responses associated with Chl t, DRB, DLB, FLB, NL, SD, DQI, and RGRph. Group 5 (F1C6) did not positively favor any of the variables evaluated.

The Pearson correlation matrix (Figure 8) revealed associations among morphological, biomass production, and physiological variables in Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings grown under different treated cassava wastewater biofertilizer concentrations and application strategies.

The correlation matrix revealed relevant associations, including a moderate positive correlation between stem collar diameter (SD) and Dickson Quality Index (DQI) ($r = 0.69$), as well as between fresh leaf biomass (FLB) and relative water content (RWC) ($r = 0.59$). A very strong negative correlation was observed between FLB and fresh stem biomass (FSB) ($r = -0.89$), as well as between FSB and dry stem biomass (DSB) ($r = -0.82$). The number of leaves (NL) showed positive correlations with all response variables except FSB, with which it exhibited a moderate negative correlation ($r = -0.53$).

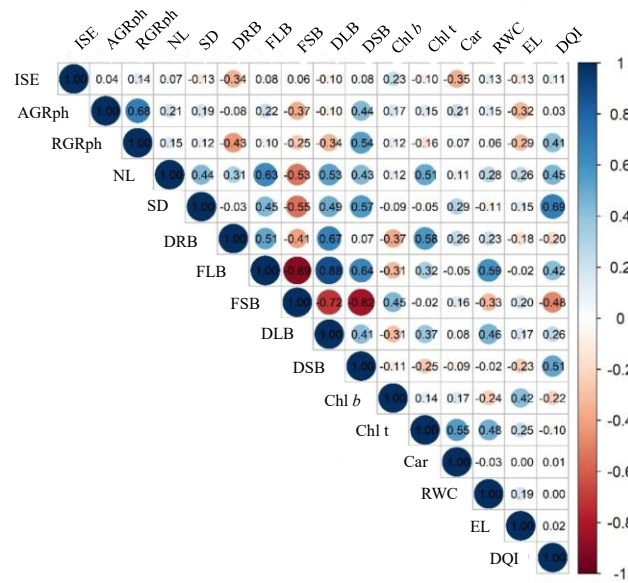


Fig. 8 Pearson correlation matrix between morphological, biomass production, and physiological variables of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings subjected to different concentrations of cassava wastewater biofertilizer and application strategies.

Discussion

The results of this study highlight significant differences in seedling responses to the application strategy and concentration of treated cassava wastewater biofertilizer in *Mimosa caesalpinifolia* Benth. seedlings. These findings are consistent with our initial hypothesis that both the application strategy and biofertilizer concentration can promote positive responses in seedling growth, physiological performance, and overall quality.

The Emergence Speed Index (ESI) observed under the split application of treated cassava wastewater biofertilizer at 184.6 mL may be associated with the high potassium content and electrical conductivity of cassava wastewater. A single-dose application of the full recommended amount may abruptly increase the salt concentration in the substrate solution, markedly reducing its water potential.

This effect may impair root water uptake, inducing stomatal closure to prevent further reductions in plant water status. Thus, split application may help avoid abrupt fluctuations in the electrical conductivity of the soil solution (Chen et al., 2025). Notably, the period between germination and seedling establishment is considered one of the most sensitive stages to abiotic stress because several intense physiological processes occur during this phase, including cell division, tissue expansion, and reserve mobilization (Guo et al., 2024).

Potassium (K^+) supply strongly affects seedling growth and absolute and relative growth rates because this macronutrient is essential in actively growing tissues, such as buds, young leaves, and root apices. Potassium plays critical regulatory, metabolic, and osmotic roles in healthy seedling development and is essential for the synthesis of proteins, starch, and sugars, as well as contributing to cellulose synthesis, which strengthens the cell wall, and to the formation of chlorophyll precursors. In addition, by regulating guard-cell turgor, potassium controls stomatal opening and closure. This regulation allows CO_2 uptake for

photosynthesis while reducing water loss through transpiration, thereby increasing the tolerance of young plants to drought (Taiz and Zeiger, 2017).

The soil resting period after cassava wastewater application may have contributed to establishing more favorable conditions for the absolute growth rate of plant height (AGRph) and relative growth rate of plant height (RGRph) in Sabiá seedlings. This interval may have allowed organic matter transformation and degradation of potentially phytotoxic cyanogenic compounds naturally present in the biofertilizer, such as hydrocyanic acid, as well as nutrient redistribution within the soil matrix. This process is particularly relevant when cassava wastewater biofertilizer is used as a potassium source because K^+ , owing to its high solubility, can be rapidly incorporated into the soil solution and exchange complex. Therefore, early application followed by a resting period may reduce seed exposure to instantaneously high concentrations of organic compounds and salts, promoting more stable chemical and biological conditions during seedling growth (Santos Moura et al. 2018).

The number of leaves was higher when the highest biofertilizer concentration was applied using the split strategy (219.6 mL). This response may be related to the role of potassium in osmotic regulation and cell turgor, promoting water uptake by cells and generating the physical pressure required for cell elongation and expansion during leaf development. In contrast to the findings of the present study, research on agricultural crops has demonstrated that potassium supply significantly affects the number of leaves produced and total leaf area. However, excessive potassium application may cause cationic and osmotic imbalances in the soil, impairing calcium (Ca) and magnesium (Mg) uptake through leaching and ultimately reducing leaf number or leaf area (Ramos et al. 2020; Costa et al. 2021; Torres et al. 2024).

Regarding stem collar diameter in Sabiá seedlings, the single-dose application of the recommended biofertilizer concentration resulted in higher values, except at the 36.6 mL concentration. Thus, increasing concentrations of treated cassava wastewater biofertilizer did not compromise this variable relative to seedlings receiving the biofertilizer through split application. These findings suggest that applying the full recommended amount in a single dose may provide greater seedling vigor and quality, resulting in greater biomass accumulation and improved support of the shoot. In the context of using cassava wastewater as a nutrient source, the observed increase may indicate that nutrients supplied by the biofertilizer, particularly K and N, enhanced structural growth and assimilate allocation to stem development. However, agronomic information regarding nutrient release patterns, appropriate application rates, and fertilization efficiency remains limited, which may ultimately compromise seedling quality (Petranski et al. 2026).

Pereira et al. (2025), when investigating the effects of cassava wastewater biofertilizer concentrations on cassava cultivation, reported a 60.19% increase in cassava stem diameter with the application of $176.5 \text{ m}^3 \text{ ha}^{-1}$ of cassava wastewater, demonstrating the potential of this residue as an alternative nutrient source. However, this result differs from our findings, in which application of the full recommended amount up to 183 mL increased stem collar diameter, whereas higher concentrations reduced this variable, indicating that the effects of cassava wastewater are concentration dependent.

The different biofertilizer concentrations and application strategies (single-dose or split application) directly affected fresh and dry biomass accumulation in Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings. Increasing biofertilizer concentrations under split application (183 and 219.6 mL) resulted in the

highest fresh and dry stem biomass and dry leaf and root biomass. This response may indicate that split application promotes more efficient nutrient allocation to the plant while avoiding the more pronounced effects associated with a single-dose application, thereby maintaining greater nutrient availability in the soil solution.

Thus, this strategy may have reduced the negative effects of soil salinity by mitigating reductions in osmotic potential associated with the high electrical conductivity (9.14 dS m^{-1}) and low pH (4.10) of the biofertilizer. These conditions may favor biofertilizer stabilization in the soil. In addition to initiating biofertilizer mineralization, the interval between applications may have promoted nutrient mineralization and reduced residual cyanogenic compounds, since linamarin and lotaustralin present in cassava wastewater can release hydrocyanic acid (HCN), which may subsequently be volatilized and/or degraded by microbial processes. Bezerra et al. (2019) reported that increasing cassava wastewater concentrations in the soil increased exchangeable sodium concentration, although lower concentrations did not result in a tendency toward soil salinization or sodification.

In contrast to the biomass variables, the highest Dickson Quality Index (DQI) values were observed as biofertilizer concentration increased from C4 (146.4 mL) to C6 (219.6 mL). Although all biofertilizer concentrations and application strategies resulted in DQI values ≥ 2.0 , considered by Hunt et al. (1990) to indicate high-quality forest seedlings, it is noteworthy that seedlings receiving concentration C2 (73.2 mL) under split application had a DQI of 1.34, whereas the remaining treatments exhibited higher values.

The DQI is widely used as a reliable indicator of seedling quality because it integrates morphological characteristics and provides information on seedling quality and biomass distribution, which are directly associated with higher survival rates after transplanting. This is particularly relevant for species such as Sabiá, which is commonly used for the recovery of degraded areas in arid and semiarid regions, where environmental conditions may further limit post-transplant survival.

According to Luo et al. (2024), seedling survival in semiarid regions is primarily limited by low water availability, high precipitation variability, and extreme temperatures. Therefore, the present study indicates a potential strategy for mitigating these stressors, particularly water deficit, since cassava wastewater biofertilizer is a liquid resource that may contribute to improved seedling development under water-limited conditions.

The results also showed that split application of treated cassava wastewater biofertilizer increased photosynthetic pigment contents at different concentrations, with the split application of 146.4 mL resulting in the highest chlorophyll b, total chlorophyll, and carotenoid contents. This response may be associated with greater nutrient availability in the soil solution, including potassium and key elements such as N and Mg, which were present at concentrations of $300 \text{ mg N-NH}_3 \text{ L}^{-1}$ and $1474 \text{ mg Mg L}^{-1}$, respectively, as well as with the presence of natural plant hormones, such as cytokinins, which have been reported in some fertilizers (Mahmoud et al., 2019).

Another factor that may have contributed to the higher photosynthetic pigment contents under split application is improved nitrogen availability. According to Chen et al. (2024), nitrogen is one of the major constituents of chlorophyll and plays a central role in the formation of photosynthetic pigments. Nitrogen

deficiency can reduce chlorophyll content and ultimately impair light capture and the efficiency of photosynthetic electron transport under restricted N supply.

Greater electrolyte leakage was observed under the split application strategy up to the 109.8 mL concentration. Above this concentration, greater cell-wall damage was observed in Sabiá seedlings at 60 days after sowing, indicating that both the application strategy and biofertilizer concentration directly influenced cell membrane integrity. In contrast, the single-dose application of the recommended 183 mL concentration resulted in the greatest damage, which may be associated with salt stress, as seedlings may not yet have achieved adequate osmotic adjustment or activated antioxidant defense mechanisms. At the highest concentration (219.6 mL), however, lower cell-wall damage was observed.

Consistent with this interpretation, Habibi et al. (2025) reported evidence that integrated nutritional management strategies can enhance growth and photosynthetic performance while reducing electrolyte leakage under conditions of high electrical conductivity, as observed with cassava wastewater biofertilizer. In addition, greater potassium availability in the soil solution may reduce electrolyte leakage and enhance the accumulation of protective metabolites, such as proline and phenolic compounds, which act as osmoprotectants under saline, water-deficit, and/or osmotic stress conditions (ValizadehKaji and Nikoogoftar Sedghi, 2020).

In the present study, split application increased relative water content (RWC) as cassava wastewater biofertilizer concentration increased from 146.4 mL, indicating an inverse response relative to electrolyte leakage, although the correlation between these variables was weak (0.19). Relative water content is particularly important for increasing the likelihood of Sabiá seedling survival, both because of the high electrical conductivity inherent to the biofertilizer and because of the edaphoclimatic conditions characteristic of arid and semiarid regions, even though this species is relatively tolerant of water deficit.

The effects of cassava wastewater biofertilizer concentrations and application strategies may be related to the ability of the species to adapt to dry environments, allowing it to survive and regenerate under the xerophytic conditions typical of the Caatinga. However, it should also be noted that Sabiá is the most salt-sensitive species among native species of the Brazilian semiarid region, with documented negative effects on both young plants and seedling production (Felix et al. 2025).

According to the Principal Component Analysis (PCA), the treatment associated with the highest DQI was the application of 183 mL of cassava wastewater biofertilizer as a single dose (F1C5). Therefore, this application strategy may promote a higher post-transplant survival rate because of the higher DQI observed.

Conclusions

Split and single-dose application strategies of cassava wastewater biofertilizer during topdressing, at different concentrations, affected all morphometric and production variables of Sabiá (*Mimosa caesalpinifolia* Benth.) seedlings.

Split application of cassava wastewater biofertilizer during topdressing at a concentration of 183 mL resulted in the highest Dickson Quality Index. The soil resting period and biofertilizer application strategy directly influenced the physiological development of the seedlings.

The high electrical conductivity of cassava wastewater biofertilizer is a limiting factor for its use in the production of forest seedlings that are sensitive to salinity.

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Author contributions

Conceptualization: J.G.R., L.D.A.B., A.R.S.; methodology: V.L.A.L., V.F.S., L.D.A.B.; software: J.G.R., A.R.S., V.F.S.; validation: L.D.A.B., V.L.A.L., L.M.F.S.; formal analysis: L.D.A.B., J.G.R., L.M.F.S.; investigation: L.D.A.B., B.J.P.F., E.S.A., V.F.O.S.; resources: G.S.L., B.J.P.F., V.L.A.L.; data curation: E.S.A., V.F.O.S., A.R.S.; writing original draft preparation: L.D.A.B., A.R.S., J.G.R.; writing and review and editing: G.S.L., E.S.A., V.F.O.S., L.M.F.S.; visualization: L.D.A.B., J.G.R.; supervision: V.L.A.L., G.S.L.; project administration: V.L.A.L., J.G.R.; funding acquisition: G.S.L., V.L.A.L., B.J.P.F. All authors have read and agreed to the published version of the manuscript.

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Data availability

The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

The experimental research and field studies involving the plant material of *Mimosa caesalpiniiifolia* used in this study, including the collection and use of seeds, complied with all relevant institutional, national, and international guidelines and legislation. No specific permits were required, since the seeds were obtained and used under controlled experimental conditions at the Federal University of Campina Grande.

Consent for publication

Not applicable.

Permission for plant material

The seeds of *Mimosa caesalpiniiifolia* used in this study were obtained from a commercial seed supplier. No wild or protected plant species were collected for this research; therefore, no specific permission or license was required.

Acknowledgments

Not applicable

Competing interests

The authors declare no competing interests.

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