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EFFECTS OF WATER DEFICIT AND HYDROGEL ON THE MORPHOPHYSIOLOGICAL TRAITS OF GUAVA UNDER SEMIARID CONDITIONS

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ABSTRACT

Guava is of great socioeconomic importance in the Semiarid region of the Northeast, but its expansion is still limited by the low water availability in these regions. Therefore, management strategies combined with the use of water-retaining polymers can ensure better production of this crop. In this context, the objective of this study was to evaluate the effect of hydrogel on the morphophysiological aspects of guava trees subjected to water deficit. The experiment was conducted in a greenhouse belonging to the Center for Agrofood Science and Technology of the Federal University of Campina Grande, Pombal, PB. The experimental design used was randomized blocks, in a 5 × 4 factorial scheme, referring to five irrigation intervals - T (1, 2, 3, 4 and 5 days) and four doses of Hydrogel - H (0, 2, 4 and 6 g dm-3) with three replicates and two plants per plot, totaling 120 experimental units. High chlorophyll levels occurred when electrolyte leakage caused by soil water deficit increased. The increase in water saturation deficit was confirmed in guava plants with reduced growth, phytomass accumulation and Dickson quality index. Five-day irrigation intervals drastically reduced the number of guava leaves and also intensified carotenoid production in these plants.

Keywords: *Psidium guajava* L.; water scarcity; soil conditioner.

1 INTRODUCTION

Guava (*Psidium guajava* L.) is a crop of significant socioeconomic importance for the Brazilian fruit market due to the increasing demand for fresh fruits and agro-industrial products (Lacerda et al. 2022). The value of guava fruits lies both in fresh consumption and in industrial processing for juices, pulps, ice creams, and jams, owing to its high nutritional content, which is rich in ascorbic acid, vitamins, and fiber (Pradhan et al. 2021; Kumar et al. 2022).

However, the cultivation of this species in the northeastern Semiarid region of Brazil is constrained by low water availability, a condition exacerbated by the salinity of water from artesian wells, rendering it unsuitable for irrigation (Santos et al. 2017). Low precipitation, high evapotranspiration, reduced relative humidity, and poorly developed soils with low water retention capacity (Lima et al. 2020) result in water deficits. Therefore, irrigation management must prioritize water conservation without compromising plant development (Golla 2021).

An appropriate irrigation schedule that balances water supply with crop requirements and soil water-holding capacity is essential for agricultural development, preventing water waste (Souza et al. 2023; Torres et al. 2023). However, infrequent irrigation leads to water deficit, limiting water uptake and reducing stomatal conductance, transpiration, and photosynthesis, which negatively affects plant growth and the allocation of photoassimilates (Silva et al. 2023).

Nevertheless, extended irrigation intervals can be adopted to conserve water through the use of soil conditioners such as water-retentive polymers. These materials are capable of absorbing, retaining, storing, and releasing water according to plant demand. Moreover, they can enhance the physical and hydraulic properties of the soil. These polymers are biodegradable, non-toxic, and environmentally safe (Saha et al. 2020).

The application of 3.0 g L^{-1} of hydrogel via soil improved growth and biomass production in *Eucalyptus urograndis* under irrigation near field capacity (Silva et al. 2024). In *Mimosa caesalpiniifolia*, the use of hydrogel in the substrate combined with a two-day irrigation interval resulted in stomatal responses comparable to those observed under daily irrigation (Antas et al. 2024).

From this perspective, aiming to optimize guava production in Semiarid regions, this study evaluated the morphophysiological responses of guava trees under water deficit and hydrogel application in the Semiarid region of Paraíba, Brazil, with the goal of supporting irrigation management strategies in water-scarce areas. It is essential to intensify research on the tolerance of guava to water stress, considering both irrigation management and hydrogel use, to develop suitable agronomic practices.

2 MATERIALS AND METHODS

2.1 Site description and experimental design

The research was conducted from September 2022 to February 2023 in a greenhouse at the Center for Agri-Food Science and Technology (CCTA) of the Federal University of Campina Grande (UFCG), located in the municipality of Pombal, Paraíba, at geographic coordinates 6°47'20" S and 37°48'01" W, and an elevation of 194 m. Meteorological data recorded during the experimental period are presented in Fig. 1.

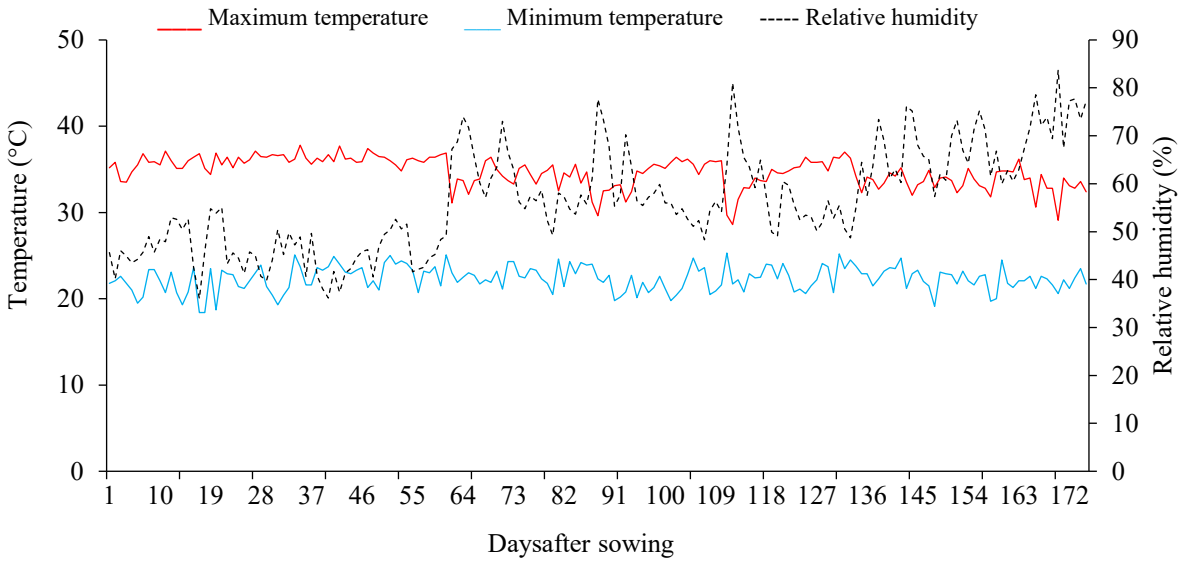


Fig. 1. Climate data of maximum and minimum temperature (ºC), precipitation (mm) and relative humidity (%) during the experimental period.

A randomized block experimental design was used in a 5 × 4 factorial scheme, corresponding to five irrigation intervals (T: 1, 2, 3, 4, and 5 days) and four hydrogel doses (H: 0, 2, 4, and 6 g dm^{-3} of substrate), with three replications and two plants per plot, totaling 120 experimental units. The irrigation intervals and doses of the water-retentive polymer used in the experiment were based on the study by Pereira (2017).

2.2 Conducting the experiment

Guava seeds (cv. Paluma) were obtained from the orchard of the fruit-growing sector of the Experimental Farm "Rolando Henrique Rivas Castelón" of CCTA–UFCG, Pombal Campus. Sowing was carried out in plastic bags measuring 10 × 18 cm, filled with 0.5 dm^3 of a substrate composed of a 2:1 (v/v) mixture of soil and sand. The soil used, classified as sandy loam, was collected at a depth of 0.30 m from an agricultural area in the municipality of Pombal, Paraíba. The physical-hydraulic and chemical properties of the soil were determined according to the methodology of Teixeira et al. (2017) (Table 1).

Table 1. Physical-hydric and chemical characteristics of the soil used in the experiment.

			Chemical characteristics					
pH H_2O	M.O.	P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+

(1:2.5)	g kg^{-1}	(mg kg^{-1})	cmol$_c$ kg^{-1}					
5.58	2.93	39.2	0.23	1.64	9.07	2.78	0.0	8.61

Chemical characteristics				Physical characteristics				
CE_{es}	CEC	SAR	PES	Granulometric fraction (g kg^{-1})			Humidity (dag kg$^{-1)}$	
(dS m^{-1})	cmol$_c$ kg^{-1}	(mmol L^{-1})$^{0.5}$	%	Sand	Silt	Clay	33.42 KPa	1519.5
2.15	22.33	0.67	7.34	572.7	100.7	326.6	25.91	12.96

pH – Hydrogen potential, M.O – Organic matter: Walkley-Black Wet Digestion; Ca^{2+} and Mg^{2+} extracted with KCl 1 M pH 7,0; Na^+ e K^+ extracted using NH_4OAc 1 M pH 7,0; Al^{3+}+H^+ extracted using CaOAc 0,5 M pH 7,0; ECse - Electrical conductivity of the saturation extract; CEC - Cation exchange capacity; SAR - Sodium adsorption ratio of the saturation extract; PES - Percentage of exchangeable sodium; [1.2] referring to field capacity and permanent wilting point.

Hydrogel doses corresponding to the treatments (0, 2, 4, and 6 g dm^{-3} of substrate) were incorporated into the prepared substrate. The hydrogel used was the commercial product Forth Gel®, pre-hydrated for 30 minutes according to the recommendations of the manufacturer.

Starting at 60 days after sowing (DAS), fertilization with nitrogen, phosphorus, and potassium was initiated every 15 days, based on the recommendations of Novais et al. (1991). Doses equivalent to 100, 300, and 150 mg kg^{-1} of soil of N, P_2O_5, and K_2O, respectively, were applied via fertigation in three split applications. Urea was used as the nitrogen source, monoammonium phosphate for phosphorus, and potassium chloride for potassium. As for micronutrients, foliar applications of Dripsol Micro were performed every 20 days at a concentration of 1 g L^{-1}. The product contains Mg^{2+} (1.1%), B (0.85%), Cu (Cu-EDTA, 0.5%), Fe (Fe-EDTA, 3.4%), Mn (Mn-EDTA, 3.2%), Mo (0.05%), and Zn (4.2%), with EDTA as the chelating agent (70%).

During the first 30 days after sowing (DAS), the seedlings were irrigated daily. From that point onward, irrigation treatments were applied according to the established intervals, continuing until 172 DAS. For each irrigation event corresponding to the five irrigation intervals, the volume of water to be applied was determined by gravimetric lysimetry, in which the irrigation depth was restored based on the difference in pot weight (Silva et al. 2023), as shown in Equation 1.

$$L = (\theta cc - \theta a) \times Z \times A \quad (1)$$

Where:

L = Irrigation depth required at the irrigation event (mm) (mm);

Θcc = Soil volumetric moisture at field capacity (cm^3/cm^3);

Θa = Current volumetric moisture (cm^3/cm^3); and,

Z = Effective root depth (mm).

A = Bag area (m^2).

2.3 Variables Analyzed

Chloroplast pigments were determined at 172 DAS. Leaf samples were collected from the central portion of the lamina for quantification of chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and carotenoids (CAROT), according to Lichtenthaler (1987), using the third fully expanded leaf from the apex. Pigment concentrations were determined from extracts prepared in 80% acetone solution using a spectrophotometer at absorbance wavelengths of 470, 646, and 663 nm, following Equations 2, 3, and 4:

$$\text{Chlorophyll } a \text{ (Cl } a\text{)} = 12.25\ ABS_{663} - 2.81\ ABS_{646} \quad (2)$$

$$\text{Chlorophyll } b \text{ (Cl } b\text{)} = 21.50\ A_{646} - 5.10\ ABS_{663} \quad (3)$$

$$\text{Total carotenoids (CAROT)} = \frac{1000\ ABS470 - 1{,}82Cla - 85{,}02Clb}{198} \quad (4)$$

Based on the values of chlorophyll *a* and *b*, the chlorophyll *a*/*b* ratio (*a*/*b*) and total chlorophyll (Total Chl) were calculated and expressed in mg g^{-1} fresh mass (FM).

At 172 DAS, leaf water saturation deficit (WSD) was also determined in three fully expanded leaves. Immediately after collection, the fresh mass (FM) of the leaves was recorded, followed by immersion in distilled water for 24 hours. After removing excess water, the turgid mass (TM) was measured. The samples were then dried in a forced-air oven at 65 °C ± 3 °C to constant mass to determine the dry mass (DM). The WSD was calculated according to Weatherley (1950), using Equation 5.

$$DSH = \frac{(MT - MF)}{(MT - MS)} \times 100 \quad (5)$$

Where: DSH = Relative water content (%);

MF= Fresh leaf mass (g);

MT= Turgid mass (g);

MS = Dry mass (g).

Electrolyte leakage (EL) from the leaf lamina was also determined at 172 DAS, following the method described by Scotti-Campos et al. (2013). Ten leaf discs (113 mm² each) were taken from the third leaf from the apex and immersed in 50 mL of double-distilled water for 24 hours at 25 °C to determine the initial electrical conductivity (Ci). The samples were then heated in a forced-air oven at 80 °C for 90 minutes, after which the final electrical conductivity (Cf) was measured. The percentage of EL was calculated using Equation 6.

$$\%EE = \frac{Ci}{Cf} \times 100 \quad \text{.....(6)}$$

Where:

%EE = Electrolyte leakage from the leaf blade;

Ci= Initial electrical conductivity (dS m^{-1}); and,

Cf= Final electrical conductivity (dS m^{-1}).

Seedling growth was evaluated at 172 DAS by analyzing the number of mature leaves (ML, >3 cm in length), plant height (PH, in cm, measured from the soil to the apical bud), stem diameter (SD, in mm, measured 2 cm above the soil surface), and leaf area (LA), estimated with a graduated ruler based on the length of the midrib, according to Lima et al. (2012).

$$LA_{plant} = \sum LA = 0.3205 \times L^{2,0412} \quad (7)$$

Where:

AF_{plant} = plant leaf area (cm^2)

L = midrib length (cm)

Fresh biomass of leaves (LFB), stems (SFB), and roots (RFB) was determined, allowing for the calculation of shoot fresh biomass (SFBio) and total fresh biomass (TFB) as the sum of these components at 172 DAS. The plants were separated into roots, stems, and leaves, weighed fresh, oven-dried at 65 °C, and weighed again. Fresh and dry biomass were measured using a semi-analytical balance (precision of 0.001 g) and expressed in g/plant.

Seedling quality was determined using the Dickson Quality Index (DQI) (Dickson et al. 1960), as shown in Equation 8:

$$IQD = (FST)/[\left(\frac{AP}{DC}\right) + \left(\frac{FSPA}{FSR}\right)] \quad (8)$$

Where:

IQD= Dickson Quality Index;

AP = plant height (cm);

DC = stem diameter (mm);

FST = total dry biomass (g per plant);

FSPA = shoot dry biomass (g per plant); and

FSR = root dry biomass (g per plant).

2.4 Statistical Analysis

Data were analyzed using Principal Component Analysis (PCA) in SigmaPlot 12.5, reducing the dimensionality of the original dataset through linear combinations of the variables. The PCA retained only variables with correlation coefficients ≥ 0.5 and components with eigenvalues ≥ 1.0 that explained more than 10% of the total variance.

Variables not fitting the PCA model (correlation coefficient < 0.5) were subjected to analysis of variance (F-test, $p < 0.05$) and, when significant, to linear and polynomial regression analysis using SISVAR 5.6 (Ferreira et al. 2019), for both irrigation intervals and hydrogel doses.

3 RESULTS

Principal Component Analysis (PCA) explained 73.37% of the variance in the original dataset across the first two components (Tables 2 and 3). The first component, which accounted for 53.84% of the variance, included significant associations ($p \leq 0.01$) among most variables (Fig. 2). A negative correlation was observed between water saturation deficit (r = -0.61) and several growth and biomass variables: leaf area (r = 0.67); plant height (r = 0.78); Dickson Quality Index (r = 0.84); fresh biomass of leaves (r = 0.88), stems (r = 0.89), roots (r = 0.81), shoots (r = 0.94), and total biomass (r = 0.96); and dry biomass of leaves (r = 0.85), stems (r = 0.90), roots (r = 0.71), shoots (r = 0.94), and total (r = 0.95). The second component (22.53%) grouped electrolyte leakage (r = -0.61), chlorophyll a (r = -0.92), chlorophyll b (r = -0.95), total chlorophyll (r = -0.96), and the chlorophyll a/b ratio (r = 0.82) (Table 3).

Table 3. Eigenvalues, percentage of total variance explained, in the multivariate analysis of variance (MANOVA) and the correlation coefficients (r) between original variables and the principal components of fresh stem mass (FSP), fresh leaf mass (FLP), fresh root mass (FRP), fresh shoot mass (FSPA), total fresh mass (TFP), dry stem mass (DSP), dry leaf mass (DLP), dry root mass (DRP), dry shoot mass (DSPA) and total dry mass (TDP).

Principal component (PCs)	Principal component (PCs)	
	PC1	PC2
Eigenvalues (λ)	10.22	4.28
Percentage of total variance (S2%)	53.84	22.53
Hotelling's test (T2) for T	0.00	0.02
Hotelling's test (T2) for H	0.00	0.07
Hotelling's test (T2) for interaction (T × H)	0.00	0.26

	Correlation coefficient									
PCs	FSP	FLP	FRP	FSPA	TFP	DSP	DLP	DRP	DSPA	TDP
PC1	0.89	0.88	0.81	0.94	0.96	0.90	0.85	0.71	0.94	0.95
PC2	0.21	0.21	-0.2	0.22	0.1	-0.08	-0.18	-0.34	-0.14	-0.2
	Average values									
	FSP	FLP	FRP	FSPA	TFP	DSP	DLP	DRP	DSPA	TDP
T1H0	12.44	15.13	7.08	27.57	34.66	5.81	5.42	3.22	11.23	14.45
T1H2	18.41	20.36	12.79	38.77	51.57	8.98	6.30	5.11	15.28	20.38
T1H4	15.21	15.55	10.86	30.76	41.63	5.52	3.27	2.46	8.79	11.26
T1H6	15.76	20.59	9.60	36.35	45.95	7.42	7.55	2.93	14.97	17.90
T2H0	11.61	16.12	6.56	27.73	34.29	4.45	4.83	2.91	9.28	12.19
T2H2	11.68	13.81	7.22	25.49	32.71	4.78	4.54	3.24	9.32	12.55
T2H4	12.30	17.29	6.37	29.59	35.96	4.74	5.16	2.87	9.90	12.77
T2H6	13.83	20.13	6.92	33.96	40.88	3.98	5.10	2.34	9.08	11.41
T3H0	11.51	16.13	6.69	27.64	34.33	4.40	4.53	2.64	8.93	11.56
T3H2	13.32	17.43	8.50	30.75	39.25	5.28	5.12	3.30	10.40	13.70
T3H4	13.82	22.59	9.72	36.41	46.13	6.62	7.56	3.76	14.15	17.91
T3H6	11.59	16.77	7.08	28.37	35.45	3.62	4.25	3.64	7.86	11.50
T4H0	13.48	16.51	8.54	29.98	38.52	6.31	6.62	2.48	12.93	15.40
T4H2	13.62	17.24	11.39	30.85	42.24	6.29	6.54	3.80	12.84	16.63
T4H4	11.16	16.15	9.06	27.31	36.37	5.01	6.49	3.46	11.50	14.95

T4H6	14.11	18.10	10.37	32.21	42.58	5.89	6.30	3.60	12.18	15.78
T5H0	8.82	13.52	5.90	22.33	28.24	3.53	4.15	2.55	7.68	10.23
T5H2	8.83	11.76	5.78	20.59	26.37	3.62	3.63	2.34	7.25	9.59
T5H4	8.93	12.41	6.75	21.34	28.10	3.62	2.69	2.63	6.30	8.94
T5H6	10.61	14.12	4.54	24.73	29.28	4.56	4.17	1.97	8.73	10.69

T1H0 = irrigation intervals 1 and dose 0; T1H2 = irrigation intervals 1 and dose 2; T1H4 = irrigation intervals 1 and dose 4; T1H6 = irrigation intervals 1 and dose 6; T2H0 = irrigation intervals 2 and dose 0; T2H2 = irrigation intervals 2 and dose 2; T2H4 = irrigation intervals 2 and dose 4; T2H6 = irrigation intervals 2 and dose 6; T3H0 = irrigation intervals 3 and dose 0; T3H2 = irrigation intervals 3 and dose 2; T3H4 = irrigation intervals 3 and dose 4; T3H6 = irrigation intervals 3 and dose 6; T4H0 = irrigation intervals 4 and dose 0; T4H2 = irrigation intervals 4 and dose 2; T4H4 = irrigation intervals 4 and dose 4; T4H6 = irrigation intervals 4 and dose 6; T5H0 = irrigation intervals 5 and dose 0; T5H2 = irrigation intervals 5 and dose 2; T5H4 = irrigation intervals 5 and dose 4; T5H6 = irrigation intervals 5 and dose 6.

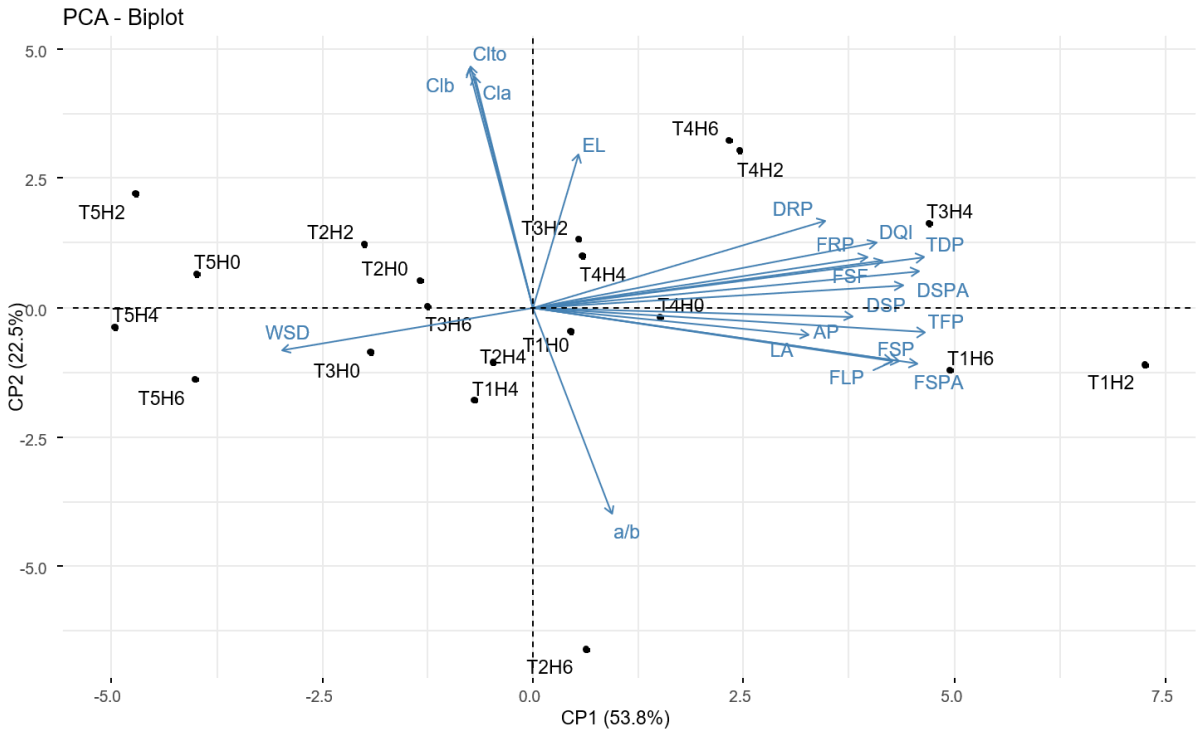


Fig. 2. Two-dimensional projection of the principal component scores for factors T and B and variables analyzed in the two principal components (PC1 and PC2).

As shown in Table 2, increased electrolyte leakage was associated with higher levels of chloroplast pigments. The highest average values were observed in guava seedlings irrigated every four days (T4H2 and T4H6), reaching 42.43 for chlorophyll a, 17.99 for chlorophyll b, and 59.44 mg g^{-1} FW for total chlorophyll. Irrigation every two days (T2H6) resulted in the lowest pigment levels, with reductions of 30.16%, 52.52%, and 35.78% for chlorophyll a, b, and total, respectively.

Table 2. Eigenvalues and percentage of total variance explained in the multivariate analysis of variance (MANOVA) and the correlation coefficients (r) between original variables and the principal components of electrolyte leakage (EL), water saturation deficit (WSD), chlorophyll *a* (Cl a), chlorophyll *b* (Cl b), total Cl (total chlorophyll), chlorophyll a/b ratio (a/b), leaf area (LA), plant height (PH), Dickson quality index (DQI).

Principal component (PCs)	Principal component (PCs)	
	PC1	PC2
Eigenvalues (λ)	10.22	4.28
Percentage of total variance (S2%)	53.84	22.53
Hotelling's test (T2) for T	0.00	0.02
Hotelling's test (T2) for H	0.00	0.07
Hotelling's test (T2) for interaction (T × H)	0.00	0.26

PCs	Correlation coefficient								
	EL	WSD	Cl a	Cl b	Cl totais	a/b	LA	PH	DQI
PC1	0.11	-0.61	-0.14	-0.15	-0.15	0.19	0.67	0.78	0.84
PC2	-0.61	-0.25	-0.92	-0.95	-0.96	0.82	0.1	0.03	-0.25
	Average values								
	EL	WSD	Cl a	Cl b	Cl totais	a/b	LA	PH	DQI
T1H0	13.59	23.61	36.85	12.98	49.83	2.86	949.41	77.95	1.41
T1H2	10.67	14.35	37.91	11.95	49.86	3.23	1020.35	84.67	1.65
T1H4	10.73	18.39	36.52	12.96	49.48	2.84	683.20	71.30	0.60
T1H6	12.05	6.86	35.92	12.60	48.52	2.87	1270.54	73.47	1.24
T2H0	12.65	10.88	39.06	14.79	53.85	2.68	849.75	65.33	0.85

T2H2	13.01	17.84	40.66	15.03	55.69	2.71	791.51	61.43	0.90
T2H4	12.81	16.82	34.82	13.52	48.34	2.60	864.78	76.78	0.75
T2H6	11.79	19.48	29.63	8.54	38.17	3.67	1201.91	74.48	0.59
T3H0	11.50	26.75	38.17	13.79	51.96	2.79	940.73	70.75	0.73
T3H2	15.61	18.70	39.82	15.14	54.96	2.69	944.18	74.92	0.92
T3H4	15.87	16.02	39.71	14.97	54.68	2.67	1207.28	80.57	1.33
T3H6	14.01	14.76	38.76	13.75	52.51	2.82	914.06	71.15	0.75
T4H0	13.46	14.01	37.85	13.38	51.23	2.83	1098.60	68.98	1.08
T4H2	14.17	13.84	42.43	16.66	59.09	2.56	1042.40	72.67	1.06
T4H4	13.32	15.87	39.45	14.50	53.95	2.76	957.16	74.35	1.01
T4H6	13.66	13.42	41.45	17.99	59.44	2.33	1099.14	75.45	1.07
T5H0	12.61	23.32	42.14	14.43	56.56	2.92	770.50	70.77	0.68
T5H2	15.52	19.12	41.86	16.07	57.93	2.61	813.97	64.13	0.68
T5H4	10.93	30.00	40.01	14.24	54.25	2.81	1024.63	61.25	0.53
T5H6	10.60	18.42	35.28	13.83	49.11	2.60	697.41	54.38	0.55

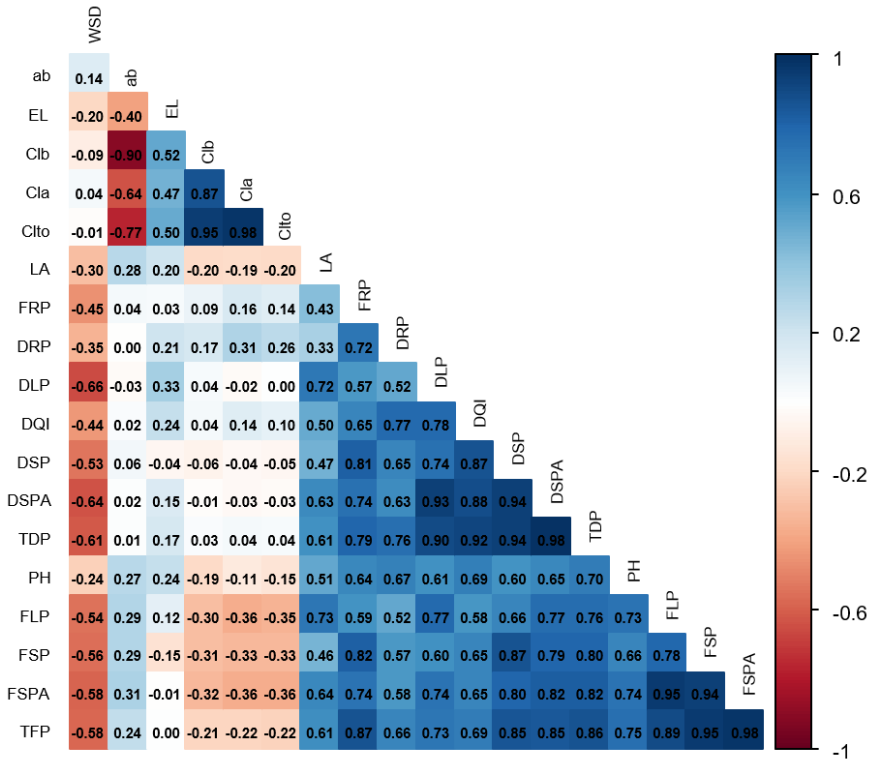
T1H0 = irrigation intervals 1 and dose 0; T1H2 = irrigation intervals 1 and dose 2; T1H4 = irrigation intervals 1 and dose 4; T1H6 = irrigation intervals 1 and dose 6; T2H0 = irrigation intervals 2 and dose 0; T2H2 = irrigation intervals 2 and dose 2; T2H4 = irrigation intervals 2 and dose 4; T2H6 = irrigation intervals 2 and dose 6; T3H0 = irrigation intervals 3 and dose 0; T3H2 = irrigation intervals 3 and dose 2; T3H4 = irrigation intervals 3 and dose 4; T3H6 = irrigation intervals 3 and dose 6; T4H0 = irrigation intervals 4 and dose 0; T4H2 = irrigation intervals 4 and dose 2; T4H4 = irrigation intervals 4 and dose 4; T4H6 = irrigation intervals 4 and dose 6; T5H0 = irrigation intervals 5 and dose 0; T5H2 = irrigation intervals 5 and dose 2; T5H4 = irrigation intervals 5 and dose 4; T5H6 = irrigation intervals 5 and dose 6.

The 'Paluma' guava cultivar showed a 77.13% reduction in water saturation deficit under daily irrigation and 6 g dm^{-3} of hydrogel incorporated into the substrate, compared to plants irrigated every five days with 4 g dm^{-3} of the water-retainer, which caused the highest DSH values. As the water saturation deficit increased under these conditions, both plant height and the Dickson Quality Index decreased sharply, with minimum values of 61.25 cm (T5H6) and 0.53 (T5H4), respectively.

The best performance for plant height (84.67 cm) and Dickson Quality Index (1.65) was achieved with 2 g dm^{-3} of hydrogel under daily irrigation (T1H2). Daily irrigation was also effective for leaf area, which increased by 46.22% when associated with 6 g dm^{-3} of hydrogel compared to daily irrigation combined with 4 g dm^{-3} of the polymer.

The 4 g dm^{-3} hydrogel dose mitigated the adverse effects of water deficit by promoting greater leaf biomass accumulation in guava seedlings irrigated every three days. However, under less frequent irrigation (every five days), reductions of 47.54% in fresh biomass (T5H2) and 64.41% in dry biomass (T5H4) of leaves were observed. For the remaining biomass components, daily irrigation resulted in higher fresh and dry biomass. In contrast, irrigation every five days led to declines of 52.09% (T5H0), 64.50% (T5H6), 46.89% (T5H2), and 48.47% (T5H2) in fresh biomass of stem, shoot, root, and total biomass, respectively, and reductions of 59.59% (T5H2 and T5H4), 61.44% (T5H6), 58.76% (T5H4), and 56.13% (T5H4) in dry biomass of stem, shoot, root, and total biomass, respectively (Table 3).

According to the Pearson correlation matrix (Fig. 3), guava plants with greater growth and biomass production were negatively correlated with water saturation deficit. In contrast, chlorophylls *a*, *b*, and total were positively correlated with electrolyte leakage.



Water saturation deficit (DSH), electrolyte leakage (EE), chlorophyll a (Cla), chlorophyll b (Clb), total chlorophyll (Cltotais) and chlorophyll a/b ratio (a/b). Leaf area (AF), plant height (AP), Dickson quality index (IQD), fresh leaf phytomass (FFF), fresh stem phytomass (FFC), fresh root phytomass (FFR), fresh shoot phytomass (FFPA), total fresh phytomass (FFT), dry leaf phytomass (FSF), dry stem phytomass (FSC), dry root phytomass (FSR), dry shoot phytomass (FSPA) and total dry phytomass (FST). Water saturation deficit (WSD), electrolyte leakage (EE), chlorophyll a (Cla), chlorophyll b (Clb), total chlorophyll (Cltotais) and chlorophyll a/b ratio (a/b). Leaf area (AF), plant height (PH), Dickson quality index (DQI), fresh leaf phytomass (FLP), fresh stem phytomass (FSP), fresh root phytomass (FRP), fresh shoot phytomass (FFP), total fresh phytomass (FFT), dry leaf phytomass (FSF), dry stem phytomass (FSC), dry root phytomass (FSR), dry shoot phytomass (FSPA) and total dry phytomass (FST).

Fig. 3. Pearson correlation between physiological and guava growth variables under irrigation shifts and hydrogel doses.

Analysis of variance (Table 4) showed a significant effect of irrigation frequency on carotenoid content (CAROT) and leaf number in *Paluma* guava. Hydrogel doses significantly influenced carotenoid content and stem diameter at 175 days after sowing.

Table 4. Summary of the analysis of variance regarding the carotenoid content (CAROT), number of leaves (NF) and stem diameter (DC) of guava trees under irrigation shifts and hydrogel doses, 172 days after sowing.

Source of variation	DF	Mean Squares		
		CAROT	NL	SD
Irrigation intervals (T)	4	0.3966^{*}	22.3005^{ns}	5.0074^{ns}
Linear regression	1	0.0235^{ns}	71.3020^{**}	4.9654^{**}
Quadratic regression	1	0.9691^{*}	2.7514^{ns}	2.1692^{**}
Hydrogel doses (H)	3	1.0108^{**}	68.4250^{ns}	1.9379^{**}
Linear regression	1	0.0604^{ns}	85.86^{**}	3.0401^{**}
Quadratic regression	1	2.05297^{**}	0.3375^{ns}	1.2615^{*}
T × H	12	0.4006^{ns}	33.9901^{ns}	1.1951^{ns}
Block	2	0.0530^{ns}	3.1593^{ns}	0.6999^{*}

Residual	38	0.1609	5.2854	0.1741
CV (%)		8.75	7.21	6.80
Mean		4.58	31.90	6.13

ns,**, * not significant, significant at $p \leq 0.01$ and at $p \leq 0.05$, respectively, DF-degree of freedom

Irrigation every five days increased carotenoid content (4.76 mg g^{-1} FW), representing a 6.93% rise compared to the three-day cycle (4.43 mg g^{-1} FW) (Fig. 4A). The water-retaining polymer did not enhance carotenoid content in the leaves (Fig. 4C), with the highest values recorded in plants without the polymer (4.83 mg g^{-1} FW), regardless of irrigation frequency.

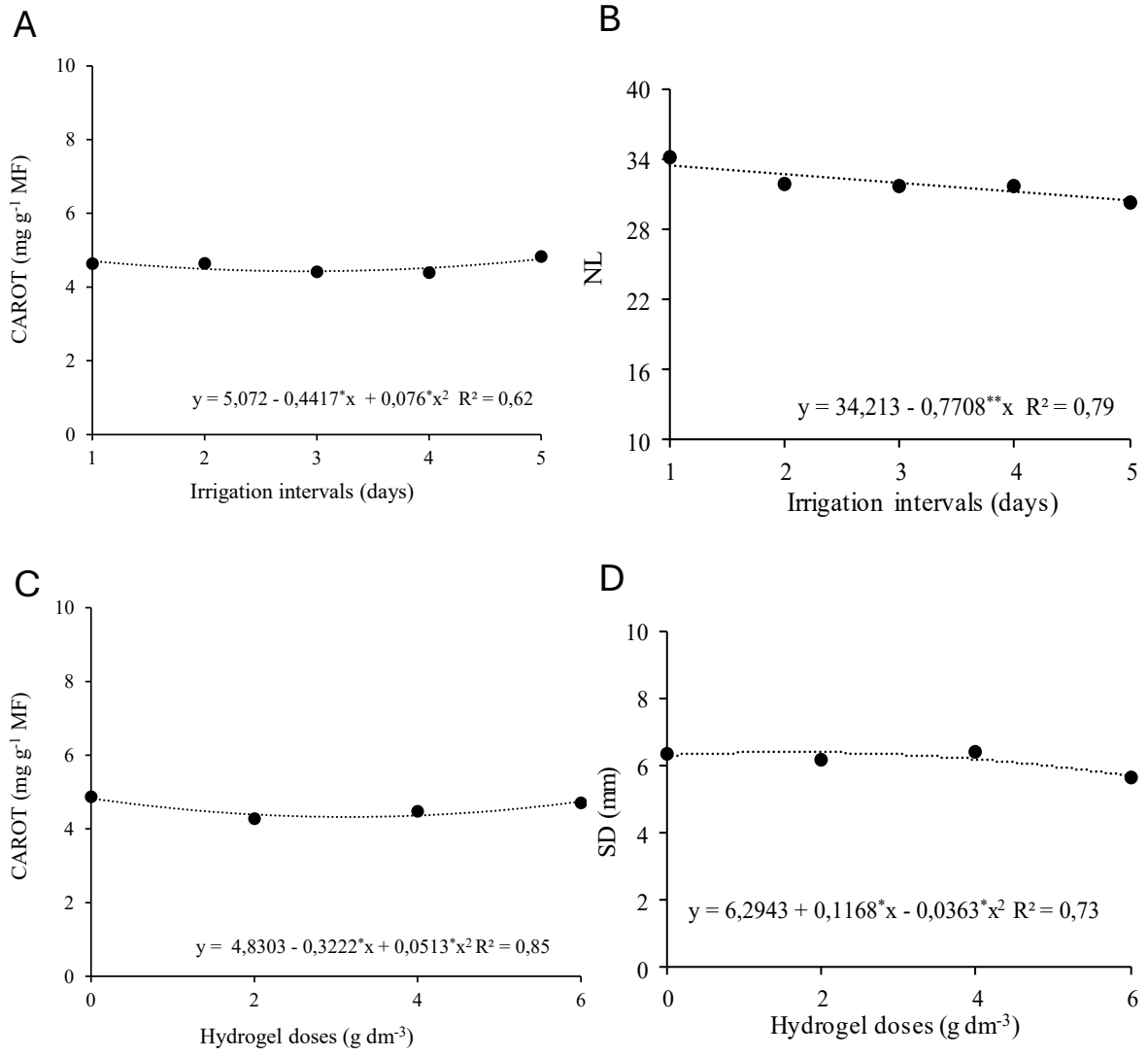


Fig. 4. Carotenoid content (CAROT) - A and number of leaves (NL) - B under irrigation shifts (1, 2, 3, 4 and 5 days) and carotenoid content (CAROT) - C and stem diameter (SD) - D under hydrogel doses, 175 days after sowing.

Leaf number decreased by 2.25% with each additional day between irrigations, a trend also observed for plant height and the Dickson Quality Index, both of which were negatively affected by five-day irrigation intervals (Fig. 4B).

For stem diameter (Fig. 4D), the 2 g dm^{-3} dose showed the best performance (6.38 mm), with a 10.97% reduction compared to the lowest value (5.68 mm) found in plants grown with 6 g dm^{-3} of hydrogel.

4 DISCUSSION

Prolonged water deficit induces stomatal resistance and reduces transpiration, leading to the formation of reactive oxygen species (ROS), such as superoxide, singlet oxygen, and hydrogen peroxide. These ROS degrade the phospholipid bilayer of cell membranes, resulting in the loss of cellular contents (Wu et al. 2022). However, ROS also act as stress signals, triggering plant defense mechanisms that minimize cytotoxicity and enhance pigment production, thereby protecting the photosynthetic apparatus (Roque et al. 2025). A similar increase in chlorophyll content in response to water deficit has been reported in canola (Cardoso et al. 2023) and sugar apple (Torres et al. 2023).

Despite the increase in photosynthetic pigments, the electrolyte leakage associated with water stress reduced the chlorophyll *a*/*b* ratio (Table 2). This decline impairs photosynthesis, since chlorophyll *a* is essential for light harvesting, while chlorophyll *b* assists in energy absorption and transfer. An ideal chlorophyll *a*/*b* ratio (3:1) is crucial for efficient electron flow between photosystems (Lacerda et al. 2025).

The highest water saturation deficits resulted from reduced cellular water volume, reflecting the decline in soil water potential due to infrequent irrigation. This condition decreases turgor pressure, impairs mitosis in meristematic tissues, and leads to poorer growth and seedling quality (Parkash and Singh, 2020).

The improved performance in plant height, leaf area, and Dickson Quality Index may be attributed to the benefits of hydrogels (Kumar et al. 2020). Hydrogels increase soil water retention capacity and improve soil physical properties such as porosity, bulk density, and permeability, thereby enhancing nutrient availability and transport. These factors contribute to photosynthetic activity and result in more robust and higher-quality plants.

Biomass accumulation may be linked to the water absorption capacity of hydrogels, owing to their high molecular weight, negative charge, and hydrophilic functional groups, which help prevent water loss through

311 percolation (Abdallah 2019; Yuan et al. 2025). Increased water availability in the soil promotes stomatal opening
312 and carbon assimilation during photosynthesis, enhancing electron transport and preventing damage to thylakoid
313 membranes. This, in turn, boosts photosynthesis and the allocation of photoassimilates (Parkash and Singh, 2020;
314 Fischer and Melgarejo, 2021).

315 Under the conditions of this study, the soil conditioner did not alleviate the negative effects of water
316 restriction for most of the variables evaluated in guava; however, it proved beneficial under daily irrigation. A
317 similar pattern was observed in *Eugenia myrcianthes Nied.* seedlings, where leaf area and biomass were drastically
318 reduced, and hydrogel was ineffective in mitigating water deficit (Silverio et al. 2024).

319 Carotenoids function as antioxidants, neutralizing singlet oxygen and protecting cell membranes.
320 Therefore, higher carotenoid contents may indicate the activation of secondary defense mechanisms in plants under
321 water deficit (Sun et al. 2018), as observed here with increased chlorophyll levels under limited irrigation. This
322 response contrasts with findings by Roque et al. (2025), who reported reduced chlorophyll and carotenoid contents
323 in *Paluma* guava grown under water deficit (50% ETr).

324 The reduction in the number of leaves (Fig. 4B) is a drought-avoidance strategy that enables guava plants
325 to minimize water loss through transpiration (Lacerda et al. 2025).

326 Water-retaining polymers improve water use efficiency, which positively affects plant growth. This
327 characteristic is highly relevant, as increases in stem diameter (Fig. 4D) are associated with greater robustness and
328 better field establishment (Henrique, 2021).

329 **5 CONCLUSION**

330 Electrolyte leakage increased under soil water deficit, resulting in elevated chlorophyll contents.

331 Increasing water saturation deficit led to reduced growth, biomass accumulation, and Dickson Quality
332 Index in guava plants.

333 Hydrogel enhanced fresh and dry biomass accumulation under daily irrigation.

334 A five-day irrigation interval drastically reduced leaf number in guava plants but stimulated carotenoid
335 production.

336 Guava plants showed greater stem diameter when cultivated with 2 g dm^{-3} of water-retaining polymer.

337

338 **6 DECLARATION OF CONFLICT OF INTEREST**

339 The authors declare no conflict of interest

340

7 AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

8 DATA AVAILABILITY STATEMENT

All datasets supporting the results of this study are included in the article itself.

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