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Liquid fertilizers on photochemical efficiency and gas exchange in yellow passion fruit under saline stress[1]

Fertilizantes líquidos na eficiência fotoquímica e trocas gasosas em maracujazeiro-amarelo sob estresse salino

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HIGHLIGHTS:

Substrate salinity increased due to application of liquid fertilizers associated with 4.0 dS m^{-1} water.
Water-use efficiency in 'Guinezinho' yellow passion fruit enhanced under 4.0 dS m^{-1} water salinity.
Positive impact of Codasal™ application on CO_2 assimilation rate and carboxylation efficiency in yellow passion fruit seedlings.

ABSTRACT: The Northeast region of Brazil is the primary producer of yellow passion fruit. In recent years, water scarcity has led passion fruit growers to use highly saline water for cultivation. Therefore, implementing technologies that alleviate the negative effects of salt stress on plants is a promising approach, particularly in semi-arid conditions. This study aimed to assess the efficacy of organomineral fertilizers in mitigating salt stress effects on chlorophyll-a fluorescence and gas exchange in 'Guinezinho' yellow passion fruit seedlings. The treatments were arranged in randomized blocks with four replicates and four seedlings per plot, following a 2 × 3 factorial design. The factors considered were irrigation using water with low (0.18 dS m^{-1}) and high (4.0 dS m^{-1}) electrical conductivity and three liquid organomineral attenuators (Codasal™, Aminoagro Raiz™, and a mixture of Codasal™ + Aminoagro Raiz™ at a 1:1 v/v ratio), applied through fertigation. Irrigation with water containing 4.0 dS m^{-1} electrical conductivity, combined with liquid fertilizers, resulted in increased substrate salinity, and reduced stomatal conductance in yellow passion fruit seedlings, particularly when Codasal™ was applied. Application of Codasal™ alone or in combination with Aminoagro Raiz™ significantly enhanced variable fluorescence, quantum efficiency of PSII, CO_2 assimilation rate, and instantaneous carboxylation efficiency in 'Guinezinho' yellow passion fruit seedlings.

Key words: *Passiflora edulis* Sims, salt stress, mitigation, organomineral sources, gas exchange

RESUMO: O Nordeste é a principal região produtora de frutos de maracujazeiro-amarelo no Brasil, que devido à escassez hídrica ocorrida nos últimos anos, os passifloricultores utilizam água de elevada concentração de sais para exploração da cultura. Dessa forma, o emprego de tecnologias que possibilite a atenuação do estresse salino às plantas é uma estratégia promissora nas condições de semiárido. Objetivou-se com o trabalho avaliar a ação de fertilizantes organominerais como atenuador do estresse salino sobre a fluorescência da clorofila a e trocas gasosas de mudas maracujazeiro-amarelo acesso 'Guinezinho'. Os tratamentos foram distribuídos em blocos casualizados com quatro repetições e quatro mudas por parcela, empregando o esquema fatorial 2 × 3, referente às irrigação com água de baixa (0,18 dS m^{-1}) e alta (4,00 dS m^{-1}) condutividade elétrica e três atenuadores organomineral líquidos (Codasal®, Aminoagro Raiz® e mistura de Codasal® + Aminoagro Raiz® - proporção de 1/1 v/v), via fertirrigação. A irrigação com água de 4,0 dS m^{-1} associado com fertilizantes líquidos aumentam a salinidade do substrato e reduz a condutância estomática das mudas de maracujazeiro-amarelo, principalmente, com aplicação de Codasal®. A aplicação individual ou associado de Codasal® com Aminoagro Raiz® promove aumentos na fluorescência variável, eficiência quântica do PSII, taxa de assimilação de CO_2 e eficiência instantânea de carboxilação em mudas de maracujazeiro-amarelo, acesso "Guinezinho".

Palavras-chave: *Passiflora edulis* Sims, estresse salino, mitigação, fontes organomineral, trocas gasosas

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Introduction

Yellow passion fruit (*Passiflora edulis* Sims) is a fruit crop well-suited to the edaphoclimatic conditions of the semi-arid region in northeastern Brazil (Ramos et al., 2022). However, water scarcity in the region has compelled producers to resort to using water with high salt concentrations for agricultural purposes and during seedling production, including those of yellow passion fruit (Souto et al., 2016; Oliveira et al., 2018; Leal et al., 2021; Silva et al., 2021a; Silva et al., 2021b).

Irrigation with high-salinity water leads to a gradual accumulation of salts in substrates, thereby compromising the stabilization and productivity of yellow passion fruit seedlings (Bezerra et al., 2014). A quality decline in seedlings is attributed to osmotic factors, as roots struggle to absorb water from substrate, and ionic factors, causing nutritional imbalances and specific toxicity, especially due to sodium (Na^+) and chloride (Cl^-) ions (Zörb et al., 2019; Arif et al., 2020; Pan et al., 2021).

Nevertheless, applying salt stress attenuators using mineral and organic fertilizers has shown successful results in improving the physiology of yellow passion fruit seedlings (Freire et al., 2014; Bezerra et al., 2014; Figueiredo et al., 2020; Lima et al., 2020). Individual or simultaneous application of liquid potassium (K^+) and calcium (Ca^{2+}) fertilizers can mitigate salt stress effects by regulating osmotic balance, enhancing photosystem efficiency and gas exchange, facilitating stress signaling, and competing with Na^+ (Hasanuzzaman et al., 2018; Seifikalho et al., 2019; Schulze et al., 2021).

Liquid fertilizers, either alone or in combination, hold the potential to reduce the detrimental impacts of saline stress on the photosynthetic apparatus of yellow passion fruit, enabling the production of seedlings with high-quality standards, even when irrigated with highly saline water. Therefore, this study aimed to evaluate the effectiveness of organomineral fertilizers as attenuators of salt stress effects on chlorophyll-a fluorescence and gas exchange in seedlings of 'Guinezinho' yellow passion fruit accession.

Material and Methods

The experiment was conducted from October to November 2019 at the Seedling Production Sector, located in the Center for Human, Social, and Agrarian Sciences of the Federal University of Paraíba in Bananeiras, Paraiba State, Brazil (06° 45' 04" S, 35° 38' 00" W, 552 m above sea level). The benches used for the experiment were protected with shading screens, which blocked 50% of solar radiation.

Bananeiras has an average temperature of 22.0 °C and an annual relative air humidity of 63.2%. The plant material evaluated in the study was the yellow passion fruit accession 'Guinezinho', widely known and cultivated by producers in the states of Paraíba and Rio Grande do Norte in Brazil (Bezerra et al., 2014).

The experimental design followed a randomized block layout, employing a 2 × 3 factorial scheme. This included two levels of irrigation water electrical conductivity: low (0.18 dS m^{-1}) and high (4.0 dS m^{-1}), based on previous studies conducted by Bezerra et al. (2014) and Silva et al. (2021a). Additionally, three liquid fertilizer combinations were used: Codasal™ (CS), Aminoagro Raiz™ (AR), and a mixture of Codasal™ + Aminoagro Raiz™ (CS + AR) in a 1:1 v/v ratio. These fertilizers were applied via fertigation in the substrate. Each treatment had four replicates, with four plants per plot, resulting in a total of 24 plots. The treatment involving irrigation with low saline water and the application of Codasal™ served as the control, as the product is designed to mitigate saline stress in plants and is widely used in the regional market, while Aminoagro Raiz™ was utilized as an alternative treatment.

The substrate used in the experiment comprised 2 dm^3 of organic soil obtained from compost, collected at a depth of 0-0.20 m from the Agriculture Sector. The soil was characterized for its chemical attributes related to fertility and salinity, as detailed in Table 1 (Teixeira et al., 2017).

After collection, soil samples were crushed to break up clods and dried in shade. Then, it was passed through a 2-mm mesh sieve and thoroughly mixed for homogenization. Basic fertilization of the substrate was conducted by applying 1.5 g dm^{-3} of simple superphosphate (18% P_2O_5, 16% Ca, and 10% S) and 0.3 g dm^{-3} of potassium sulfate (50% K_2O and 15% S). This corresponded to a dose of 300 mg dm^{-3} of P_2O_5 and 150 mg dm^{-3} of K_2O, respectively (Bezerra et al., 2019).

For seedling production, black polyethylene bags with dimensions of 0.15 m × 0.25 m and a volumetric capacity of 2.12 dm^3 were used as containers. Sowing was conducted by placing five seeds equidistantly and evenly distributed at a depth of 1 cm in each container. Thinning was conducted nine days after sowing (DAS), retaining the most vigorous plant per container.

At 10 and 40 days after emergence (DAE), Codasal™, Aminoagro Raiz™, and their mixture (Codasal™ + Aminoagro Raiz™) were applied to each plant in a volume of 50 mL, delivered via irrigation water. Codasal™ and Aminoagro Raiz™ were applied at a concentration of 2 mL L^{-1}, while the Codasal™ + Aminoagro Raiz™ mixture was applied at a concentration of 1 mL L^{-1} for each liquid fertilizer. These concentrations were prepared by dissolving the fertilizers in low-salinity water (0.18 dS m^{-1}), following the manufacturers' recommendations.

Table 1. Chemical properties of the substrate used regarding fertility and salinity before the experiment

Fertility and salinity	Values
pH (1:2.5 H_2O)	5.68
Ca^{2+} ($cmol_c$ dm^{-3})	7.80
Mg^{2+} ($cmol_c$ dm^{-3})	4.90
K^+ ($cmol_c$ dm^{-3})	0.57
Al^{3+} ($cmol_c$ dm^{-3})	0
Na^+ ($cmol_c$ dm^{-3})	0.07
$H^+ + Al^{3+}$ ($cmol_c$ dm^{-3})	4.62
SB ($cmol_c$ dm^{-3})	13.34
CEC ($cmol_c$ dm^{-3})	17.96
V (%)	74.27
P (mg dm^{-3})	202.10
SOM (g kg^{-1})	40.05
Organic carbon (g kg^{-1})	23.23
Electrical conductivity dS m^{-1} H_2O (1:2.5)	0.55

Fertility - P, K^+, Na^+: Mehlich 1 Extractant; SB - Sum of exchangeable bases ($Ca^{2+} + Mg^{2+} + K^+ + Na^+$); ($H^+ + Al^{3+}$) – extracted by 0.5 M calcium acetate pH 7.0; CEC - Cation exchange capacity [SB + ($H^+ + Al^{3+}$)]; Al^{3+}, Ca^{2+}, Mg^{2+} - extracted by 1 M KCl pH 7.0; SOM - Soil organic matter by Walkley-Black method

Codasal™ liquid organomineral fertilizer is a dark solution that contains nutrients complexed in lignosulphonate (6.0% N, 8.7% CaO, 14.7% lignosulphonate complexing agent, and a saline index of 40.74%). Aminoagro Raiz™ is characterized by being a dark solution rich in nutrients and organic matter (11% N, 1% K_2O, 17% total carbon, and a saline index of 8.7%). The electrical conductivity of the prepared attenuators was measured as 0.40 dS m^{-1} for Codasal™, 1.61 dS m^{-1} for Aminoagro Raiz™, and 1.0 dS m^{-1} for the Codasal™ + Aminoagro Raiz™ mixture.

Low-salinity water (ECw = 0.18 dS m^{-1}) was sourced from an artesian well near the experimental site in Bananeiras, Paraíba State, Brazil. High-salinity water (4.0 dS m^{-1}) was obtained by diluting highly saline water (ECw = 117.0 dS m^{-1}) with low-salinity water (0.18 dS m^{-1}), with EC being measured by a CD-850 portable device. The highly saline water used (ECw = 117.0 dS m^{-1}) was sourced from a reservoir in the municipality of Casserengue, Paraíba State, Brazil. Irrigation using both low and high-salinity water was manually performed throughout the experiment, employing a weighing lysimeter to provide a daily volume of water equivalent to 24-h evapotranspiration. This was done to maintain the substrate at about 90% of its maximum water storage capacity. The FAO-56 Penman-Monteith equation was used to estimate the baseline evapotranspiration (ET_o) (Alves et al., 2017).

At 45 DAE, chlorophyll-a fluorescence emission was assessed for the following variables: initial fluorescence (Fo), maximum fluorescence (Fm), variable fluorescence (Fv), the quantum efficiency of photosystem II (Fw), photochemical quenching coefficient (qP), and electron transport rate (ETR). These readings were conducted using the Plant Efficiency Analyzer - PEA II™ pulse-modulated fluorometer (Hansatech Instruments Co., UK). One plant per treatment was selected for evaluations, which were made on the third pair of fully expanded leaves, counting from the apex of the seedling. The measurements took place between 09:00 and 10:00 hours after leaves had adapted to the dark for 30 minutes.

During the same period and using the same selected leaves, gas exchange variables were analyzed using a portable infrared carbon dioxide analyzer (IRGA), an LCPro+ model - Portable Photosynthesis System™ from ADC BioScientific Limited, UK. To do so, the temperature was set to 25 °C, with an irradiation of 1200 μmol photon m^{-2} s^{-1} and an airflow of 200 mL min^{-1} (Freire et al., 2014). The gas exchange variables measured included stomatal conductance (gs - mol H_2O m^{-2} s^{-1}), internal CO_2 concentration (Ci - μmol CO_2 mol^{-1}), CO_2 assimilation rate (A - μmol CO_2 m^{-2} s^{-1}), transpiration rate (E - mmol H_2O m^{-2} s^{-1}), instantaneous water-use efficiency (WUE = A/E - [(μmol CO_2 m^{-2} s^{-1})(mmol H_2O m^{-2} s^{-1})$^{-1}$]) and instantaneous carboxylation efficiency (CEi = A/Ci - [(μmol CO_2 m^{-2} s^{-1}) (mol CO_2 m^{-2} s^{-1})$^{-1}$]).

Concurrently with the seedlings' fluorescence and gas exchange evaluations, samples of the substrate from plastic containers in each treatment were collected to determine salinity. This determination was based on the electrical conductivity of the saturation extract (ECse).

Before analysis, data normality and homogeneity were assessed using the Shapiro-Wilk test. Subsequently, the data underwent analysis of variance using the F-test ($p \le 0.05$). The means related to irrigation water salinity and liquid fertilizers were compared using the Duncan test ($p \le 0.05$). Furthermore, correlation analysis between the variables was conducted using Pearson's test ($p \le 0.05$). Data analysis was performed using R statistical software version 3.4.1 (R Core Team, 2022).

Results and Discussion

Table 2 highlights a significant interaction between water salinity and liquid fertilizers, which influenced substrate electrical conductivity, maximum fluorescence, and stomatal conductance. The application of liquid fertilizers affected fluorescence, the maximum quantum efficiency of photosystem II (PSII), CO_2 assimilation rate, and instantaneous carboxylation efficiency. On the other hand, the treatments did not have a noticeable impact on initial fluorescence, photochemical quenching coefficients of variable fluorescence in photosynthesis, and leaf electron transport rate. Regarding irrigation with saline water, it had a significant effect on leaf transpiration and water use efficiency in the seedlings of the 'Guinezinho' accession of yellow passion fruit.

Table 2. Summary of analysis of variance for electrical conductivity of substrate saturation extract, chlorophyll-a fluorescence parameters and leaf gas exchange in seedlings of yellow passion fruit ('Guinezinho' accession) under saline water irrigation (SW) and liquid fertilizer application (LF)

SV	Block	Saline water	Liquid fertilizer	SW × LF	Residual	CV (%)
DF	3	1	2	2	12	
ECse	0.49^{ns}	15.13**	28.64**	13.58**		7.73
F_0	10173.4^{ns}	10141.83^{ns}	20106.65^{ns}	1993.38^{ns}		24.09
Fm	26598.51^{ns}	4832.83^{ns}	64498.04*	41847.26*		3.88
Fv	62959.67**	28978.02^{ns}	108234.65**	37758.04^{ns}		4.49
Fw	0.0018^{ns}	0.0016^{ns}	0.0035*	0.0030^{ns}		3.11
qP	0.0033^{ns}	0.0003^{ns}	0.0031^{ns}	0.0016^{ns}		15.00
ETR	272.96^{ns}	182.87^{ns}	111.83^{ns}	43.29^{ns}		10.01
gs	0.042^{ns}	0.292**	0.007^{ns}	0.061*		15.08
Ci	22.79^{ns}	445.99**	6.49^{ns}	49.76^{ns}		1.39
A	5.40^{ns}	5.90^{ns}	12.89*	2.53^{ns}		7.30
E	0.27^{ns}	10.49**	0.61^{ns}	2.77^{ns}		8.67
WUE	0.019^{ns}	0.158**	0.024^{ns}	0.023^{ns}		5.65
CEi	0.000049^{ns}	0.00009^{ns}	0.000126*	0.000034^{ns}		7.20

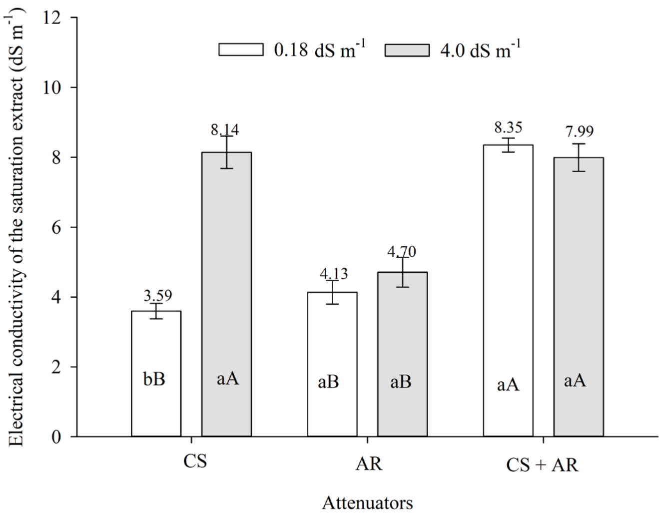
SV - source of variation; DF - degrees of freedom; CV - coefficient of variation; ns, *, ** - non-significant, significant at $p \le 0.05$, and $p \le 0.01$ by the F-test, respectively. ECse - saturation extract electrical conductivity; F_0 - initial fluorescence; Fm - maximum fluorescence; Fv - variable fluorescence; qP - photochemical quenching coefficient; ETR - electron transport rate; gs - stomatal conductance; Ci - internal CO_2 concentration; A - CO_2 assimilation rate; E - transpiration rate; WUE - instantaneous water-use efficiency; CEi - instantaneous carboxylation efficiency

The observed Fo value is lower than the range of 949.35 to 672.56 reported by Diniz et al. (2021) for seedlings of yellow passion fruit cv. ‘Gigante Amarelo’ irrigated with saline water (3.1 dS m^{-1}), but higher than the values found by Andrade et al. (2022) for yellow passion fruit accession ‘Guinezinho’ irrigated with water up to 2.8 dS m^{-1} (121.84 to 146.77). In this study, qP values did not vary in yellow passion fruit seedlings under water stress, indicating no damage to the re-oxidative capacity of quinone A (Qa), the formation of a transthylakoid proton gradient, and the xanthophyll cycle (Gomes et al., 2018). The ETR values obtained were higher than those reported by Silva et al. (2021a), who observed values ranging from 28.92 to 17.58 in yellow passion fruit cv. ‘Redondo Amarelo’ irrigated with saline waters.

Figure 1 demonstrates an increase in substrate salinity irrespective of saline water irrigation and organomineral inputs, compared to the initial salinity of 0.55 dS m^{-1} (Table 1). The application of Codasal™ led to a 126.7% increase in substrate salinity under irrigation with water of 4.0 dS m^{-1}. However, in treatments with Aminoagro Raiz™ and Codasal™ + Aminoagro Raiz™ applications, there was no significant difference in substrate salinity between low and high-saline water irrigation.

In the substrate irrigated with 0.18 dS m^{-1} water, the application of Codasal™ + Aminoagro Raiz™ mix resulted in the highest salinity increments, 132.6% higher than Codasal™ alone and 102.17% higher than Aminoagro Raiz™ (Figure 1). Under high-salinity water irrigation, CS and CS + AR caused the greatest increases in substrate salinity, with values of 73.2 and 70% higher than the substrate with AR, respectively.

Substrate salinization can be attributed to the salt content of the irrigation water and the small container volume. Even with low-salinity water (Bezerra et al., 2014), the daily irrigation frequency contributed to the gradual accumulation of salts over time. The higher increases in ECse observed with Codasal™ compared to Aminoagro Raiz™ are due to the difference in their saline indexes, which are 40.74 and 8.7%, respectively.

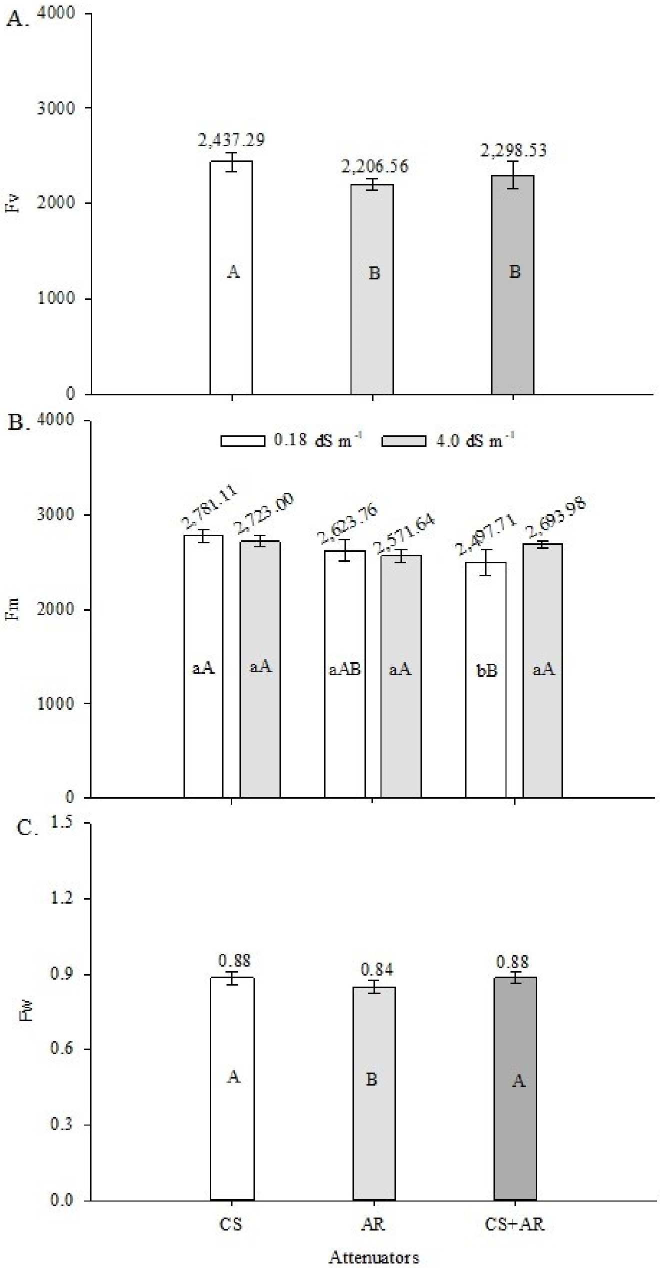


Vertical bars represent the standard deviation (n = 4). Lowercase letters indicate no significant difference (p > 0.05) according to the Duncan test for low and high-salinity water. Uppercase letters indicate no significant difference (p > 0.05) for the application of CS (Codasal™), AR (Aminoagro Raiz™), and CS + AR (Codasal™ + Aminoagro Raiz™) mix

Figure 1. Substrate saturation extract’s electrical conductivity at 45 days after emergence (DAE) of seedlings of yellow passion fruit, ‘Guinezinho’ accession, under irrigation with water (0.18 and 4.0 dS m^{-1}) and application of liquid fertilizers

Higher saline indexes indicate greater salinization capacity of the substrate. Similar increases in substrate salinity have been observed in seedlings of various fruit species irrigated with non-saline and saline water, such as yellow passion fruit (Bezerra et al., 2014), noni - *Morinda citrifolia* L. (Souto et al., 2016) and jackfruit - *Artocarpus heterophyllus* L. (Oliveira et al., 2018).

Variable fluorescence in yellow passion fruit was higher in plants treated with substrate application of Codasal™ (Figure 2A). Compared to AR and CS + AR, Codasal™ led to



Vertical bars represent the standard deviation (n = 4). Lowercase letters (A and B) indicate no significant difference (p > 0.05) according to the Duncan test for low and high-salinity water. Uppercase letters (A and C) indicate no significant difference (p > 0.05) for the application of CS (Codasal™), AR (Aminoagro Raiz™), and CS + AR (Codasal™ + Aminoagro Raiz™) mix. Uppercase letters (B) indicate no significant difference (p ≤ 0.05) for the application of CS (Codasal™), AR (Aminoagro Raiz™), and CS + AR (Codasal™ + Aminoagro Raiz™) mix for a water of the same salinity

Figure 2. Values of variable fluorescence - Fv (A) and maximum quantum efficiency of PSII - Fw (C) as a function of the application of liquid fertilizers and maximum fluorescence - Fm (B) of seedlings of yellow passion fruit, ‘Guinezinho’ accession, irrigated with water of low and high salinity and under application of liquid fertilizers

increments of 10.45 and 6.03% in the Fv of yellow passion fruit 'Guinezinho' accession. Similar patterns were observed in the maximum quantum efficiency of PSII (Figure 2C), with the highest values observed in plants treated with Codasal™ (0.885), which did not significantly differ from those treated with the Codasal™ + Aminoagro Raiz™ mix (0.884). In both cases, Fw in yellow passion fruit seedlings was 4.3% higher compared to the application of Aminoagro Raiz™.

The calcium in Codasal™ acts as a secondary messenger cation, regulating stomatal closure and restricting water loss. However, this can limit the entry of CO_2 and its assimilation (Seifikalhor et al., 2019). Despite that, the increases in Fv and Fw indicate full operation of the PSII reaction centers and stability of the photosynthetic apparatus under water restrictions (Pan et al., 2021). The values in Figure 2C suggest no photoinhibition damage to the PSII in yellow passion fruit seedlings treated with liquid fertilizers, as the range from 0.75 to 0.85 indicates optimal functioning of the photosynthetic apparatus (Ramos et al., 2022).

Fm exhibited a significant difference in plants treated with the CS + AR mix, showing higher values under irrigation with water of 4.0 dS m^{-1} (Figure 2B). Regarding the application of salt stress attenuators, for 0.18 dS m^{-1} water, Codasal™ (a solution of Ca complexed with organic acids) resulted in the highest Fm values, which did not differ statistically from Aminoagro Raiz™ (a solution with K). However, there was no difference in Fm with the application of salt stress attenuators in plants irrigated with water of 4.0 dS m^{-1}.

The effects of Codasal™ individually and combined with Aminoagro Raiz™ on Fm suggest that these inputs, containing nitrogen (both), calcium (CS), and potassium (AR) in their composition, mitigated the detrimental effects of salts. Nitrogen is a constituent element of osmoregulatory and osmoprotective substances such as glycine betaine and proline, making the plant more tolerant to salinity (Ashraf et al., 2018). Potassium plays a role in enzyme activation, stomatal regulation, and water balance in the plant (Hasanuzzaman et al., 2018), while calcium acts as a signaling agent increasing its cytosol concentration (Seifikalhor et al., 2019) during stressful situations. The lack of deficit in the photoreduction of quinone A and the flow of electrons between photosystems, indicated by the highest Fm value, suggests that the quinone was effectively reduced, and the reaction centers reached their maximum capacity for photochemical reactions (Keller et al., 2019).

The stomatal conductance (gs) of yellow passion fruit seedlings was reduced under irrigation with 4.0 dS m^{-1} water, but only showed a significant difference in plants treated with Aminoagro Raiz™ as a water salinity attenuator (Figure 3A). In this scenario, gs in seedlings decreased by 38.8% when irrigated with 4.0 dS m^{-1} water. Stomatal conductance reduction under salt stress is a protective mechanism to prevent water loss through transpiration, but it also restricts the plant's ability to absorb water (Arif et al., 2020; Figueiredo et al., 2020). Attenuators stimulate the reduction of osmotic potential within the root system, facilitating water absorption and osmotic adjustment of plants in a saline environment (Freire et al., 2014). However, reductions in gs limit the entry of CO_2 into leaf mesophyll cells, potentially increasing susceptibility to photochemical damage due to the limited availability of CO_2 and the entry of excessive energy into photosystem II (Zörb et al., 2019).

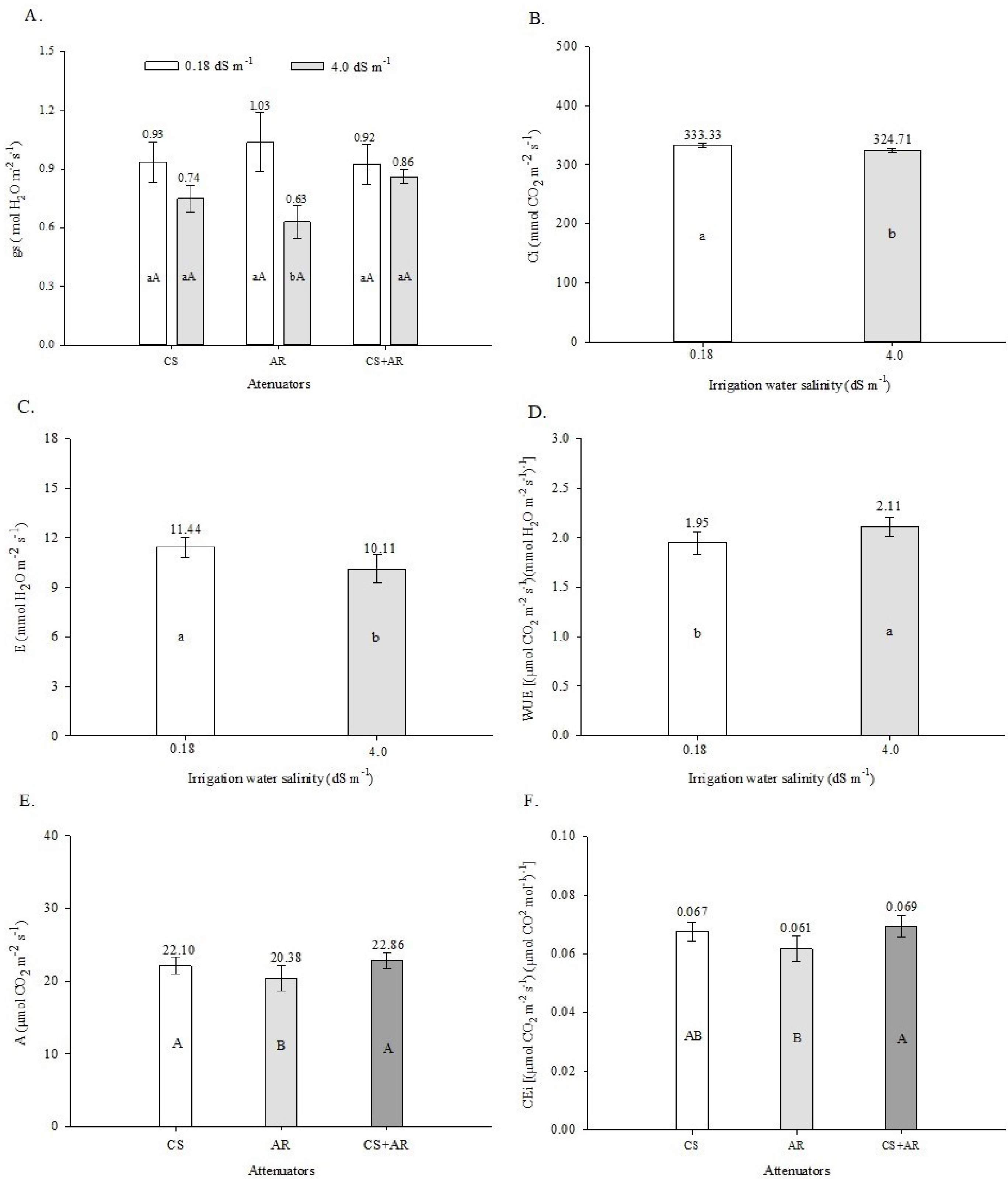
No significant effects were observed on stomatal conductance (gs) in yellow passion fruit under different irrigation waters, although Codasal™ (0.18 dS m^{-1}) and the Codasal™ + Aminoagro Raiz™ mix (4.0 dS m^{-1}) showed numerical superiority. The presence of Ca^{2+} and K^+ in the composition of organomineral attenuators plays important roles in stomatal opening and closure, with calcium acting as a signaling agent and potassium serving as an osmoregulator (Hasanuzzaman et al., 2018; Seifikalhor et al., 2019).

Irrigation with high-salinity water reduced internal carbon concentration and leaf transpiration in yellow passion fruit seedlings by 2.6 and 11.62%, respectively (Figures 3B and C). Reduction in transpiration is a potential mechanism to minimize the absorption of toxic ions, such as Na^+ and Cl^-, through the transpiration flow, by reducing stomatal opening (Lima et al., 2020). However, under salt stress conditions, CO_2 diffusion into the cell is also diminished by non-stomatal factors, thereby limiting RuBP (ribulose biphosphate) regeneration (Mukherjee et al., 2021).

However, despite the reduction in intercellular CO_2 (Figure 3B), yellow passion fruit seedlings irrigated with high-salinity water exhibited an increase in instantaneous water use efficiency of 8.2% compared to those cultivated under electrical conductivity (ECw) of 0.18 dS m^{-1} (Figure 3C). These results differ from those reported by Silva et al. (2021b), who observed a reduction in water use efficiency in seedlings of yellow passion fruit, 'Guinezinho' accession, with increasing water salinity up to 2.8 dS m^{-1}. However, equivalent results were reported by Figueiredo et al. (2020), who found an increased water use efficiency of yellow passion fruit seedlings up to an ECw of 2.2 dS m^{-1}, suggesting that the species, due to its tolerance to salinity, can maintain carbon assimilation up to a certain level of stress.

The application of Codasal™ and the Codasal™ + Aminoagro Raiz™ mix resulted in increased CO_2 assimilation rate and instantaneous carboxylation efficiency in yellow passion fruit seedlings (Figures 3E and F). Compared to Aminoagro Raiz™, CS and CS + AR increased the CO_2 assimilation rate by 8.43 and 16.2%, and instantaneous carboxylation efficiency by 9.83 and 13.1%, respectively.

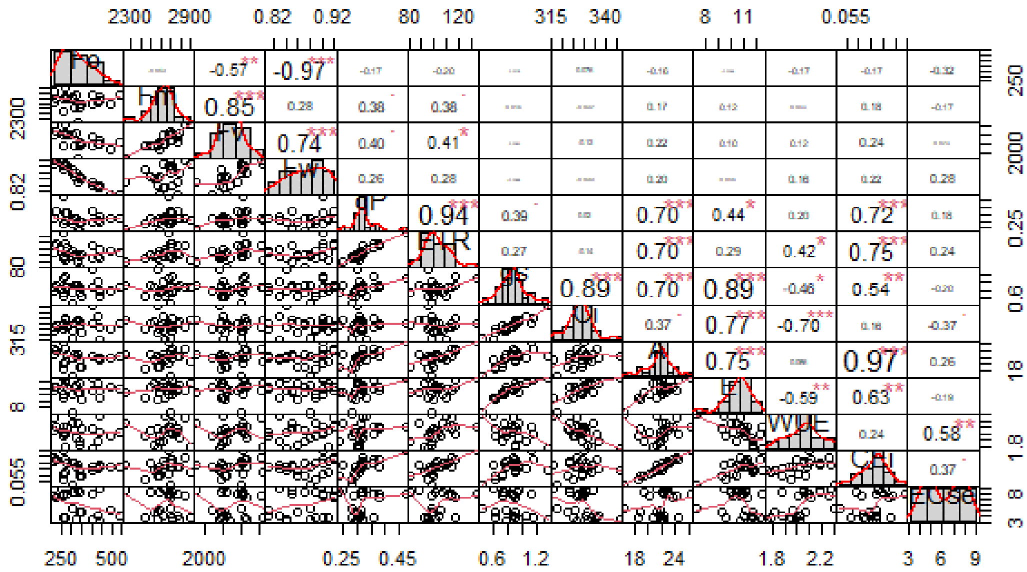
The increase in CO_2 assimilation rate can be attributed to the composition of Codasal™, which contains calcium complexed with lignosulphonate. This compound indirectly participates in photosynthesis by regulating the transcription and translation of genes encoding chloroplast proteins and enzymes (Wang et al., 2019). Calcium is a low-mobility element, and the presence of complexed calcium increases its absorption efficiency due to enhanced membrane permeability, resulting in lower resistance to its penetration (Wang et al., 2022). Moreover, carboxylation efficiency improves as the internal CO_2 concentration induces stomatal closure, and Ca^{2+} acts as a signaling agent in this process. This mechanism enhances the efficiency of CO_2 uptake and incorporation into the Calvin-Benson cycle, mediated by the enhanced activity of RuBP (ribulose biphosphate) (Schulze et al., 2021).



Vertical bars represent the standard deviation (n = 4). Lowercase letters (A, B, C, and D) indicate no significant difference ($p > 0.05$) according to the Duncan test for water of low and high salinity. Uppercase letters (E and F) indicate no significant difference ($p > 0.05$) for the application of CS (Codasal™), AR (Aminoagro Raiz™), and CS + AR (Codasal™ + Aminoagro Raiz™) mix. Uppercase letter (A) indicates no significant difference ($p > 0.05$) for the application of CS (Codasal™), AR (Aminoagro Raiz™), and CS + AR (Codasal™ + Aminoagro Raiz™) mix for water of the same salinity

Figure 3. Stomatal conductance – gs (A) under irrigation with low- and high-salinity water and liquid fertilizer application. Internal carbon concentration - Ci (B), leaf transpiration - E (C), and water-use efficiency - WUE (D) under irrigation with low- and high-salinity water, and net photosynthesis rate – A (E) and instantaneous carboxylation efficiency - CEi (F) under liquid fertilizer application

As depicted in Figure 4, strong positive correlations were observed between Fm and Fv (0.85), Fv and Fw (0.74), and qP and ETR (0.94). Additionally, there were increases in the internal carbon concentration with higher stomatal openings (0.89), and the net photosynthesis rate was high in conjunction with increments in the photochemical quenching



*, ** and *** - significant at p ≤ 0.05, at p ≤ 0.01 and at p ≤ 0.001by the Pearson's test, respectively

Figure 4. Pearson's correlation between chlorophyll fluorescence variables, gas exchange of yellow passion fruit seedlings, and salinity of substrate irrigated with low- and high-salinity water and salinity attenuator application

coefficient, electron transport rate, and stomatal conductance (0.70).

These strong positive correlations can be explained by the detrimental effect of salt stress on yellow passion fruit plants. Such correlations are typically indicative of disturbances in the photosynthetic apparatus. The decrease observed in these correlations suggests an inhibition of photochemical activity. Furthermore, the correlation between qP and ETR corresponds to low efficiency of energy dissipation through photochemical processes. In this case, the compromised energy flow in the electron transport chain becomes evident due to the increase in salinity, affecting the photosynthetic system (Gomes et al., 2018).

Leaf transpiration in yellow passion fruit seedlings increased with the higher stomatal opening (0.89), internal carbon concentration (0.77), and CO_2 assimilation rate (0.75). Moreover, a negative correlation was observed between intercellular CO_2 concentration and instantaneous water-use efficiency (-0.70), indicating that higher intercellular CO_2 levels result in lower water-use efficiency by plants. The intrinsic water use efficiency (CEi) of yellow passion fruit seedlings was influenced by several variables, showing positive responses to increments in qP (0.72), ETR (0.75), gs (0.54), A (0.97), and E (0.63). Additionally, plants exhibited increased water-use efficiency with higher substrate salinity (0.58).

An increased internal carbon concentration is linked to enhanced stomatal conductance, as plants can capture more atmospheric CO_2 (Cabrera et al., 2021). According to Leal et al. (2021), a rise in stomatal conductance is associated with a higher influx of CO_2 into the leaf mesophyll, increased transpiration, and consequently, an elevation in net photosynthesis. However, there was a reduction in water-use efficiency with higher intercellular CO_2 levels. Stomatal opening is known to be closely related to adequate levels of instantaneous carboxylation efficiency. Therefore, with increased transpiration and stomatal conductance, there is a greater input of CO_2, resulting in higher carboxylation by RuBP (ribulose biphosphate), which has a substrate affinity (Iñiguez et al., 2019).

Conclusions

1. Irrigation with 4.0 dS m^{-1} water leads to increased substrate salinity and reduced stomatal conductance in yellow passion fruit seedlings, particularly with the application of Codasal™.

2. Irrigation with saline water decreases transpiration and internal CO_2 concentration in yellow passion fruit seedlings, but it increases instantaneous water-use efficiency.

3. In the presence of high salinity water, application of Codasal™ alone or in combination with Aminoagro Raiz™ enhances variable fluorescence, quantum efficiency of photosystem II, CO_2 assimilation rate, and instantaneous carboxylation efficiency in seedlings of yellow passion fruit 'Guinezinho' accession.

Literature Cited

Alves, E. da. S, Lima, D. F., Barreto, J. A. S., dos Santos, D. P., dos Santos, M. A. L. Determinação do coeficiente de cultivo para a cultura do rabanete através de lisimetria de drenagem. Irriga, v.22, p.194-203, 2017. http://dx.doi.org/10.15809/irriga.2017v22n1p194-203

Andrade, E. M. G.; Lima, G. S. de; Lima, V. L. A. de; Silva, S. S. da; Dias, A. S.; Gheyi, H. R. Hydrogen peroxide as attenuator of salt stress effects on the physiology and biomass of yellow passion fruit. Revista Brasileira de Engenharia Agrícola e Ambiental. v.26, p.571-578, 2022. http://dx.doi.org/10.1590/1807-1929/agriambi.v26n8p571-578

Arif, Y.; Singh, P.; Siddiqui, H.; Bajguz, A.; Hayat, S. Salinity induced physiological and biochemical changes in plants: An omic approach towards salt stress tolerance. Plant Physiology and Biochemistry, v.156, p.64-77, 2020. https://doi.org/10.1016/j.plaphy.2020.08.042

Ashraf, M.; Shahzad, S. M.; Imtiaz, M., Rizwan, M. S.; Arif, M. S.; Kausar, R. Nitrogen nutrition and adaptation of glycophytes to saline environment: a review. Archives of Agronomy and Soil Science., v.64, p.1181-1206, 2018. https://doi.org/10.1080/03650340.2017.1419571

Bezerra, M. A. F.; Pereira, W. E.; Bezerra, T. C.; Cavalcante, L. F.; Medeiros, S. A. da S. Água salina e nitrogênio na emergência e biomassa de mudas de maracujazeiro amarelo. Agropecuária Técnica, v.35, p.150-160, 2014. https://doi.org/10.25066/agrotec.v35i1.19920

Bezerra, M. A. F.; Pereira, W. E.; Bezerra, T. C.; Cavalcante, L. F.; Medeiros, S. A. da S. Nitrogen as a mitigator of salt stress in yellow passion fruit seedlings. Semina: Ciências Agrárias, v.40, p.611-622, 2019. https://doi.org/10.5433/1679-0359.2019v40n2p611

Cabrera, J. C. B.; Hirl, R. T.; Schäufele, R.; Macdonald, A.; Schnyder, H. Stomatal conductance limited the CO_2 response of grassland in the last century. BMC Biology, v.50, p.1-14, 2021. https://doi.org/10.1186/s12915-021-00988-4

Diniz, G. L.; Nobre, R. G.; Lima, G. S. de; Soares, L. A. dos A.; Gheyi, H. R. Irrigation with saline water and silicate fertilization in the cultivation of 'Gigante Amarelo' passion fruit. Revista Caatinga, v.34, p.199-207, 2021. http://dx.doi.org/10.1590/1983-21252021v34n120rc

Figueiredo, F. R. A.; Nóbrega, J. S.; Fátima, R. T. de; Ferreira, J. T. A.; Pereira, M. B.; Lopes, M. de F. de Q.; Pereira, W. E.; Albuquerque, M. B. de. Morphophysiology of yellow passion fruit seedlings under application of nitrogen and potassium and irrigation with high salinity water. Semina: Ciências Agrárias, v.41, p.1897-1908, 2020. https://doi.org/10.5433/1679-0359.2020v41n5Supl1p1897

Freire, J. L. de O.; Dias, T. J.; Cavalcante, L. F.; Fernandes, P. D.; Lima Neto, A. J. de. Rendimento quântico e trocas gasosas em maracujazeiro-amarelo sob salinidade hídrica, biofertilização e cobertura morta. Revista Ciência Agronômica, v.45, p.82-91, 2014. https://doi.org/10.1590/S1806-66902014000100011

Gomes, M. de M. de A.; Ramos, M. J. M.; Torres Netto, A.; Rosa, R. C. C.; Campostrini, E. Water relations, photosynthetic capacity, and growth in passion fruit (*Passiflora edulis* Sims f. flavicarpa Deg.): seedlings and grafted plants. Revista Ceres, v.65, p.135-143, 2018. http://dx.doi.org/10.1590/0034-737X201865020004

Hasanuzzaman, M.; Bhuyan, M. H. M. B.; Nahar, K.; Hossain, M. S.; Mahmud, J. A.; Hossen, M. S.; Masud, A. A. C.; Moumita, M. F. Potassium: A vital regulator of plant responses and tolerance to abiotic stresses. Agronomy, v.8, p.1-9, 2018. https://doi.org/10.3390/agronomy8030031

Iñiguez, C.; Galmés, J.; Gordillo, F. J. L. Rubisco carboxylation kinetics and inorganic carbon utilization in polar versus cold-temperate seaweeds. Journal of Experimental Botany, v.70, p.1283-1297, 2019. https://doi.org/10.1093/jxb/ery443

Keller, B.; Vass, I.; Matsubara, S.; Paul, K.; Jedmowski, C.; Pieruschka, R.; Nedbal, L.; Rascher, U.; Muller, O. Maximum fluorescence and electron transport kinetics determined by light-induced fluorescence transients (LIFT) for photosynthesis phenotyping. Photosynthesis Research, v.140, p.221-233, 2019. https://doi.org/10.1007/s11120-018-0594-9

Leal, Y. H.; Dias, T. J.; Souza, A. das G.; Bezerra, A. C.; Rodrigues, L. S.; Albuquerque, M. B. de; Leal, M. P. da S.; Silva, A. J. da; Lucena, M. F. R. de. Gas exchanges and chlorophyll content in green pepper plants under bio-fertilization and times of application. Bioscience Journal, v.37, p.1-11, 2021. https://doi.org/10.14393/BJ-v37n0a2021-53661

Lima, G. S. de; Fernandes, C. G. J.; Soares, L. A. dos A.; Gheyi, H. R.; Fernandes, P. D. Gas exchange, chloroplast pigments and growth of passion fruit cultivated with saline water and potassium fertilization. Revista Caatinga, v.33, p.184-194, 2020. http://dx.doi.org/10.1590/1983-21252020v33n120rc

Mukherjee, S.; Mukherjee, A.; Das, P.; Bandyopadhyay, S.; Chattopadhyay, D.; Chatterjee, J.; Majumder, A. L. A salt-tolerant chloroplastic FBPase from *Oryza coarctata* confers improved photosynthesis with higher yield and multi-stress tolerance to indica rice. Plant Cell, Tissue and Organ Culture, v.145, p.561–578, 2021. https://doi.org/10.1007/s11240-021-02026-1

Oliveira, F. I. F. de; Souto, A. G. de L.; Cavalcante, L. F.; Medeiros, W. J. F. de; Medeiros, S. A. da S.; Oliveira, F. F. de. Biomass and chloroplast pigments in jackfruit seedlings under saline stress and nitrogen fertilization. Revista Caatinga, v.31, p.622-631, 2018. https://doi.org/10.1590/1983-21252018v31n310rc

Pan, L.; Cui, S.; Dinkins, R. D.; Jiang, Y. Plant growth, ion accumulation, and antioxidant enzymes of endophyte-infected and endophyte-free tall fescue to salinity stress. Acta Physiologiae Plantarum, v.43, p.1-10, 2021. https://doi.org/10.1007/s11738-021-03268-4

R Core Team. R: A language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2022.

Ramos, J. G.; Lima, V. L. A. de; Lima, G. S. de; Paiva, F. J. da S.; Pereira, M. de O.; Nunes K. G. Hydrogen peroxide as salt stress attenuator in sour passion fruit. Revista Caatinga, v.35, p.412-422, 2022. http://dx.doi.org/10.1590/1983-21252022v35n217rc

Schulze, S.; Dubeaux, G.; Ceciliato, P. H. O.; Munemasa, S.; Nuhkat, M.; Yarmolinsky, D.; Aguilar, J.; Diaz, R.; Azoulay-Shemer, T.; Steinhorst, L.; Offenborn, J. N.; Kudla, J.; Kollist, H.; Schroeder, J. I. A role for calcium-dependent protein kinases in differential CO_2-and ABA-controlled stomatal closing and low CO_2-induced stomatal opening in Arabidopsis. New Phytologist, v.229, p.2765–2779, 2021. https://doi.org/10.1111/nph.17079

Seifikalhor, M.; Aliniaeifard, S.; Shomali, A.; Azad, N., Hassani, B.; Lastochkina, O.; Li, T. Calcium signaling and salt tolerance are diversely entwined in plants. Plant Signaling & Behavior, v.14, p.1-15, 2019. https://doi.org/10.1080/15592324.2019.1665455

Silva, I. J. da; Silva, F. de A. da; Fernandes, P. D.; Dias, M. dos S.; Lacerda, C. N. de; Silva, A. A. R. da; Marcelino, A. D. A. de L.; Melo, A. R. de; Reis, L. S.; Lima, R. F. de. Produção de mudas de maracujazeiro-amarelo sob salinidade da água de irrigação. Research, Society and Development, v.10, p.1-10, 2021a. http://dx.doi.org/10.33448/rsd-v10i9.18178

Silva, A. A. R. da; Veloso, L. L. de S. A.; Lima, G. S. de; Azevedo, C. A. V. de; Gheyi, H. R.; Fernandes, P. D. Hydrogen peroxide in the acclimation of yellow passion fruit seedlings to salt stress. Revista Brasileira de Engenharia Agrícola e Ambiental, v.25, p.116-123, 2021b. http://dx.doi.org/10.1590/1807-1929/agriambi.v25n2p116-123

Souto, A. G. de L.; Cavalcante, L. F.; Lima Neto, A. J. de; Mesquita, F. de O.; Santos, J. B. dos. Biometria em plantas de noni sob irrigação com águas salinas e lixiviação dos sais do solo. Revista Ciência Agronômica, v.47, p.316-324, 2016. https://doi.org/10.5935/1806-6690.20160037

Teixeira, P. C.; Donagemma, G. K.; Fontana, A.; Teixeira, W. G. Manual de métodos de análise de solo. 3.ed. Rio de Janeiro: Embrapa Solos. 2017, 573p.

Wang, Q.; Yang, S.; Wan, S.; LI, X. The significance of calcium in photosynthesis. International Journal of Molecular Sciences, v.20, p.1-14, 2019. https://doi.org/10.3390/ijms20061353

Wang, Z.; Yao, Y.; Yang, Y. Fulvic acid-like substance-Ca (II) complexes improved the utilization of calcium in rice: Chelating and absorption mechanism. Ecotoxicology and Environmental Safety, v.237, p.1-8, 2022. https://doi.org/10.1016/j.ecoenv.2022.113502

Zörb, M.; Geilfus, C. M.; Dietz, K. J. Salinity and crop yield. Plant Biology, v.21, p.31-38, 2019. https://doi.org/10.1111/plb.12884