Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 20 September 2023
https://doi.org/10.14295/CS.v14.4020

Photochemical efficiency and growth of sugar apple under irrigation with saline water and foliar nitrogen

Reynaldo Teodoro de Fatima[1]*, Jackson Silva Nóbrega[2], Jean Télvio Andrade Ferreira[1], Wilma Freitas Celedônio [2], João Everthon da Silva Ribeiro[2], Walter Esfrain Pereira[2], Antônio Gustavo de Luna Souto[3], Geovani Soares de Lima[1]

[1]Federal University of Campina Grande, Campina Grande, Brasil
[2]Federal University of Paraíba, Areia, Brasil
[3]Federal University of Vale do São Francisco, Petrolina, Brasil
*Corresponding author, e-mail: reynaldo.t16@gmail.com

Abstract

Salt stress has compromised the worldwide expansion of fruit farming by causing damage to light energy regulation and crop growth, which can be mitigated by applying foliar nitrogen (N). From this perspective, this study aimed to evaluate the chlorophyll contents, fluorescence, and the growth of sugar apple seedlings under irrigation with saline water and foliar N fertilisation. The experiment was conducted in a plant nursery and following a randomized block design referring to five electrical conductivity levels of irrigation water (0.5, 1.15, 2.75, 4.35, and 5.0 dS m^{-1}) and five foliar N levels (0.0, 0.33, 1.15, 1.97, and 2.3 g L^{-1}), with four replications and two plants per plot, totaling nine combinations generated by the Box central composite design. Irrigation water salinity reduces the growth of sugar apple seedlings irrigated with conductivity levels over 1.7 dS m^{-1} at 90 days after emergence. Foliar N fertilisation increased the photochemical efficiency and growth of sugar apple seedlings. The foliar application of 1.93 g L^{-1} mitigate the deleterious effects of water salinity on the photochemical efficiency and growth of sugar apple seedlings.

Keywords: *Annona squamosa*, chlorophyll, fluorescence, initial growth, nitrogen, salt stress

Introduction

Sugar apple (*Annona squamosa* L.), also known as sugar apple or ata, is a small fruit species of the family Annonaceae whose center of origin is in Central America, showing high adaptability to tropical and subtropical climate regions (Figueiredo et al., 2019). The rusticity, high nutritional quality, and significant acceptance by the consumer market, with the potential for fruit and by-product export, have contributed to the expansion of commercial sugar apple orchards in Brazil in the last few decades, especially in the Northeast, which due to the high adaptation to this region, concentrates a large part of the national production (Rodrigues et al., 2018).

However, orchards in these areas generally show low yields resulting from poor crop management and irrigation, resulting in yields lower than 2.0 t ha^{-1} (Lemos, 2014). This scenario has been managed using production technologies such as pruning, localized irrigation, and manual pollination, which contribute to obtaining yields higher than 10 t ha^{-1} $year^{-1}$ (Oliveira et al., 2016). For that purpose, it is indispensable to use high-quality seedlings since yield losses in this stage significantly affect the field expression of the crop production potential (Riikonen & Luoranen, 2018).

The water limitation in northeastern Brazil, caused by the scarcity of rain and high transpiration in the reservoirs, has led producers to use water sources containing soluble salts as a way of supplying the water demand of crops in the region, which due to poor management has limited obtaining of quality seedlings for the field (Oliveira et al., 2017; Souza et al., 2017). Behaviour that is associated with the effects of the salinity of the irrigation water, which are expressed by the excessive accumulation of salts close to the root system of the plants, initially compromising water and nutrient uptake from the soil solution and causing physiological and nutritional imbalances in plants (Lima

Received: 05 June 2022
Accepted: 24 April 2023

et al., 2015; Veloso et al., 2019). Subsequently, specific ions such as sodium and chloride cause toxicity in plant tissues, reducing the metabolic and physiological plant activity and generating reactive oxygen species - ROS (Gomes et al., 2017; Silva et al., 2020).

As an alternative, recent studies have addressed the importance of an adequate nitrogen (N) supply to mitigate deleterious effects on plant growth and physiology under salt stress conditions (Oliveira et al., 2017; Bezerra et al., 2018; Song et al., 2019; Silva Neta et al., 2021). This fact is related to the structural role of N in plants as the basic constituent of organic compounds such as amino acids, proteins, enzymes, and organelles (Lin et al., 2013). Chloroplasts stand out among these structures, representing around 75% of the total N present in the leaves and being used for the synthesis of chlorophylls, ATPases, and ribulose-1,5-bisphosphate carboxylase-oxygenase. Furthermore, this nutrient is usually limited under salt stress conditions (Negrão et al., 2017; Evans & Clarke, 2019).

Nitrogen also contributes to the plant defence mechanism, acting in the formation of secondary metabolites such as proline, glycine, and betaine, which participate in the neutralization of free radicals (Ahanger et al., 2019), in the translocation and compartmentalization of sodium (Ashraf et al., 2018), and in the maintenance of water uptake through changes in the root osmotic potential (Annunziata et al., 2017).

Despite the possible N benefits to plant acclimation in salinized environments, the literature diverges with regard to the role of conventional N fertilisation, which can be limited by root absorption sites, N forms, and salts accumulated in the soil (Bezerra et al., 2018; Figueiredo et al., 2019). In this scenario, foliar N fertilisation could become a viable alternative for the rapid plant perception of salt stress since N assimilation by the leaves maintains the metabolic activity and contributes to the preservation of photosynthesis and cell turgor (Busch et al., 2018; Otálora et al., 2018).

However, studies based on this assumption are scarce (Romero-Aranda & Syvertsen, 1996; Hu et al., 2008; Luo et al., 2015) and require new research to clarify the possibilities of foliar N fertilisation for salt stress mitigation on plant growth and physiology.

From this perspective, this study aimed to evaluate the chlorophyll contents, fluorescence, and growth of sugar apple seedlings irrigated with saline water and foliar N fertilisation.

Material And Methods

The experiment was conducted from April to August 2019 in a protected environment at the Center of Agricultural Sciences of the Federal University of Paraíba, Campus Areia, Paraíba, Brazil. The municipality is located at the following geographic coordinates: 6°58'00" S, 35°41'00" W, and at an elevation of 575 a. s. l. The regional climate is classified as As', i.e., hot summers and winter rainfall, according to the Köppen classification (Alvares et al., 2013). The mean temperature during the experimental period was 27.5°C, ranging from 18.8°C to 36.2°C.

The experimental design was in randomized blocks, with four replications and two plants per plot. The treatments consisted of the combination of five electrical conductivity levels of irrigation water (ECiw) and five foliar nitrogen levels (L_{FN}) obtained using the Box central composite design (Mateus et al., 2001), as shown in (**Table 1**).

The electrical conductivity levels of irrigation water were obtained by adding sodium chloride (NaCl) to tap water (0.5 dS m^{-1}) until obtaining the adequate proportions of each electrical conductivity using a portable Instrutherm® microprocessor conductivity meter (model CD-860). The ECiw values were chosen based on Andrade et al. (2018), who observed the effects of salinity on sugar apple (*Annona squamosa* L.) seedlings irrigated with electrical conductivity levels up to 4.5 dS m^{-1}.

The N levels were established considering the inexistence of studies addressing foliar fertilisation in seedlings but observing the N level of 300 mg of N per dm^{-3} of soil recommended for pot cultivation proposed by Novais et al. (1991). The N requirement was supplied using a commercial product based on urea and composed of 99 g L^{-1} N.

The seeds were obtained from fruits collected in a sugar apple orchard located at the Irrigation Perimeter Várzeas de Sousa, municipality of Aparecida, Paraíba. The experiment was conducted in black 1.2-dm^3 polyethylene bags by sowing five seeds per bag. The plants were thinned to one plant per bag 25 days after

Table 1. Representation of the treatments obtained by combining the electrical conductivity of irrigation water (ECiw) with foliar nitrogen levels (L_{FN})

Treatment	Combinations		Values	
	ECiw	L_{FN}	ECiw (dS m^{-1})	L_{FN} (g L^{-1})
1	-1	-1	1.15	0.33
2	-1	1	1.15	1.97
3	1	-1	4.35	0.33
4	1	1	4.35	1.97
5	-1.41(α)	0	0.50	1.15
6	1.41(α)	0	5.00	1.15
7	0	-1.41(α)	2.75	2.30
8	0	1.41(α)	2.75	0.00
9	0	0	2.75	1.15

sowing by maintaining the most vigorous seedling.

The bags were filled with a substrate based on 85% Oxisol, 10% fine sand, and 5% cattle manure. The physical and chemical characteristics of the substrate were determined according to its fertility and salinity following the methodology proposed by Richards (1954) and Teixeira et al. (2017), as seen in (**Table 2**).

Irrigation with the respective water salinities began ten days after emergence (DAE) and was performed daily and manually according to the crop requirements. The volume applied at each irrigation event was determined based on drainage lisimetry by daily providing the water volume lost by evapotranspiration on the previous day to increase the soil water to the pot capacity level. Pot capacity was determined using ten polyethylene bags in which collectors were added to determine the water volume held by the container through the difference between the water volume applied and the volume drained since the previous irrigation (Bernardo et al., 2006). A 0.10 leaching fraction was applied every 15 days based on the corresponding volume of the period to reduce salt accumulation in the substrate.

Nitrogen fertilisation began 15 DAE and was split into seven foliar applications every ten days using a manual sprayer, always in the late afternoon. These applications ended 75 DAE and totalled 175 mL per plant, consisting of 0, 58.16, 200, 341.84, and 400 mg of N per plant at increasing levels. The product was diluted in distilled water on the day of application and according to the treatments.

The evaluations of the levels of chlorophyll *a*, *b*, total chlorophyll, and chlorophyll *a/b* ratio were performed 90 DAE, from 7:00 to 9:00 a.m., through the non-destructive evaluation of the first two fully expanded leaves using a portable chlorophyll meter (ClorofiLOG®, model CFL 1030, Porto Alegre, RS), with values expressed as Falker chlorophyll index (FCI). The chlorophyll *a* fluorescence was determined in the same period with a modulated fluorometer (Sciences Inc.- Model OS-30p, Hudson, USA). For that purpose, probes were placed on the leaves for 30 minutes before the readings to adapt the structures to the dark, after which the initial fluorescence (F_0), maximum fluorescence (F_m), variable fluorescence ($F_v = F_m - F_0$), F_v/F_0 ratio, and the quantum yield of photosystem II were measured (F_v/F_m).

The growth evaluations were performed 90 DAE by measuring the plant height (PH) from the ground to the insertion of the apical meristem with a millimetre ruler, the stem diameter (SD) with a digital calliper at 5 cm from the ground, and the number of leaves (NL). Also, the length and the largest width were measured in each leaf to estimate the leaf area (FA) following the methodology proposed by Barbin et al. (2004), as seen in equation 1:

$$FA = C \times L \times 0.72 \quad (1)$$

where AF is leaf area (cm^2); C – length (cm); L – width (cm).

The relative growth rates in plant height (RGR_{PH}) and stem diameter (RGR_{SD}) were obtained from 15 to 90 DAE using the methodology proposed by Benincasa (2003) and shown in equation 2:

$$RGR = \frac{\ln A_2 - \ln A_1}{t_1 - t_2} \quad (2)$$

where RGR is relative growth rate, A_2 – plant growth 90 DAE; A_1 – plant growth 15 DAE; $t_2 - t_1$ – time difference between evaluations; ln – natural logarithm.

The data were subjected to analysis of variance and polynomial regression analysis at 1 and 5% probability using the statistical software R (R Core Team, Austria).

Table 2. Physical and chemical attributes of the substrate components used in the experiment

Physics	Value	Fertility	Value	Salinity	Value
Sand g kg^{-1}	639	pH in water (1: 2.5)	7.00	pH	7.30
Silt g kg^{-1}	227	P (mg dm^{-3})	146.32	Cees (dS m^{-1})	2.73
Clay g kg^{-1}	134	K^+ (cmol$_c$ dm^{-3})	1.61	SO_4^{-2} (mmol$_c$ L^{-1})	1.02
Textural class	Sandy-loam	Na^+ (cmol$_c$ dm^{-3})	0.27	Ca^{2+} (mmol$_c$ L^{-1})	16.00
		Al^{3+} (cmol$_c$ dm^{-3})	0.00	Mg^{2+} (mmol$_c$ L^{-1})	16.75
		H^++Al^{3+}(cmol$_c$ dm^{-3})	2.84	K^+ (mmol$_c$ L^{-1})	6.90
		Ca^{2+} (cmol$_c$ dm^{-3})	5.53	CO_3^{-2} (mmol$_c$ L^{-1})	0.00
		Mg^{2+} (cmol$_c$ dm^{-3})	1.70	HCO_3^{-2} (mmol$_c$ L^{-1})	40.00
		SB (cmol$_c$ dm^{-3})	9.11	Cl^- (mmol$_c$ L^{-1})	30.00
		CEC (cmol$_c$ dm^{-3})	11.95	Na^+ (mmol$_c$ L^{-1})	0.89
		OM (cmol$_c$ dm^{-3})	26.69	RAS (mmol$_c$ L^{-1})	0.94
				PST	0.13
				Classification	Non-saline

OM – organic matter; SB – sum of bases ($Na^+ + K^+ + Ca^{2+} + Mg^{2+}$); CEC – cation exchange capacity = SB + ($H^+ + Al^{3+}$); Cees – electrical conductivity of the saturation extract; RAS – sodium adsorption ratio = $Na^+ \times [(Ca^{2+} + Mg^{2+})/2]^{-1/2}$; PST – exchangeable sodium percentage [100 × (Na^+ / CTC)].

Results And Discussion

The interaction of factors only significantly affected the chlorophyll a/b ratio (**Table 3**). On the other hand, there was an isolated effect of the foliar N levels on all chlorophyll fluorescence variables. Furthermore, the ECiw factor only significantly affected the maximum fluorescence of sugar apple seedlings, whereas the remaining variables were not significantly affected by the evaluated factors.

Table 3. Summary of the analysis of variance for chlorophyll a (Chl *a*), b (Chl *b*), total (Chl *To*), chlorophyll a/b ratio (Chl a/b), initial fluorescence (Fo), maximum (Fm), variable (Fv), quantum yield of photosystem II (Fv/Fm) and Fv/Fo ratio in sugar apple seedlings irrigated with saline water (ECiw) and foliar nitrogen levels (LFN) at 90 days after emergence

Source of variation	DF	Mean square								
		Chl *a*	Chl *b*	Chl *To*	Chl *a/b*	Fo	Fm	Fv	Fv/Fm	Fv/Fo
Blocks	3	27.41^{**}	1.479^{*}	27.87^{**}	0.238^{**}	1668^{*}	$2.1e5^{**}$	$1.6e5^{*}$	0.002^{ns}	0.13^{ns}
Treatment	8	2.00^{ns}	0.785^{ns}	7.72^{ns}	0.281^{**}	1378^{*}	$1.5e5^{**}$	$1.7e5^{**}$	0.004^{**}	6.52^{**}
L_{FN} (L)	1	0.17^{ns}	0.634^{*}	2.32^{*}	0.259^{**}	21.4^{*}	283^{**}	397^{**}	0.073^{**}	2.25^{**}
L_{FN} (Q)	1	0.48^{ns}	0.130^{ns}	1.59^{ns}	0.142^{ns}	0.97^{ns}	26^{ns}	85^{ns}	0.018^{ns}	0.26^{ns}
ECiw (L)	1	0.40^{ns}	0.104^{ns}	1.82^{ns}	0.101^{ns}	5.46^{ns}	128^{ns}	141^{ns}	0.014^{ns}	0.28^{ns}
ECiw (Q)	1	0.33^{ns}	0.105^{ns}	0.53^{ns}	0.157^{*}	14.61^{ns}	331^{**}	168^{ns}	0.014^{ns}	0.02^{ns}
L_{FN} × ECiw	1	0.52^{ns}	0.474^{**}	1.21^{**}	0.282^{**}	9.08^{ns}	24^{ns}	18^{ns}	0.007^{ns}	0.30^{ns}
CV		4.50	5.50	3.50	3.50	6.70	6.50	7.60	2.40	7.70

ns, **, * – respectively not-significant, significant at $p \leq 0.01$ and $p \leq 0.05$ by the *F*-test; DF- degree of freedom; CV – coefficient of variation.

and for being a constituent of chlorophyll, thus reducing energy imbalance under salt stress conditions (Bezerra et al., 2018; Song et al., 2019). Therefore, the maintenance of high Chl *a* content in relation to Chl *b* is desirable since this pigment is directly related to energy transfer from the photosystems to the remaining reactions in the chloroplasts, whereas Chl *b* is the accessory pigment, and its role is to increase the wavelength absorbed and the transfer of radiant energy to the reaction centres (Gomes et al., 2017; Kume et al., 2018).

The foliar chlorophyll a/b ratio showed the highest values in the plants subjected to foliar N fertilisation with 1.52 g L^{-1} (**Figure 1**) and irrigated with 0.5 dS m^{-1} (4.17 FCI). On the other hand, the lowest FCI values were observed in the seedlings irrigated with the highest ECiw and no N fertilisation, corresponding to 3.46 FCI or 20.52% lower than the highest value (4.17 FCI). However, when associating foliar N fertilisation with irrigation at 5.0 dS m^{-1}, there were improvements in the chlorophyll a/b ratio with the application of 2.1 g L^{-1} of N, increasing the FCI to 4.11% or 18.78% higher than the value shown by plants without N fertilisation under the same conditions. The behavior that is associated with nitrogen improving antioxidant activity

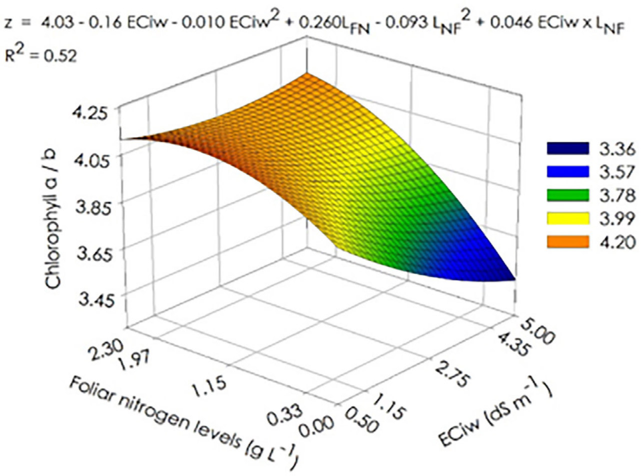

Figure 1. Foliar chlorophyll a/b ratio in sugar apple seedlings irrigated with saline water and fertilised with foliar nitrogen levels (L_{FN}) at 90 days after emergence.

The fluorescence variables showed linear gains with the increase in L_{FN} (**Figure 2**), resulting in the highest values of initial fluorescence (290.69), maximum fluorescence (2660.21), variable fluorescence (2327.03), and the Fv/Fm (0.890) and Fv/Fo ratios (8.67) at the N level of 2.3 g L^{-1}. This situation increased the Fo by 21.09% (Figure 2A), the Fm by 16.65% (Figure 2B), the Fv by 19.69% (Figure 2C), the Fv/Fm by 5.20% (Figure 2D), and the Fv/Fo by 10.04% (Figure 2E) compared to the values observed in the seedlings without N fertilisation.

The maintenance of photosynthetic pigments due to N fertilisation directly influenced the light capture efficiency of the photosystem II. Even with the increase in photochemical loss (F_0), the electron excitation was compensated (Fm and Fv) and increased the photochemical efficiency in energy transfer from P680 to the electron transport chain (Lin et al., 2013). A similar fluorescence increase trend due to N fertilisation was observed by Sousa et al. (2016) in orange (*Citrus* spp.), whereas Figueiredo et al. (2019) evaluated the chlorophyll efficiency in sugar apple seedlings 60 days after sowing and observed no significant influence of N fertilisation.

The maximum fluorescence of sugar apple seedlings decreased with the increase in the electrical conductivity of irrigation water (**Figure 3**). The Fm decreased from 2588.71 to 2467.87 between the seedlings irrigated with 0.5 and 5.0 dS m^{-1}, respectively. The Fm signals when the reaction centres of PSII are closed and

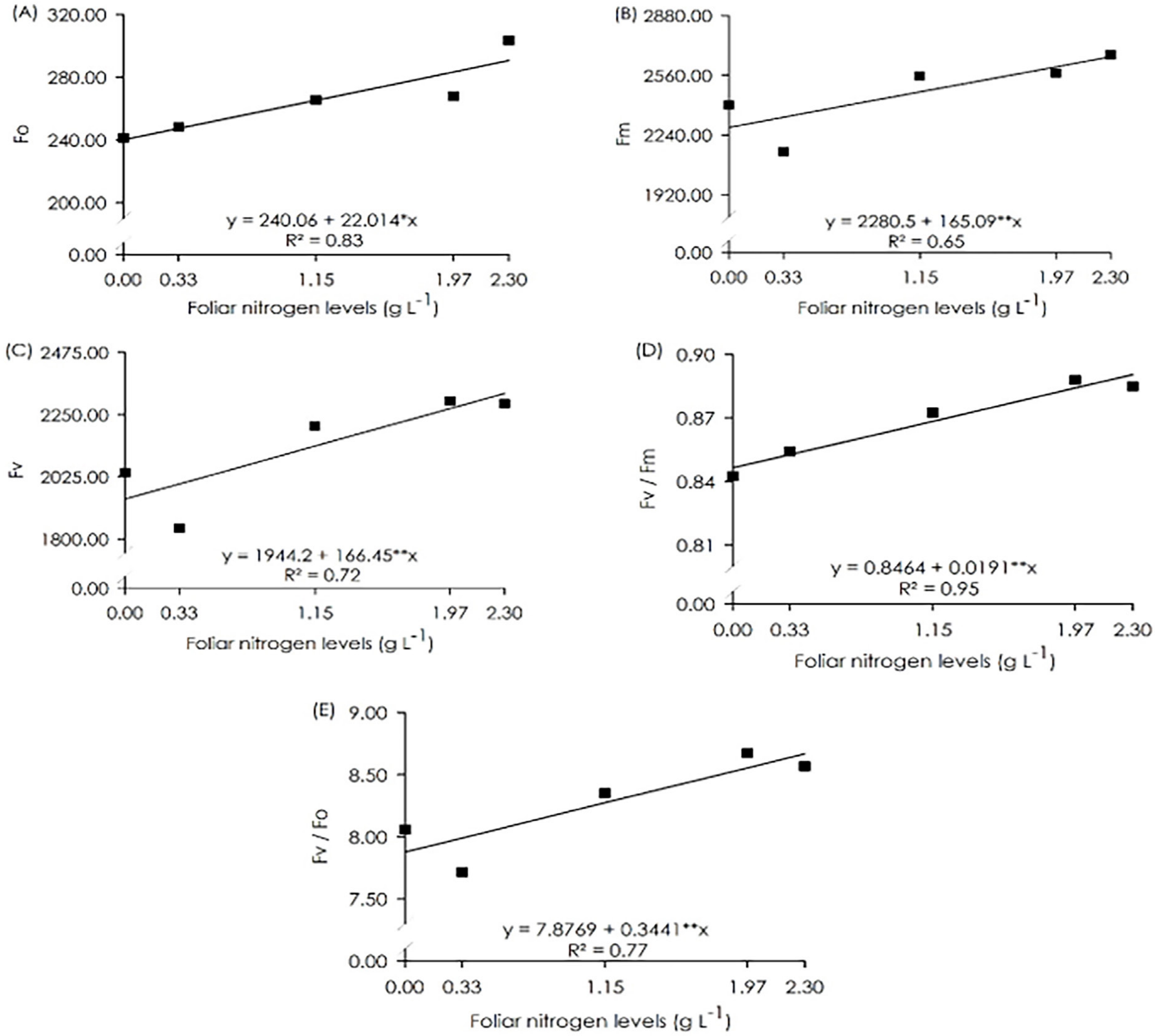

Figure 2. Initial fluorescence – Fo (A), maximum fluorescence – Fm (B), variable fluorescence – Fv (C), quantum yield of photosystem II – Fv/Fm (D), and ratio of variable to initial fluorescence– Fv/F_0 (E) in leaves of sugar apple seedlings as a function of foliar nitrogen levels (L_{FN}) at 90 days after emergence. **, * – significant at $p \leq 0.01$ and at $p \leq 0.05$ by the *F*-test.

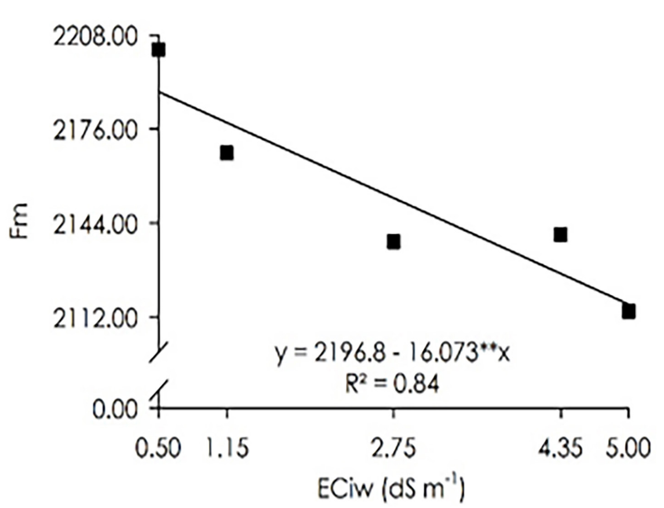

Figure 3. Maximum foliar fluorescence – Fm in sugar apple seedlings irrigated with saline water – ECiw at 90 days after emergence. ** – significant at $p \leq 0.01$ by the *F*-test

thus reach their maximum (Zivcak et al., 2014), with the reductions in this variable caused by salt stress indicating that the PSII was limited in reducing plastoquinone A (Akhter et al., 2021).

The sugar apple growth variables showed a significant effect for the interaction (**Table 4**) between L_{FN} and irrigation water salinity (ECiw) on all evaluated variables.

The relative growth of sugar apple seedlings in plant height was inhibited by the increase in irrigation water salinity (**Figure 4**A). The lowest RGR_{PH} value was observed in the plants without N fertilisation and irrigated with 5.0 dS m^{-1} (0.0023 cm cm^{-1} day^{-1}), with losses of 82.17% in relation to the plants without N application and irrigated with 0.5 dS m^{-1}. Behaviour that is associated with water restriction caused by the osmotic effect of salts close to the

Table 4. Summary of the analysis of variance for the relative growth rates in plant height (RGR_{PH}) and stem diameter (RGR_{SD}) from 15 to 90 days after emergence, and plant height (PH), stem diameter (SD) number of leaves (NL), and leaf area (LA) sugar apple seedlings irrigated with saline water (ECiw) and foliar nitrogen levels (L_{FN}) at 90 days after emergence

Source of variation	DF	Mean square					
		RGR_{PH}	RGR_{SD}	PH	SD	NL	LA
Blocks	3	1.66e-6^{ns}	8.70e-7**	21.80^{ns}	0.22^{ns}	2.12^{ns}	848.00^{ns}
Treatment	8	2.89e-6**	3.24e-5**	81.66**	1.59**	26.58**	4318.00**
L_{FN} (L)	1	6.34e-3**	6.56e-3**	12.39**	1.76**	7.19**	60.00**
L_{FN} (Q)	1	1.10e-3^{ns}	1.02e-3^{ns}	1.47^{ns}	0.12^{ns}	0.12^{ns}	48.10**
ECiw (L)	1	2.92e-3**	3.35e-3**	1.87^{ns}	0.08^{ns}	1.82**	46.70*
ECiw (Q)	1	1.68e-4^{ns}	1.96e-3*	1.08^{ns}	0.14^{ns}	4.02**	11.70^{ns}
L_{FN} x ECiw	1	5.60e-4**	3.42e-4*	3.47**	0.47**	0.94**	29.20**
CV		8.90	5.50	9.60	4.40	9.70	13.50

DF – degree of freedom; L – linear; Q – quadratic; CV – coefficient of variation; ns, **, * – respectively non-significant, significant at $p \leq 0.01$ and $p \leq 0.05$.

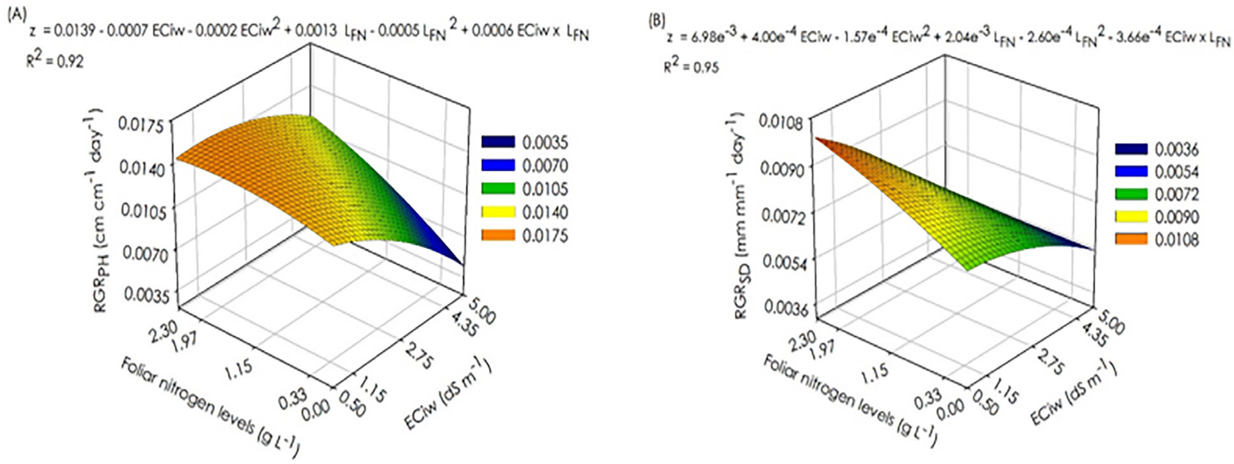

Figure 4. Relative growth rate in plant height – RGR_{PH} (A) and stem diameter – RGR_{SD} (B) of sugar apple seedlings irrigated with saline water and fertilised with foliar nitrogen (L_{FN}) levels in the period from 15 to 90 days after emergence.

rhizosphere, which reduces cellular turgor and increases energy expenditure for the synthesis of osmolytes for the roots, resulting in limitations in plant growth (Silva Neta et al., 2021; Pinheiro et al., 2022). Similar losses were reported by Veloso et al. (2019) in soursop (*Annona muricata* L.) irrigated with electrical conductivity levels up to 3.0 dS m^{-1}.

Nitrogen fertilisation increased the RGR_{PH} of sugar apple seedlings, with the highest value in the plants irrigated with non-saline water and 0.84 g of foliar N L^{-1} (0.0136 cm cm^{-1} dia^{-1}), corresponding to values 0.0007 and 0.0113 cm cm^{-1} day^{-1} higher than those observed in the plants without N application and irrigated with 0.5 and 5.0 dS m^{-1}, respectively. Nitrogen can mitigate the effects of salt stress when applied at the level of 2.3 g L^{-1}, increasing the RGR_{PH} by 313.04% in the plants irrigated with 5.0 dS m^{-1} in relation to those that did not receive N (0.0023 cm cm^{-1} day^{-1}). This improvement in plant height can be attributed to the roles of N in cell wall stability, damaged under salt stress conditions and resulting in increased elasticity and, consequently, greater cell expansion, which is reflected in stem growth (Landi & Esposito, 2017).

A similar behaviour was observed in the relative growth in stem diameter, with the highest values in the seedlings irrigated with non-saline water and 1.24 g L^{-1} of N fertilisation (0.0199 mm mm^{-1} day^{-1}) (Figure 4B). Salinity reduced the RGR_{SD} of sugar apple seedlings, especially when irrigated with 5.0 dS m^{-1} in the plants that did not receive foliar N, decreasing by 57.79% compared to the highest value observed (0.0199 mm mm^{-1} day^{-1}). Under these irrigation conditions with 5.0 dS m^{-1}, N application at the level of 1.90 g L^{-1} resulted in the RGR_{SD} of 0.0144 mm mm^{-1} day^{-1}, increasing by 71.43%.

Foliar N fertilisation improved the growth of sugar apple seedlings 90 DAE (**Figure 5**), resulting in the highest growth in the seedlings irrigated with non-saline water (0.5 dS m^{-1}) and fertilised via foliar application with 2.3 g L^{-1} of N (31.00 cm) for plant height (Figure 5A); with 0.93 g L^{-1} of N (6.07 mm) for stem diameter (Figure 5B); with 1.53 g L^{-1} of N (13.93 leaves) for the number of leaves (Figure 5C), and with 2.30 g L^{-1} of N (466.80 cm^2) for the leaf area (Figure 5D). The lowest values were observed in the plants without N fertilisation and irrigated with the highest ECiw, reducing the PH by 57.97% (13.03 cm), the SD by 39.54%

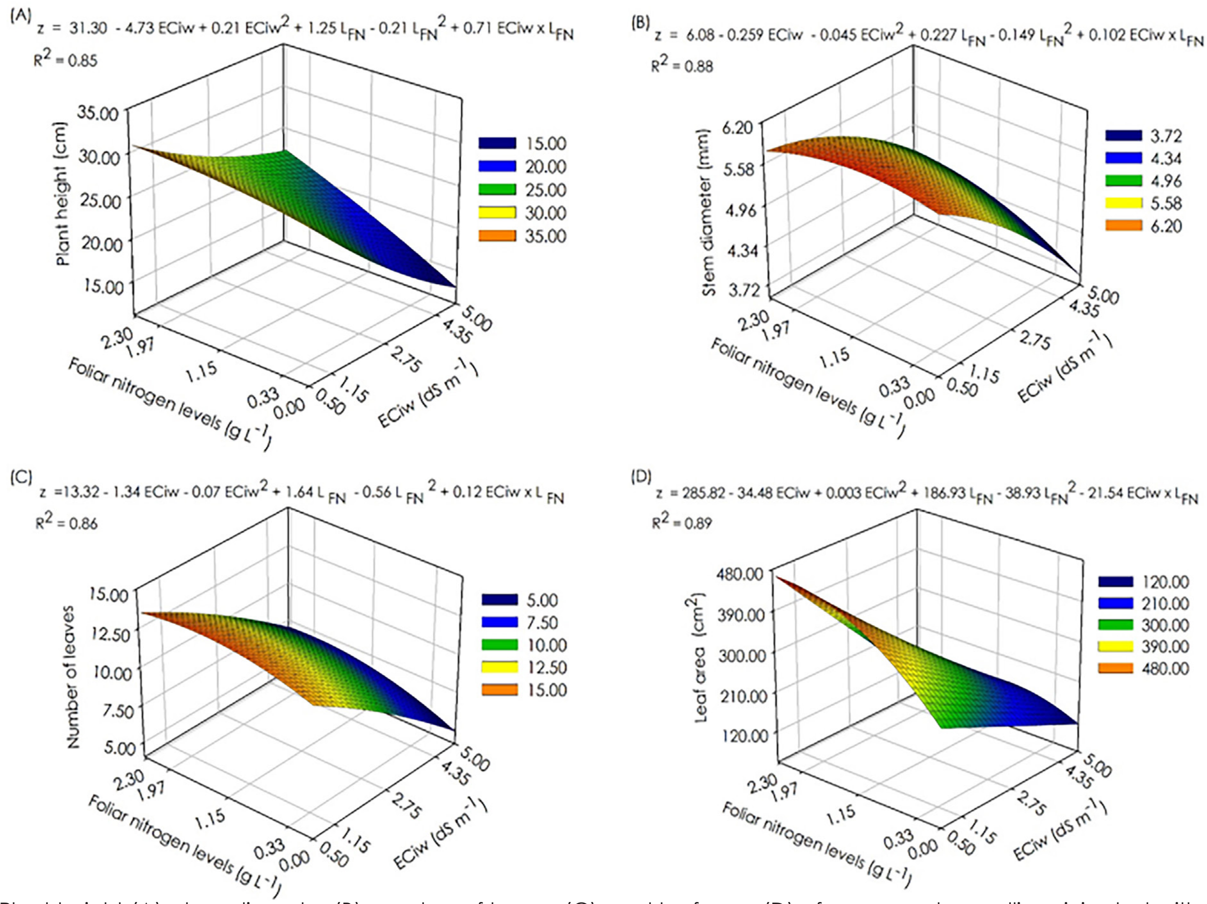

Figure 5. Plant height (A), stem diameter (B), number of leaves (C), and leaf area (D) of sugar apple seedlings irrigated with saline water and fertilised with foliar nitrogen (L_{FN}) levels at 90 days after emergence.

(3.67 mm), the NL by 64.97% (4.88 leaves), and the LA by 75.46% (114.57 cm^2). The growth reduction in sugar apple seedlings results from prolonged plant exposure to salts, imposing limitations to the cell water potential, reducing cell elongation and division, and causing metabolic dysfunctions, which accelerate the leaf senescence process and inhibit the formation of new leaves (Yadav et al., 2019). Similar responses to salt stress were observed by Pinheiro et al. (2019) in cotton (*Gossypium hirsutum* L.) and by Oliveira et al. (2017) in jackfruit (*Artocarpus heterophyllus*).

However, N application in the sugar apple seedlings, even under high-salinity conditions (5.0 dS m^{-1}), mitigated the effects of salt stress, with the highest N level (2.3 g L^{-1}) increasing plant height (22.83 cm) and stem diameter (4.57 mm) by 75.21 and 24.52% in relation to the plants irrigated with 5.0 dS m^{-1} and without N application. This situation was also observed for the number of leaves and leaf area, with the respective levels of 2.00 and 1.00 g L^{-1} of foliar N resulting in the highest values of these variables under this condition (7.11 leaves and 153.78 cm^2), increasing by 45.70% and 34.22% in relation to the seedlings that did not receive foliar N and irrigated with 5.0 dS m^{-1}.

Nitrogen might have contributed to increasing the synthesis of organic osmolytes, responsible for osmotic regulation between roots and soil, favouring water and nutrient uptake and minimizing the deleterious effects of accumulating specific ions in the plant tissues, thus improving the metabolic plant activity, carbon assimilation and distribution, and plant growth (Ashraf et al., 2018; Song et al., 2019).

Conclusions

Irrigation water salinity reduces the growth of sugar apple seedlings under irrigation with electrical conductivity levels above 1.7 dS m^{-1} at 90 days after emergence.

Foliar nitrogen (N) fertilisation increased the photochemical efficiency and the growth of sugar apple seedlings.

The foliar application of 1.93 g L^{-1} of N can mitigate the deleterious effects of water salinity on the photochemical efficiency and growth of sugar apple seedlings.

Acknowledgments

To the Coordination for the Improvement of

Higher Education Personnel (CAPES) and the National Council for Scientific and Technological Development (CNPq) for the concession of the scholarships.

References

Ahanger, M.A., Qin, C., Begum, N., Maodong, Q., Dong, X.X., El-Esawi, M., El-Sheikh, M.A., Alatar, A.A., Zhang, L. 2019. Nitrogen availability prevents oxidative effects of salinity on wheat growth and photosynthesis by up-regulating the antioxidants and osmolytes metabolism, and secondary metabolite accumulation. *BMC Plant Biology* 19: 1-12.

Akhter, M.S., Noreen, S., Mahmood, S., Ashraf, M., Alsahli, A.A., Ahmad, P. 2021. Influence of salinity stress on PSII in barley (*Hordeum vulgare* L.) genotypes, probed by chlorophyll-a fluorescence. *Journal of King Saud University-Science* 33: 101239.

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L.M., Sparovek, G. 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift* 22: 711-728.

Andrade, F.H.A., Pereira, W.E., Morais, R.R., Silva, A.F., Barbosa Neto, M.A.B. 2018. Effect of phosphorus application on substrate and use of saline water in sugar-apple seedlings. *Pesquisa Agropecuária Tropical* 48: 190-199.

Annunziata, M.G., Ciarmiello, L.F., Woodrow, P., Maximova, E., Fuggi, A., Carillo, P. 2017. Durum wheat roots adapt to salinity remodeling the cellular content of nitrogen metabolites and sucrose. *Frontiers in Plant Science* 7: 1-16.

Benincasa, M.M.P. 2003. *Análise de crescimento de plantas, noções básicas*. FUNEP, Jaboticabal, Brazil. 41 p.

Bernardo, S., Soares, A.A., Mantovani, E.C. 2006. *Manual de irrigação*. UFV, Viçosa, Brazil. 625 p.

Bezerra, I.L., Gheyi, H.R., Nobre, R.G., Lima, G.S., Santos, J.B., Fernandes, P.D. 2018. Interaction between soil salinity and nitrogen on growth and gaseous exchanges in guava. *Revista Ambiente & Água*13: 1-12.

Busch, F.A., Sage, R.F., Farquhar, G.D. 2018. Plants increase CO_2 uptake by assimilating nitrogen via the photorespiratory pathway. *Nature Plants* 4: 46-54.

Evans, J.R., Clarke, V.C. 2019. The nitrogen cost of photosynthesis. *Journal of Experimental Botany* 70: 7-15.

Figueiredo, F.R.A., Gonçalves, A.C.M., Ribeiro, J.E.S., Silva, T.I., Nóbrega, J.S., Dias, T.J., Albuquerque, M. B. 2019. Gas exchanges in sugar apple (*Annona squamosa* L.) subjected to salinity stress and nitrogen fertilization. *Australian Journal of Crop Science* 13: 1835-2707.

Gomes, M.A.C., Pestana, I.A., Santa-Catarina, C., Hauser-Davis, R.A., Suzuki, M.S. 2017. Salinity effects on photosynthetic pigments, proline, biomass and nitric oxide in *Salvinia auriculata* Aubl. *Acta Limnologica Brasiliensia* 29: 1-13.

Hu, Y., Burucs, Z., Schmidhalter, U. 2008. Effect of foliar fertilization application on the growth and mineral nutrient content of maize seedlings under drought and salinity. *Soil Science and Plant Nutrition* 54: 133-141.

Kume, A., Akitsu, T., Nasahara, K. N. 2018. Why is chlorophyll b only used in light-harvesting systems? *Journal of Plant Research* 131: 961-972.

Landi, S., Esposito, S. 2017. Nitrate uptake affects cell wall synthesis and modeling. *Frontiers in Plant Science* 8: 1-9.

Lemos, E.E.P. 2014. The production of annona fruits in Brazil. *Revista Brasileira de Fruticultura* 36: 77-85.

Lima, G.S., Nobre, R.G., Gheyi, H.R., Soares, L.A.A., Silva, A.O. 2015. Produção da mamoneira cultivada com águas salinas e doses de nitrogênio. *Revista Ciência Agronômica* 46: 1-10.

Lin, Y.C., Hu, Y.G., Ren, C.Z., Guo, L.C., Wang, C.L., Jiang, Y., Zeng, Z.H. 2013. Effects of nitrogen application on chlorophyll fluorescence parameters and leaf gas exchange in naked oat. *Journal of Integrative Agriculture* 12: 2164-2171.

Luo, Z., Kong, X., Dai, J., Dong, H. 2015. Soil plus foliar nitrogen application increases cotton growth and salinity tolerance. *Journal of Plant Nutrition* 38: 443-455.

Mateus, N.B., Barbin, D., Conagin, A. 2001. Viability of center composite design. *Acta Scientiarum* 23: 1537-1546.

Negrão, S., Schmöckel, S.M., Tester, M. 2017. Evaluating physiological responses of plants to salinity stress. *Annals of Botany* 119: 1-11.

Novais, R. F., Neves J. C. L., Barros N. F. 1991. Ensaio em ambiente controlado. Oliveira A.J. (ed.). *Métodos de Pesquisa em Fertilidade do Solo*. Embrapa, Brasília, Brazil. p. 189-253.

Oliveira, A.S., Castellani, M.A., Nascimento, A.S., Moreira, A.A. 2016. Perfil do sistema de produção de pinha nos polos de fruticultura da Bahia, com ênfase nos aspectos fitossanitários da cultura. *Extensão Rural* 23: 95-111.

Oliveira, F.Í.F., Souto, A.G.L., Cavalcante, L.F., Medeiros, W.J.F., Bezerra, F.T.C., Bezerra, M.A.F. 2017. Quality of jackfruit seedlings under saline water stress and nitrogen fertilization. *Semina: Ciências Agrárias* 38: 2337-2350.

Otálora, G., Piñero, M.C., López-Marín, J., Varó, P., Del Amor, F.M. 2018. Effects of foliar nitrogen fertilization on the phenolic, mineral, and amino acid composition of escarole (*Cichorium endivia* L. var. *latifolium*). *Scientia Horticulturae* 239: 87-92.

Pinheiro, F.W.A., Lima, G.S., Gheyi, H.R., Soares, L.A.A., Oliveira, S.G., Silva, F.A. 2021. Gas exchange and yellow passion fruit production under irrigation strategies using brackish water and potassium. *Revista Ciência Agronômica* 53: 1-11.

Pinheiro, F.W.A., Lima, G.S., Gheyi, H.R., Silva, S.S., Dias, A.S., Soares, L.A.A., Fernandes, P.D. 2019. NK combinations do not alleviate the effects of salt stress on gas exchange, photosynthetic pigments and growth of cotton (‘*Gossypium hirsutum* L.). *Australian Journal of Crop Science* 13: 1353.

Richards, L.A. 1954. *Diagnosis and improvement of saline and alkaline soils*. United States Salinity Laboratory Staff, 160 p.

Riikonen, J., Luoranen, J. 2018. Seedling production and the field performance of seedlings. *Forests* 9: 740.

Rodrigues, B.R.A., Nietsche, S., Mercadante-Simões, M.O., Pereira, M.C.T., Ribeiro, L.M. 2018. Climatic seasonality influences the development of pollen grains and fruiting in Annona squamosa. *Environmental and Experimental Botany* 150: 240-248.

Romero-Aranda, R., Syvertsen, J.P. 1996. The influence of foliar-applied urea nitrogen and saline solutions on net gas exchange of citrus leaves. *Journal of the American Society for Horticultural Science* 121: 501-506.

Silva Neta, A. M. D. S., Soares, L. A. A., Lima, G. S., Silva, L. A., Ferreira, F. N., Fernandes, P.D. 2021. Morphophysiology of the passion fruit ‘BRS Rubi do Cerrado’irrigated with saline waters and nitrogen fertilization. *Comunicata Scientiae* 12: 1-9.

Silva, A.A.R., Lima, G.S., Azevedo, C.A.V., Veloso, L.L.S.A., Gheyi, H.R. 2020. Salicylic acid as an attenuator of salt stress in soursop. *Revista Caatinga* 33: 1092-1101.

Silva, P.S.L., Barbin, D., Gonçalves, R.J.S., Firmino, J.D.C., Fonseca, I.C. 2004. Leaf area estimatites of custard apple tree progenies. *Revista Brasileira de Fruticultura*, 26: 558-560.

Song, X., Zhou, G., Ma, B.L., Wu, W., Ahmad, I., Zhu, G., Yan, W., Jiao, X. 2019. Nitrogen Application improved photosynthetic productivity, chlorophyll fluorescence, yield and yield components of two oat genotypes under saline conditions. *Agronomy* 9 :115.

Sousa, J.R.M., Gheyi, H.R., Brito, M.E.B., Lacerda, C.F., Silva, F.V., Soares, F.A.L. 2016. Quantum efficiency of photosystem II and production of orange under salt stress and nitrogen fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental* 20: 434-440.

Souza, L.P., Nobre, R.G., Silva, E.M., Gheyi, H.R., Soares, L.A.A. 2017. Produção de porta-enxertos de goiabeira cultivados com água de diferentes salinidades e doses de nitrogênio. *Revista Ciência Agronômica* 48: 596-604.

Teixeira, P.C., Donagemma, G.K., Fontana, A., Teixeira, W.G. 2017. *Manual de métodos de análise de solo*. Embrapa, Brasília, DF 573 p.

Veloso, L.L.S.A., Silva, A.A.R., Capitulino, J.D., Lima, G.S., Azevedo, C.A.V., Gheyi, H.R., Nobre, R.G., Fernandes, P.D. 2019. Photochemical efficiency and growth of soursop rootstocks subjected to salt stress and hydrogen peroxide. *AIMS Agriculture and Food* 5: 1–13.

Yadav, S.P., Bharadwaj, R., Nayak, H., Mahto, R., Singh, R.K., Prasad, S.K. 2019. Impact of salt stress on growth, productivity and physicochemical properties of plants: A review. *International Journal of Comparative Sociology* 7: 1793-1798.

Zivcak, M., Brestic, M., Kalaji, H.M., Govindjee. 2014. Photosynthetic responses of sun- and shade-grown barley leaves to high light: is the lower PSII connectivity in shade leaves associated with protection against excess of light. *Photosynthesis Research* 119: 339-354.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.