Ciências Agrárias
SEMINA

DOI: 10.5433/1679-0359.2023v44n4p1235

Morphophysiology and production components of mini-watermelon under water replenishment and nitrogen fertilization levels

Morfofisiologia e componentes de produção de mini-melancia sob níveis de reposição hídrica e adubação nitrogenada

Maila Vieira Dantas[1]; Cassiano Nogueira de Lacerda[1]; Iara Almeida Roque[1]; Francisco Alves da Silva[1]; Geovani Soares de Lima[2]*; Lúcia Helena Garófalo Chaves[2]; Lauriane Almeida dos Anjos Soares[3]; Hans Raj Gheyi[2]; Jackson Silva Nóbrega[4]; Luderlândio de Andrade Silva[4]

Highlights

The irrigation amount of 125% ETr increases plant growth and gas exchange.
Irrigation at 50% ETr inhibits the morphophysiology of mini-watermelon.
Fertilization with 50% N and irrigation at 125% ETr increase gas exchange.

Abstract

In the semi-arid region of Northeast Brazil, the combination of irregular rainfall and high evapotranspiration creates a consistent water deficit in plants for most months of the year. This factor prominently limits the vegetable production potential. Consequently, finding effective strategies to alleviate the adverse impacts of water deficit on plants becomes imperative to ensure successful cultivation under irrigated conditions. Within this framework, the objective of this study was to evaluate the influence of nitrogen fertilization on both the morphophysiology and production components of 'Sugar Baby' mini-watermelon plants. The experiment was carried out at the 'Rolando Rivas Castellón' experimental farm in São Domingos, PB, Brazil, within controlled greenhouse conditions. A randomized block design was employed using a 4 × 4 factorial

[1] Doctoral Scholar of Agricultural Engineering Course, Post Graduate Program in Agricultural Engineering, Center of Technology and Natural Resources, Universidade Federal de Campina Grande, UFCG, Campina Grande, PB, Brazil. E-mail: maila.vieira02@gmail.com; cassianonogueiraagro@gmail.com; yara.roque.sb@gmail.com; chico.lis@hotmail.com

[2] Profs., Post Graduate Program in Agricultural Engineering, UFCG, Campina Grande, PB, Brazil. E-mail: geovani.soares@professor.ufcg.edu.br; hgarofalo@hotmail.com; hgheyi@gmail.com

[3] Prof[a], Academic Unit of Agricultural Sciences, Center of Agrifood Science and Technology, UFCG, Pombal, PB, Brazil. E-mail: laurispo.agronomia@gmail.com

[4] Junior Postdoctoral Fellow, Post Graduate Program in Agricultural Engineering, Center of Technology and Natural Resources, UFCG, Campina Grande, PB, Brazil. E-mail: jacksonnobrega@hotmail.com; luderlandioandrade@gmail.com

* Author for correspondence

Received: Apr. 26, 2023 Approved: Aug. 23, 2023

arrangement consisting of four distinct water replenishment levels (50, 75, 100 [control], and 125% of the crop's actual evapotranspiration [ETr]) and four nitrogen application rates (50, 75, 100, and 125% of the recommended rate). Each treatment combination was replicated three times, leading to a total of 48 plants being studied. Gas exchange parameters, content of photosynthetic pigments, relative water content, and electrolyte leakage were assessed. Furthermore, growth metrics, biomass production, production components, and the postharvest quality of 'Sugar Baby' mini-watermelon fruits were also evaluated. Subjecting the plants to deficit irrigation with 50% ETr reduced gas exchange, synthesis of photosynthetic pigments, growth, and fruit quality of 'Sugar Baby' mini-watermelon, irrespective of the nitrogen rate. On the other hand, the irrigation amount of 125% ETr coupled with nitrogen fertilization at 100% of the recommended rate provided higher values of total chlorophyll content, number of leaves, dry mass of root, stem, shoot, and total plant, and the pH value of 'Sugar Baby' mini-watermelon.
Key words: Citrullus lanatus. Water deficit. Nitrogen.

Resumo

No semiárido do Nordeste do Brasil, a irregularidade de chuvas e elevada evapotranspiração proporcionam déficit hídrico nas plantas na maior parte dos meses do ano, destacando-se como fator limitante para produção de olerícolas. Assim, a identificação de estratégias capazes de amenizar os efeitos do déficit hídrico nas plantas é essencial para produção sob condições irrigadas. Nesse contexto, objetivou-se avaliar o efeito da adubação nitrogenada na morfofisiologia e nos componentes de produção de mini-melancia 'Sugar Baby'. O experimento foi conduzido na Fazenda Experimental 'Rolando Rivas Castellón', São Domingos, Paraíba, sob condições de casa de vegetação, utilizando-se o delineamento de blocos casualizados em esquema fatorial 4 × 4, correspondendo a quatro níveis de reposição hídrica (50, 75, 100 - controle e 125% da evapotranspiração real da cultura - ETr) e quatro doses de nitrogênio - DN (50, 75, 100 e 125% da dose recomendada), com 3 repetições, totalizando 48 plantas. Foram avaliadas as variáveis de trocas gasosas, os teores de pigmentos fotossintéticos, o conteúdo relativo de água e o extravasamento de eletrólitos, o crescimento e a produção de fitomassa, os componentes de produção e a qualidade pós-colheita dos frutos de mini-melancia. A irrigação deficitária com 50% da evapotranspiração real inibiu as trocas gasosas, a síntese de pigmentos fotossintéticos, o crescimento, e a qualidade dos frutos da mini-melancieira 'Sugar Baby', independente da dose de nitrogênio. A lâmina de água com 125% da evapotranspiração real combinada à adubação de 100% da recomendação de nitrogênio proporcionou maiores teores de clorofilas totais, número de folhas e de fitomassa seca das raízes, caule, total, parte aérea e pH dos frutos de mini-melancieira 'Sugar Baby'.
Palavras-chave: Citrullus lanatus. Déficit hídrico. Nitrogênio.

Introduction

Agricultural endeavors within the semi-arid region of Northeast Brazil face significant limitations owing to the qualitative and quantitative scarcity of water. This scarcity is a result of several factors, including limited rainfall, elevated annual evapotranspiration, and low relative humidity. Rainfall is concentrated within a narrow window of months, leaving extended periods marked by drought (Soares et al., 2018; H. C. Brito et al., 2022; Pinheiro et al., 2022). Compounding these challenges, soils in this region are less developed and possess limited water holding capacity, readily draining and evaporating available moisture (Silva et al., 2019a).

In light of these conditions, meticulous management of irrigation becomes indispensable for ensuring viable agricultural output, especially in the cultivation of crops like vegetables (G. S. de Lima et al., 2020; Pacheco & Rodrigues, 2022). One such crop is the mini-watermelon (Citrullus lanatus), known for its general adaptability to hot and semi-arid environments (Z. V. S. R. Oliveira et al., 2022). This nationally significant crop is renowned for its organoleptic and nutritional attributes (Dal Mora et al., 2021). Notably, it possesses medicinal properties owing to the presence of antioxidants such as lycopene, beta-carotene, vitamin C, and the amino acid citrulline, all of which confer positive effects on human health (Anjos et al., 2022). This combination of characteristics grants watermelon considerable socioeconomic potential, fostering employment and growth in agricultural production zones (Carnicel et al., 2020).

However, the considerable water demands of watermelon act as a constraint to agricultural production in these regions (D. R. M. Silva et al., 2014). Plants subjected to water scarcity undergo physiological alterations, leading to diminished stomatal conductance, reduced water and nutrient absorption, as well as decreased transpiration and photosynthesis. These changes culminate in decreased accumulation and distribution of photoassimilates (S. S. de Silva et al., 2021; Soares et al., 2023), potentially compromising production and fruit quality (Melo et al., 2022). On the other hand, excessive soil moisture can induce issues such as oxygen deficiency and disease incidence, further jeopardizing yields (Pereira et al., 2021).

In the pursuit of strategies to mitigate the effects of water stress on plants, nitrogen fertilization emerges as a prominent alternative (G. S. de Lima et al., 2014, 2018; R. M. de Oliveira et al., 2019; Bezerra et al., 2020). Nitrogen, a fundamental component of various amino acids and proteins, contributes to cellular osmotic adjustment (P. H. F. Rocha et al., 2020). This enhances water absorption from the soil, even under conditions of reduced water potential. Additionally, nitrogen exerts antioxidant effects to counteract reactive oxygen species, which proliferate in the face of abiotic stress (I. T. M. Rocha et al., 2023).

Against this backdrop, the present study aimed to evaluate the morphophysiology and production components of 'Sugar Baby' mini-watermelon cultivated under different water replenishment levels and nitrogen application rates.

Material and Methods

The investigation was conducted from April 13 to July 5, 2022, within controlled greenhouse conditions at the Rolando Enrique Rivas Castellón Experimental Farm, affiliated with the Agrifood Science and Technology Center (CCTA/UFCG) in São Domingos, PB, Brazil (6°48' 51.7" S, 37°56'13.8" W). The climate of the region aligns with the Köppen-Geiger classification as a hot and arid BSh type, adjusted to Brazil's context. It is characterized by an average annual temperature exceeding 26.7 °C and an average annual precipitation of 800 mm. Figure 1 shows the maximum and minimum temperatures along with relative humidity data observed during the experimental period.

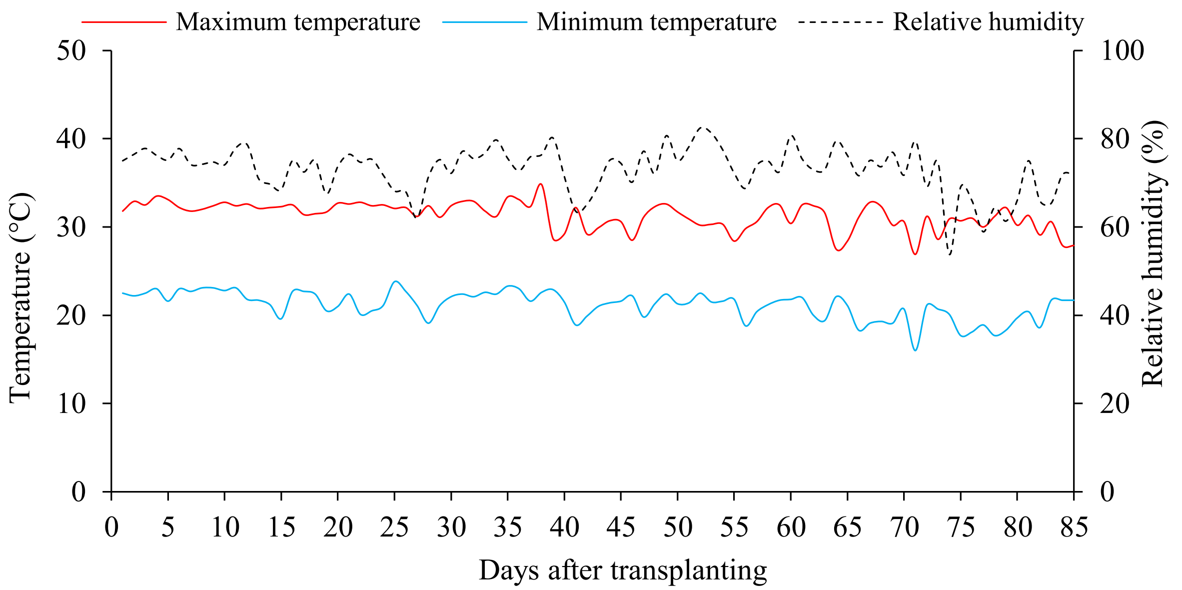

Figure 1. Maximum and minimum daily temperatures and average relative humidity observed in the internal area of the greenhouse during the experiment.

This research employed a randomized block experimental design following a 4 × 4 factorial arrangement, corresponding to four levels of water replenishment (50, 75, 100 [control], and 125% of the actual evapotranspiration of the crop [ETr]) and four nitrogen rates (50, 75, 100, and 125% of the recommendation stipulated in Novais et al. (1991)). The study incorporated three replications, each with a single plant per plot, totaling 48 experimental units. Water replenishment levels were adopted from a study conducted by Soares et al. (2015), with discernible water quantities being introduced starting 21 days post-sowing.

The experiment utilized the 'Sugar Baby' mini-watermelon variety due to its early maturation cycle, allowing harvesting 75 days post-planting. This hardy plant features robust foliage, displaying high tolerance to elevated temperatures. The round fruits boast dark green skin, tender pulp, vibrant red hue, and elevated sugar content (Silva et al., 2019b).

The plants were cultivated in 12-L plastic pots (28 cm in height and 30 cm in diameter) filled with a layer of 100 g of gravel enveloped in non-woven geotextile (Bidim OP 30). This arrangement prevented obstruction of the drainage system. A 15-mm-diameter tube was installed at the bottom, connected to a 2-L plastic container for collection of drainage water and plant water consumption measurement. The pots were filled with crushed Neossoil Regolithic soil (Entisol), a sandy texture soil collected at 0.30 cm depth from the experimental farm. The physical and chemical attributes of soil (Table 1) were determined as per Teixeira et al. (2017).

Table 1
Chemical and physical-water attributes of the soil used in the experiment, before the treatments were applied

Chemical characteristics										
pH (H_2O) (1:2.5)	OM (g kg^{-1})	P (mg kg^{-1})	K^+	Na^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H^+	ECse (dS m^{-1})	ESP %
			.... cmolc kg^{-1}							
7.19	1.40	59.5	0.49	0.07	4.70	2.63	0.00	0.00	0.58	33,33

Physical characteristics									
Particle fraction (g kg^{-1})			Texture class	Moisture (dag kg^{-1})		AW	Porosity (%)	SD	PD
Sand	Silt	Clay		33.42 kPa[1]	1519.50 kPa[2]			.... (g cm^{-3})	
735.10	201.40	63.50	Sandy loam	15.78	6.41	9.37	55.05	1.20	2.67

OM = organic matter, Walkley-Black wet digestion; Ca2+ and Mg2+ extracted with KCl 1 mol L-1, at pH 7.0; Na+ and K+ extracted using NH4OAc 1 mol L-1 at pH 7.0; Al3+ and H+ extracted using CaOAc 1 mol L-1, at pH 7.0; ECse = electrical conductivity of the saturation extract; ESP = exchangeable sodium percentage; AW = available water; SD = soil density; PD = particle density. 1,2 Referring to the moisture content in the soil corresponding to field capacity and permanent wilting point.

After irrigating soil to its maximum retention capacity in all experimental units, sowing took place. Three seeds were sown per pot at a depth of 3 cm, evenly distributed. Upon seedling emergence, thinning was conducted, keeping only the most vigorous plant per pot.

Phosphorus and potassium fertilizations were administered as topdressing, following the guidelines of Novais et al. (1991) for pot trials. Potassium chloride (60% K_2O) and monoammonium phosphate (48% P_2O_5) were applied through irrigation water at rates of 150 and 300 mg kg^{-1} soil for K_2O and P_2O_5, respectively. These applications occurred at 20, 30, 40, 50, and 60 days after sowing (DAS). Nitrogen fertilization was divided into four fertigation applications, spaced 10 days apart. Urea was utilized as a nitrogen source, providing rates of 37.5, 56.25, 75.0, and 93.75 mg of N kg^{-1} soil, corresponding to the N levels of 50, 75, 100, and 125%, respectively.

Micronutrient fertilizations occurred bi-weekly via foliar spray, starting at 30 DAS, considering the nutritional requirements of the crop. A solution of Dripsol Micro® at a concentration of 1 g L^{-1} was applied. This solution contained 1.2% magnesium, 0.85% boron, 3.4% iron, 4.2% zinc, 3.2% manganese, 0.5% copper, and 0.06% molybdenum.

The actual evapotranspiration of the crop (ETr) was determined using the drainage lysimetry method according to the approach of Bernardo et al. (2019). Water consumption was estimated using the control treatment plants (100% ETr), calculated as the difference between the applied volume of water (Va) and the drained volume from the previous irrigation (Vd), resulting in the consumed volume (Vc). Different irrigation amounts (50, 75, 100, and 125% ETr) were established by multiplying Vc by the factors of 0.50, 0.75, 1.0, and 1.25, respectively. Initially, all treatments were manually irrigated daily, maintaining soil moisture close to its maximum capacity for the first 20 DAS. Subsequently, irrigation frequency shifted to a one-day interval, adhering to the established irrigation amounts.

The plants were trained using vertical staking with nylon, where only the main branch and three lateral branches were retained per plant. Artificial pollination was conducted using a cotton swab, transferring pollen from male flowers to the stigma of female flowers. Following pollination, a thinning process was undertaken, allowing only one fruit per plant to develop. This procedure adhered to the methodology outlined by S. S. da Silva et al. (2022a) and A. A. R. da Silva et al. (2022b).

On the 51st day DAS, the following gas exchange parameters were determined: stomatal conductance (*gs*, mol H_2O m^{-2} s^{-1}), transpiration (*E*, mmol H_2O m^{-2} s^{-1}), CO_2 assimilation rate (*A*, μmol CO_2 m^{-2} s^{-1}), and intercellular CO_2 concentration (*Ci*, μmol CO_2 mol^{-1}). These measurements were performed using a portable infrared carbon dioxide analyzer (IRGA) model LCPro + Portable Photosynthesis System® (ADC BioScientific Limited, UK). The analyzer operated with an airflow rate of 200 mL min^{-1}, and environmental conditions were maintained at an atmospheric CO_2 concentration and irradiance of 1200 μmol photons m^{-2} s^{-1}, established using the photosynthetic light-response curve (Fernandes et al., 2021). Subsequent to data collection, two parameters were calculated: instantaneous water use efficiency (*iWUE* = *A/E* [μmol CO_2 m^{-2} s^{-1} / mmol H_2O m^{-2} s^{-1}]) and instantaneous carboxylation efficiency (iCE = *A/Ci* [μmol CO_2 m^{-2} s^{-1} / μmol CO_2 mol^{-1}]).

During the same period, chlorophyll contents were assessed, including chlorophyll a (Chl *a*), chlorophyll b (Chl *b*), total chlorophyll (Ch *T*), and carotenoids (Car). These measurements were conducted based on the methodology of Lichtenthaler (1987), utilizing a plant tissue disc from the third leaf counted from the apex. The disc was immersed in 80% acetone and stored in the dark for 72 h within sealed tubes. Extracts obtained were analyzed spectrophotometrically at absorbance wavelengths of 470, 646, and 663 nm, following Equations 2, 3, 4, and 5:

$$\text{Chl } a = 12.21A_{663} - 2.81A_{646} \quad (2)$$

$$\text{Chl } b = 20.13A_{646} - 5.03A_{663} \quad (3)$$

$$\text{Car} = (1000A_{470} - 1.82 \text{ Chl } a - 85.02 \text{ Chl b})/198 \quad (4)$$

$$\text{Chl T} = 17.3A_{643} + 7.18A_{663} \quad (5)$$

where Chl *a*: chlorophyll a (mg g^{-1} FW); Chl *b*: chlorophyll b (mg g^{-1} FW); Chl *T*: total chlorophyll (mg g^{-1} FW); and Car: total carotenoids (mg g^{-1} FW).

The contents of chlorophyll a (Chl *a*), b (Chl *b*), total (Chl *T*), and carotenoids were expressed in mg g^{-1} of fresh weight (FW).

At 51 DAS, electrolyte leakage in the leaf blade was assessed. Leaves from the middle third of the plant were collected, and four leaf discs, each measuring 113 mm² in area, were washed with distilled water to eliminate other adhered electrolytes. Subsequently, they were placed in a Becker with 50 mL of bidistilled water, covered with aluminum foil, and maintained at 25 ºC for 24 h. Initial electrical conductivity (Ci) was measured, after which the beakers were subjected to 80 ºC temperature for 150 min in a forced-air oven. After cooling, final electrical conductivity (Cf) was determined. Electrolyte leakage in the leaf blade was calculated according to Scotti-Campos et al. (2013), as described in Equation 6:

$$\%\,EL = \frac{Ci}{Cf} \times 100 \qquad (6)$$

where EL: electrolyte leakage in the leaf blade (%); C_i: initial electrical conductivity (dS m^{-1}); and C_f: final electrical conductivity (dS m^{-1}).

To assess the relative water content (RWC) in the leaf blade, four leaf discs with an area of 113 mm² were sampled from the upper third of the plant. These samples were immediately weighed, yielding the fresh weight (FW). Following this, the specimens were enclosed in plastic bags, submerged in 50 mL of distilled water, and conditioned for 24 h. Once this period lapsed, excess water was removed using absorbent paper, and the samples were weighed again, indicating the turgid weight (TW). Subsequently, the samples were oven-dried (at approximately 65 ± 3 ºC) until a consistent weight was achieved, rendering the dry matter (DM) of the samples. The relative water content was determined following the procedure outlined by Weatherley (1950), using Equation 7.

$$RWC = \frac{(FW - DM)}{(TW - DM)} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(7)$$

where RWC: relative water content (%); FW: leaf fresh weight (g); TW - turgid weight (g); and DM - dry matter (g);

The evaluation of growth encompassed main-stem length, stem diameter, and the number of leaves. Main-stem length was gauged as the distance from the surface of the soil in the container to the apex meristem insertion point. Stem diameter (mm) was measured three centimeters above the soil level. The number of leaves was determined by counting those with a minimum length of 3 cm, on each plant.

Fruits were harvested 76 days post-sowing, coinciding when the tendril linked to the same fruit node or peduncle was dry. To determine fruit firmness, two equidistant readings were obtained using a McCormick penetrometer, analogue model FT 327, equipped with an 8-mm-diameter tip. Results were expressed in Newton (N).

To determine the post-harvest quality, the fruits were sectioned to extract the pulp. A volume of 50 mL was subsequently withdrawn to assess total soluble solids and the potential of hydrogen (pH). Soluble solids were determined via a digital refractometer with automatic temperature compensation, with the results expressed in ºBrix. The pH value was determined through direct measurements of the fruit extract (without additional water), in triplicate, using a bench pH meter calibrated with pH 4 and 7 buffer solutions.

Plants were harvested and their components were separated and placed within appropriately labeled paper bags. These were then subjected to drying in a force air-circulation oven maintained at 65 ºC until a consistent weight was attained. Subsequently, the dry biomass of leaves, stems, and roots was ascertained by weighing on a semi-analytical scale with a precision of 0.001 g.

Results underwent an analysis of variance using the F test at a significance level of 0.05. When significance was observed, a polynomial regression analysis, encompassing both linear and quadratic models, was performed for the distinct combinations of water replenishment levels and nitrogen rates. This analysis was executed using SISVAR – ESAL statistical software version 5.6 (Ferreira, 2019). In instances where a significant interaction emerged between the factors, response surface graphs were generated using SigmaPlot software version 12.5.

Results and Discussion

A significant interaction effect between water replenishment levels and nitrogen rates was observed on several parameters of mini-watermelon plant physiology, including stomatal conductance, transpiration, intercellular CO_2 concentration, CO_2 assimilation rate, instantaneous water use efficiency, and instantaneous carboxylation efficiency (Table 2).

Table 2
Summary of analysis of variance for stomatal conductance (*gs*), transpiration (*E*), intercellular CO_2 concentration (*Ci*), CO_2 assimilation rate (*A*), instantaneous water use efficiency (*iWUE*), and instantaneous carboxylation efficiency (*iCE*) of mini-watermelon under water replenishment levels and different nitrogen rates, at 51 days after sowing

Source of variation	DF	Mean square					
		gs	*E*	*Ci*	*A*	*iWUE*	*iCE*
Water replenishment (WR)	3	0.050**	243.857**	10422.500**	6.858**	53.192^{ns}	0.0009**
Linear regression	1	0.157**	715.945**	30781.350**	20.381**	128.773*	0.002**
Quadratic regression	1	0.004^{ns}	12.322^{ns}	374.083^{ns}	0.143^{ns}	0.700^{ns}	0.000001^{ns}
Nitrogen rates (NR)	3	0.019*	31.917*	711.055^{ns}	1.193**	82.388*	0.00005^{ns}
Linear regression	1	0.020**	60.660**	1392.010^{ns}	0.070^{ns}	163.480**	0.000001^{ns}
Quadratic regression	1	0.000^{ns}	0.190^{ns}	736.330^{ns}	0.210^{ns}	51.950^{ns}	0.0001^{ns}
Interaction (WR × NR)	9	0.009*	22.509*	2440.512*	0.472**	64.535*	0.000001*
CV (%)		19.40	11.26	12.58	6.90	22.90	21.08

ns, *, and **, not significant, significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. CV = coefficient of variation.

Regarding stomatal conductance (gs), the highest value of 0.40 mol H_2O m^{-2} s^{-1} was recorded in plants subjected to an irrigation level of 125% ETr combined with nitrogen fertilization at 50% of the recommended rate. Conversely, the lowest values were observed when using 50% ETr alongside the 125% N rate (Figure 2A). The reduction in gs under water-restricted conditions is a plant defense mechanism to prevent excessive water loss through transpiration, maintaining leaf water potential and guarding against guard cell dehydration (Sá et al., 2019a).

Transpiration (*E*) displayed a similar trend to gs. Plants receiving irrigation at 125% ETr coupled with 50% N fertilization showed the highest E (31.88 mmol H_2O m^{-2} s^{-1}), while the lowest value (17.73 mmol H_2O m^{-2} s^{-1}) occurred when exposed to 50% ETr and 125% N rate. This difference of 44.38% highlights that reduced stomatal opening leads to decreased transpiration, which is accentuated as water availability decreases (Figure 2B). This emphasizes the importance of maintaining soil water content to support cell hydration, which aids in promoting stomatal opening and subsequent transpiration (Kluge et al., 2015).

In terms of intercellular CO_2 concentration (*Ci*) (Figure 2C), the highest value (232.30 µmol CO_2 mol^{-1}) was found in mini-watermelon plants irrigated with 50% of the water requirement and nitrogen rate estimated at 102% of the value recommended by Novais et al. (1991). In contrast, the lowest *Ci* (149.16 µmol CO_2 mol^{-1}) was observed in plants subjected to 125% ETr irrigation and a 50% N rate. Despite the increased *gs*, this treatment led to lower *Ci*, indicating that the combination of 125% ETr irrigation and 50% N rate improved carbon assimilation (Campos et al., 2021).

For CO_2 assimilation rate (*A*), plants cultivated under 125% ETr and a 50% N rate obtained the highest value (5.91 µmol CO_2 m^{-2} s^{-1}), while the lowest value (3.80 µmol CO_2 m^{-2} s^{-1}) occurred at the 50% water replenishment level with a nitrogen rate of 106% of the recommendation (Figure 2D). This behavior is closely related to gs, as the increased stomatal opening due to 125% ETr irrigation correlated with a 35.7% increase in CO_2 assimilation compared to plants under 50% ETr. The role of nitrogen in essential components of the photosynthesis system, such as 1,5 bisphosphate carboxylase oxygenase (RuBisCO) and phosphoenolpyruvate carboxylase (PEPcase), contributes to enhanced photosynthetic activity (J. B. dos Santos et al., 2017; Pompeu et al., 2010).

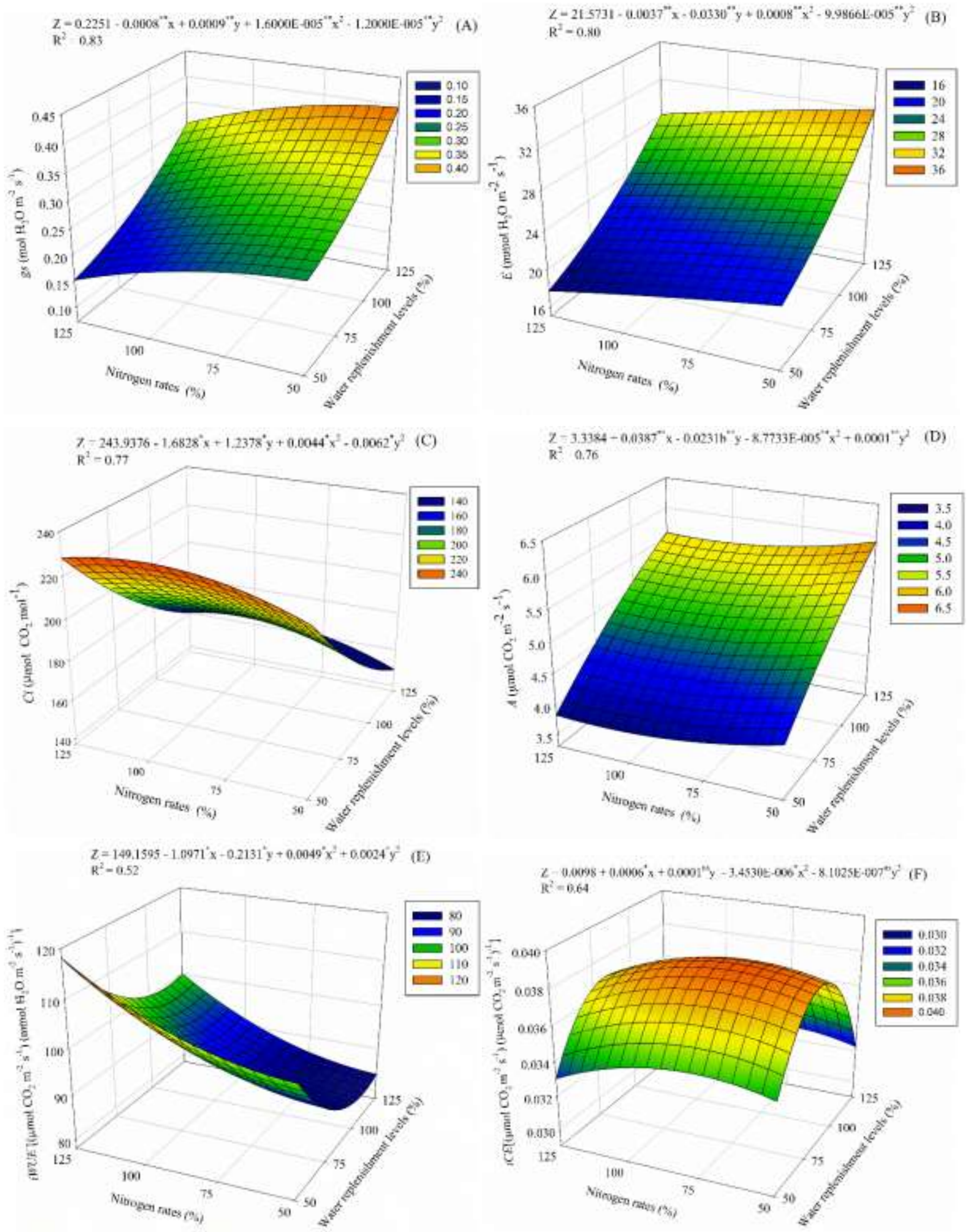

Figure 2. Stomatal conductance (*gs*, A), transpiration (*E*, B), intercellular CO_2 concentration (*Ci*, C), CO_2 assimilation rate (*A*, D), instantaneous water use efficiency (*iWUE*, E), and instantaneous carboxylation efficiency (*iCE*, F) of mini-watermelon plants as a function of the interaction between water replenishment levels and nitrogen rates, at 51 days after sowing.
X and Y- Nitrogen rates and Water replenishment levels, respectively.

Notably, under optimal water conditions, N at 50% of the rate recommended by Novais et al. (1991) enhances stomatal opening, resulting in increased transpiration and greater carbon assimilation ability in mini-watermelon plants, consequently boosting photosynthetic activity. This aligns with the role of N in synthesizing essential compounds like chlorophylls, proteins, nucleic acids, and amino acids (Saud et al., 2017; Nóbrega et al., 2021), which are involved in various physiological processes, including photosynthesis.

Mini-watermelon plants subjected to 50% ETr irrigation and 125% N recommendation achieved the highest instantaneous water use efficiency (*iWUE*), estimated at 118.15 [(μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$]. In contrast, the lowest estimated *iWUE* [83.08 ([μmol CO_2 m^{-2} s^{-1}] [mmol H_2O m^{-2} s^{-1}]$^{-1}$)] occurred under 111% ETr and a 50% N rate (Figure 2E). Comparing these two treatments, an increase of 29.68% in *iWUE* was evident with the combination of 50% ETr irrigation and 125% N recommendation. This suggests that the 125% N rate might have supported amino acid synthesis and osmotic adjustment in plants irrigated with 50% ETr, enhancing instantaneous water use efficiency. Nitrogen's role in forming solutes and secondary metabolites helps in reducing cell osmotic potential, ensuring cell turgidity even under limited water availability (Martins, 2018).

Similar findings were reported by Fátima et al. (2019) in a study involving lettuce crops, where irrigation at 50% ETr resulted in increased *Ci* (297 mmol CO_2 m²) and iWUE (2.01 μmol CO_2 m^{-2} s^{-1}). Conversely, the highest transpiration (3.89 mol H_2O m^{-2} s^{-1}) occurred under full irrigation (100% ETr), surpassing values recorded in the 50% ETr irrigation condition.

Concerning instantaneous carboxylation efficiency (*iCE*), plants subjected to 83% and 125% ETr and nitrogen rates of 73% and 125% exhibited the maximum value of 0.038 [(μmol CO_2 m^{-2} s^{-1}) (μmol m^{-2} s^{-1})$^{-1}$] and the minimum of 0.031 [(μmol CO_2 m^{-2} s^{-1}) (μmol m^{-2} s^{-1})$^{-1}$], respectively (Figure 2F). Instantaneous carboxylation efficiency denotes the capacity to process the substrate (CO_2) during photosynthesis. The augmentation of *iCE* in plants cultivated with an irrigation level of 83% ETr and a nitrogen rate estimated at 73% signifies enhanced CO_2 assimilation and its intracellular concentration. A lowered intracellular CO_2 concentration restricts CO_2 influx into mesophyll cells, causing plants to utilize CO_2 from respiration. In this context, the rise in *iCE* might be attributed to non-stomatal influences triggered by non-enzymatic inhibition (Jacinto et al., 2019).

The interaction between water replenishment levels and nitrogen rates significantly influenced main-stem length, relative water content, and electrolyte leakage in mini-watermelon plants. When considered individually, both evaluated factors led to significant differences in the number of leaves of mini-watermelon plants. However, the applied treatments did not significantly affect stem diameter (Table 3).

Table 3
Summary of analysis of variance for number of leaves (NL), main-stem length (MSL), stem diameter (SD), relative water content (RWC) and electrolyte leakage (EL%) in the leaf blade of mini-watermelon under water replenishment levels and nitrogen rates, at 51 days after sowing

Source of variation	DF	Mean square				
		NL	MSL	SD	RWC	EL%
Water replenishment (WR)	3	399.555**	4872.780**	0.757^{ns}	0.063**	2085.260**
Linear regression	1	98.810**	14007.10**	0.002^{ns}	0.180**	5573.260**
Quadratic regression	1	18.750^{ns}	249.790^{ns}	1.591^{ns}	0.000**	682.520**
Nitrogen rates (NR)	3	55.388**	2884.610**	0.369^{ns}	0.010**	328.310**
Linear regression	1	1126.666**	6176.270**	0.630^{ns}	0.180**	298.190**
Quadratic regression	1	65.333*	2289.420**	0.000^{ns}	0.009*	308.150**
Interaction (WR × NR)	9	10.574^{ns}	1533.110**	0.935^{ns}	0.0130**	89.751**
CV (%)		9.74	7.72	3.11	4.16	7.91

ns, *, and **, not significant, significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. CV = coefficient of variation.

The number of leaves in mini-watermelon plants increased linearly with water replenishment levels (Figure 3A), with a rise of 0.77% per incremental unit in irrigation amount. Plants subjected to 125% ETr demonstrated a notable 28.03% increase in number of leaves compared to those exposed to the minimum level of 50% ETr. Enhanced soil water availability promotes greater plant absorption, leading to heightened turgor pressure and subsequent cell division, ultimately contributing to elevated leaf emission (Andrade et al., 2013). Given that watermelon is a water-demanding crop relative to other vegetables, increased soil water availability could particularly benefit its growth.

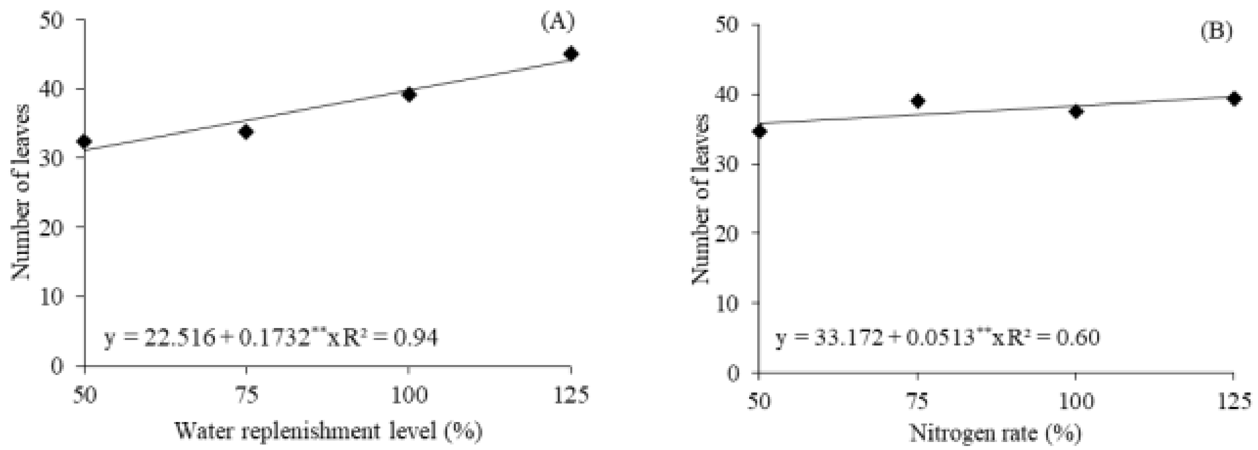

Figure 3. Number of leaves of mini-watermelon plants as a function of water replenishment levels (A) and nitrogen rates (B), at 51 days after sowing.

Nitrogen rates exhibited a linear correlation with the number of leaves in mini-watermelon plants (Figure 3B), with a growth of 0.15% for every 25% escalation in the nitrogen rate. Comparing plants exposed to a 125% nitrogen recommendation against those receiving 50% nitrogen, a 12.05% increase in number of leaves was observed. This effect arises because N is one of the main nutrients responsible for leaf emission. It is involved in the synthesis of plant growth-regulating phytohormones such as auxins and cytokinins, which facilitate cell division (Taiz et al., 2017). Furthermore, nitrogen participates in fundamental processes for plant growth and development, such as protein synthesis, ionic absorption, photosynthesis, respiration, cell proliferation, and differentiation (Malavolta, 2006).

Irrigation in the amount of 125% ETr combined with nitrogen fertilization at approximately 102% of the recommended rate resulted in substantial growth of the main branch, measuring 231.77 cm in mini-watermelon plants (Figure 4). In contrast, plants subjected to a water replenishment level of 50% ETr and fertilized with only 50% of the recommended N showed the least development of the primary branch, reaching a length of 158.03 cm. The reduction in soil moisture content curtails water and nutrient uptake by plants, leading to decreased cell turgor pressure and overall growth. Salt stress conditions also caused a linear decrease of 6.1% for each increment in the electrical conductivity of irrigation water in terms of main stem length in watermelon (Silva et al., 2019b). When investigating water stress (50% ETc) across different phenological stages of watermelon, Nascimento (2016) observed increased main branch lengths during vegetative (2.9 cm) and flowering (2.96 cm) stages under water stress treatments.

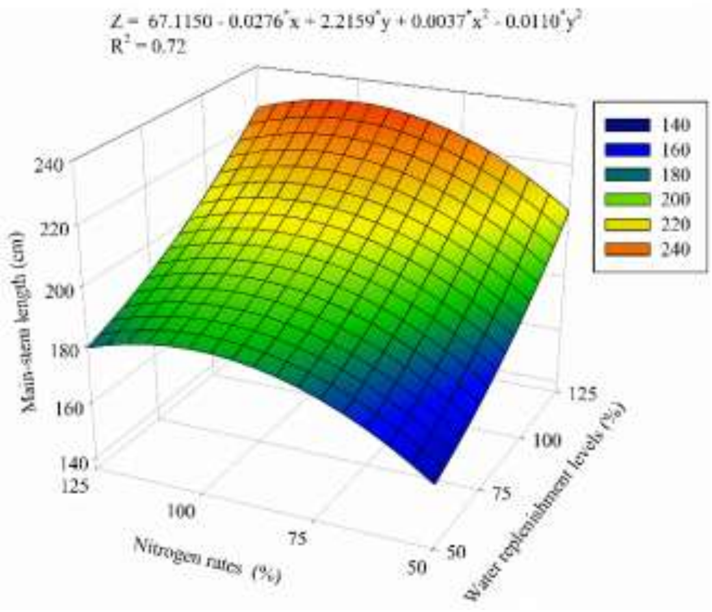

Figure 4. Main-stem length of mini-watermelon plants as a function of water replenishment levels and nitrogen rates, at 51 days after sowing.
X and Y- Nitrogen rates and Water replenishment levels, respectively.

The beneficial impact of optimal nitrogen levels under adequate water conditions is attributed to the increase in photosynthetic rates, leading to increased production of photoassimilates and consequently promoting growth, a phenomenon noted in watermelon plants by Hong et al. (2022). Li et al. (2019) reported similar findings in tomato plants, where supplying N under 80% water availability conditions stimulated dry biomass production.

Regarding relative water content in the leaf blade (Figure 5A), plants under 125% ETr and a nitrogen rate at 50% achieved a higher estimated value of 85%. In contrast, plants irrigated with 50% ETr and receiving a nitrogen rate estimated at 116% of the recommendation displayed a lower RWC (62%). The increase in relative water content signifies improved water availability, with plants accumulating higher water quantities within their cells. Additionally, an excess of N in the root zone can decrease the osmotic potential of the soil, limiting the plant's ability to absorb water (Li et al., 2019). Hence, the combination of ample water availability and a reduced N content in the soil solution contributed to enhanced leaf water content in mini-watermelon plants. The reduction in nutrient supply bears significance, allowing for lower fertilizer expenses, reduced soil residue accumulation, minimized salinization rates, and other benefits within the agricultural context (R. F. de Oliveira et al., 2018).

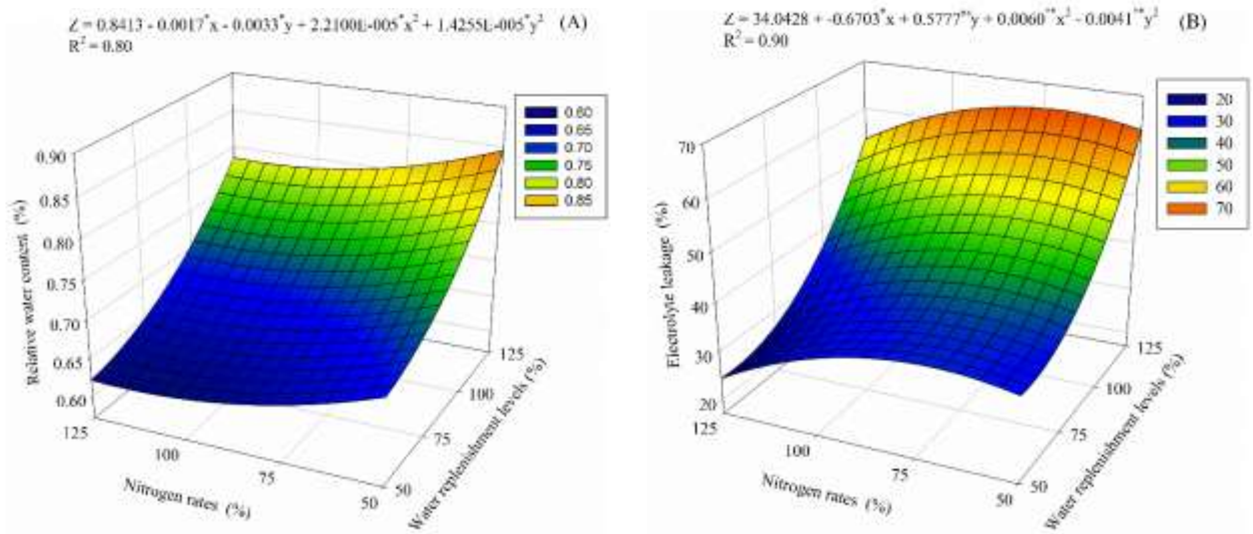

Figure 5. Relative water content (A) and electrolyte leakage (B) in the leaf blade of mini-watermelon plants as a function of water replenishment levels and nitrogen rates, at 51 days after sowing. X and Y- Nitrogen rates and Water replenishment levels, respectively.

Sá et al. (2019b) observed similar outcomes in a study assessing the effects of substrate water availability (100% and 50%) combined with four levels of bovine manure (0, 20, 40, and 60% of substrate volume) on cucumber crops. Their findings indicated that the highest relative water content was recorded in plants exposed to the 35.26%

manure level and cultivated under 100% substrate water availability.

Regarding electrolyte leakage in the leaf blade (Figure 5B), the results demonstrate that irrigation at 125% ETr and a nitrogen application rate of 73% of the recommended dosage led to a minimal value of 24.30% leakage. Conversely, the highest value of 65.09% was observed in plants subjected to a water replenishment level of 55% and fertilized with 125% of the nitrogen recommendation. In this latter scenario, the electrolyte leakage in the leaf blade of mini-watermelon plants surpassed 50%, indicating significant damage to cell membranes. As stipulated by Sullivan (1972), cell tissue is considered impaired when leaked cells exceed 50%. It is worth noting that elevated nitrogen levels can induce oxidative stress, potentially intensifying cell membrane damage, as plants are sensitive to excessive ammonium (Kováčik et al., 2020).

There was a significant interaction effect between water replenishment levels and nitrogen application rates on the content of chlorophylls a and b and carotenoids in mini-watermelon plants. Both water replenishment levels and nitrogen application rates in isolation displayed significant influence on total chlorophyll content (Table 4).

Table 4
Summary of analysis of variance for chlorophyll a (Chl a), chlorophyll b (Chl b), total chlorophyll (Chl T), and carotenoid (CAR) contents of mini-watermelon under water replenishment levels and nitrogen rates, at 51 days after sowing

Source of variation	DF	Mean square			
		NL	MSL	SD	RWC
Water replenishment (WR)	3	46.833**	3.114**	38.407**	1.521**
Linear regression	1	133.369**	8.755**	27.249**	4.322**
Quadratic regression	1	0.137^{ns}	0.264^{ns}	82.241**	0.225^{ns}
Nitrogen rates (NR)	3	2.262^{ns}	1.026**	12.369*	0.550*
Linear regression	1	1.150^{ns}	1.710**	31.890**	0.750*
Quadratic regression	1	0.610^{ns}	0.540*	4.230^{ns}	0.860*
Interaction (WR × NR)	9	5.339**	0.441*	4.191^{ns}	0.505*
CV (%)	7.91	7.60	8.10	8.45	6.43

ns, *, **, not significant, significant at p ≤ 0.05 and p ≤ 0.01, respectively. CV = coefficient of variation.

Plants cultivated under a water replenishment level of 125% ETr demonstrated the highest chlorophyll a and b levels (15.35 and 4.67 mg g^{-1} FW) when subjected to the N rates of 120% and 97% of the recommendation, respectively (Figure 6A and 6B). Conversely, plants irrigated at 50% ETr and fertilized with 50% of the recommended nitrogen displayed the lowest levels, measuring 10.19 and 3.17 mg g^{-1} FW. This discrepancy reflected a notable reduction of 33.6% and 32.1% in chlorophyll a and b contents, respectively, in comparison to the peak values achieved.

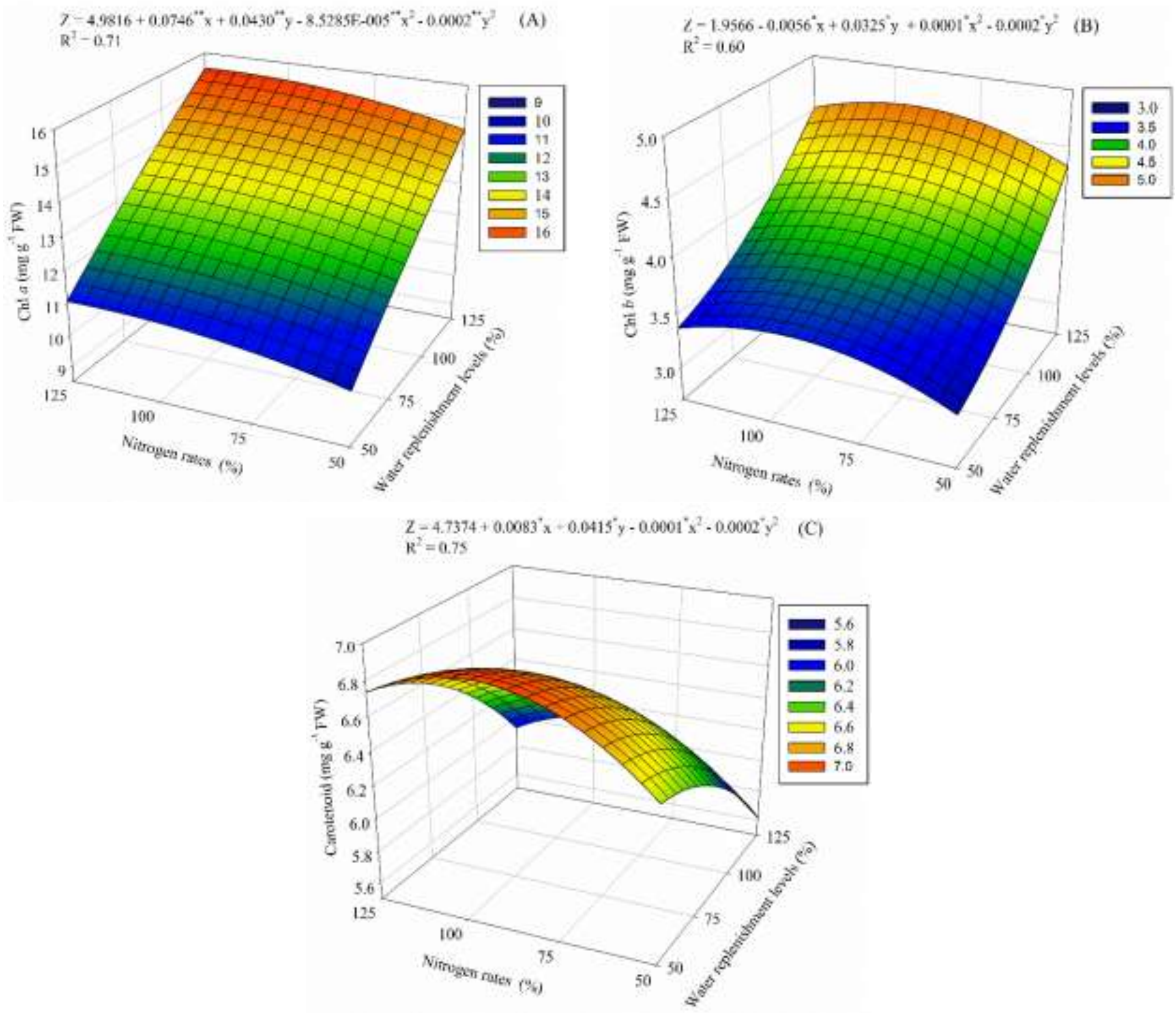

Figure 6. Chlorophyll a (A), chlorophyll b (B), and carotenoid (C) contents in mini-watermelon plants as a function of water replenishment levels and nitrogen rates, at 51 days after sowing.
X and Y- Nitrogen rates and Water replenishment levels, respectively.

Regarding chlorophyll levels in plants under optimal water availability conditions, nitrogen application rates exceeding 90% have been shown to facilitate increased levels of chlorophyll. This enhancement likely stems from improved water availability in the soil, promoting mineralization and, consequently, greater N uptake by the plants (Ullah et al., 2019). In a study conducted by Mesquita et al. (2017) assessing the impact of varied irrigation levels (100, 80, 60, and 40% ETc) and nitrogen rates (140, 110, 80, and 50 kg ha^{-1}) on melon crops, no significant effects on chlorophyll a and b contents were observed. Bezerra (2017), in a study with pumpkin, found that the highest relative chlorophyll indices were achieved in plants fertilized with 96.96% of the recommended N rate (29.02 kg ha^{-1} of N) and subjected to an irrigation amount of 50% ETr (216 mm).

Concerning carotenoid contents (Figure 6C), it is evident that the highest value of 6.90 mg g^{-1} FW was recorded in plants cultivated under a water replenishment level of 50% ETr, coupled with a nitrogen application rate of 97% of the recommendation. Conversely, the lowest value of 5.62 mg g^{-1} FW was observed in plants irrigated at 125% ETr while being fertilized with 50% of the recommended nitrogen level. This reduction in carotenoid contents may stem from the degradation of β-carotene due to photo-oxidation (Dias et al., 2019).

Water replenishment levels induced a quadratic increase in total chlorophyll content (Figure 7A), which reached a peak value of 21.67 mg g^{-1} FW in plants irrigated at 125% ETr. As suggested by Mendes et al. (2011), this increase in chlorophyll synthesis could be attributed to protective mechanisms of the plant, such as chloroplast development, possibly through an augmentation in thylakoid count or an increase in chloroplast numbers.

With respect to nitrogen rates, a linear trend was evident in total chlorophyll content, showcasing a 12.02% augmentation when contrasting the 50% and 125% rates (Figure 7B). The highest total chlorophyll value (20.38 mg g-1 FW) emerged in plants treated with a nitrogen rate of 125%. This phenomenon is explicable by the role of N as a constituent of amino acids, proteins, nucleic acids, hormones, and, notably, chlorophyll an essential organic compound for plant vitality (Fageria & Carvalho, 2014).

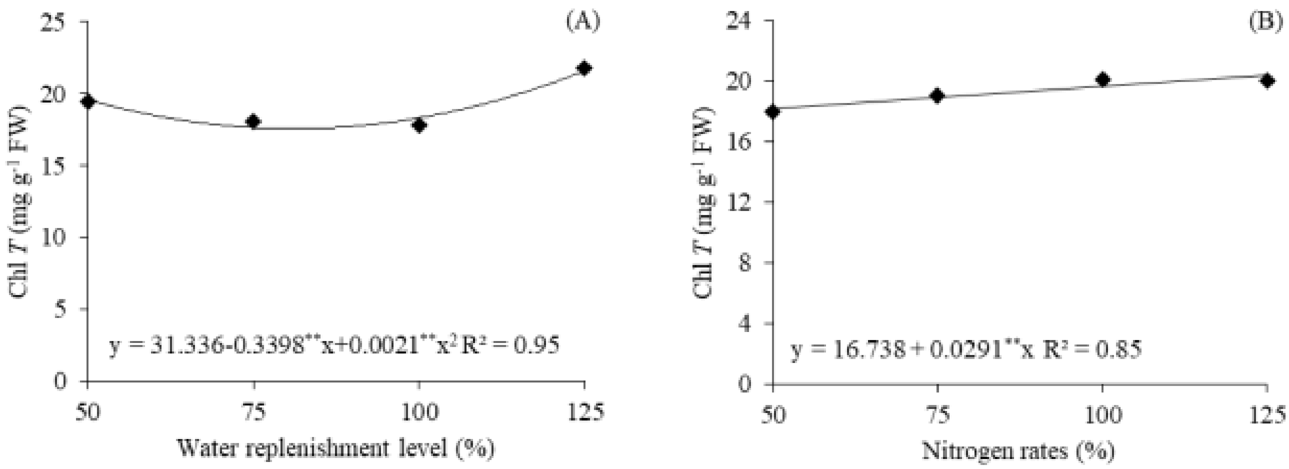

Figure 7. Total chlorophyll content (Cl *T*) in mini-watermelon plants as a function of water replenishment levels (A) and nitrogen rates (B), at 51 days after sowing.

Overall, the data indicate that the lowest nitrogen rate (50%), irrespective of water replenishment level, led to diminished levels of chlorophylls a and b, total chlorophyll, and carotenoids in mini-watermelon plants. This decline reflects impairment to the photosynthetic apparatus due to limited N availability. This limitation likely contributed to the inhibition of the synthesis of 5-aminolevulinic acid, a precursor molecule for chlorophyll (P. L. F. dos Santos et al., 2019). The reduction in chlorophyll content due to N availability is linked to the integral role of N in the chlorophyll molecule, RuBisCO, and PEPcase (Correia et al., 2005).

The interaction between water replenishment levels and nitrogen rates significantly influenced all the assessed fruit quality parameters, except pH of fruit pulp (Table 5). Nevertheless, both water replenishment levels and nitrogen rates exerted a significant effect on fruit pulp pH.

Table 5
Summary of analysis of variance for fruit firmness (FF), peel thickness (PT), soluble solids (SS), and potential of hydrogen (pH) of mini-watermelon under water replenishment levels and nitrogen rates, at 76 days after sowing

Source of variation	DF	Mean square			
		NL	MSL	SD	RWC
Water replenishment (WR)	3	698.004**	3.794*	3.394**	0.032**
Linear regression	1	807.767**	1.205^{ns}	9.780**	0.008^{ns}
Quadratic regression	1	743.242^{ns}	6.667*	0.259^{ns}	0.087**
Nitrogen rates (NR)	3	42.191^{ns}	7.130**	2.456**	0.003^{ns}
Linear regression	1	73.120^{ns}	20.120*	1.740**	0.000^{ns}
Quadratic regression	1	30.590^{ns}	0.960^{ns}	4.800**	0.000^{ns}
Interaction (WR × NR)	9	330.716**	4.001**	0.911*	0.006^{ns}
CV (%)		7.30	8.23	6.51	1.59

ns, *, **, not significant, significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. CV = coefficient of variation.

As for fruit firmness (Figure 8A), the highest value of 84.33 N was achieved in plants cultivated with 97% ETr irrigation and a nitrogen rate equal to 50% of the recommended dosage. Conversely, the lowest measurement of 64.98 N was recorded in plants exposed to the lowest water replenishment level (50% ETr) and a nitrogen rate of 106%. Thus, it is worth highlighting that diminished water availability could influence fruit peel development, consequently affecting its resistance. Firmness, a trait intrinsically linked to fruit handling, is indispensable for shelf life, physical damage resilience, and moisture retention (Cavalcante et al., 2017). The correlation between increased fruit firmness and higher nitrogen fertilization rates was also established by Campos et al. (2021) in a study involving melon crops under varied irrigation levels (40 to 100% ETr) and nitrogen fertilization rates (140, 110, 80, and 50 kg ha^{-1}).

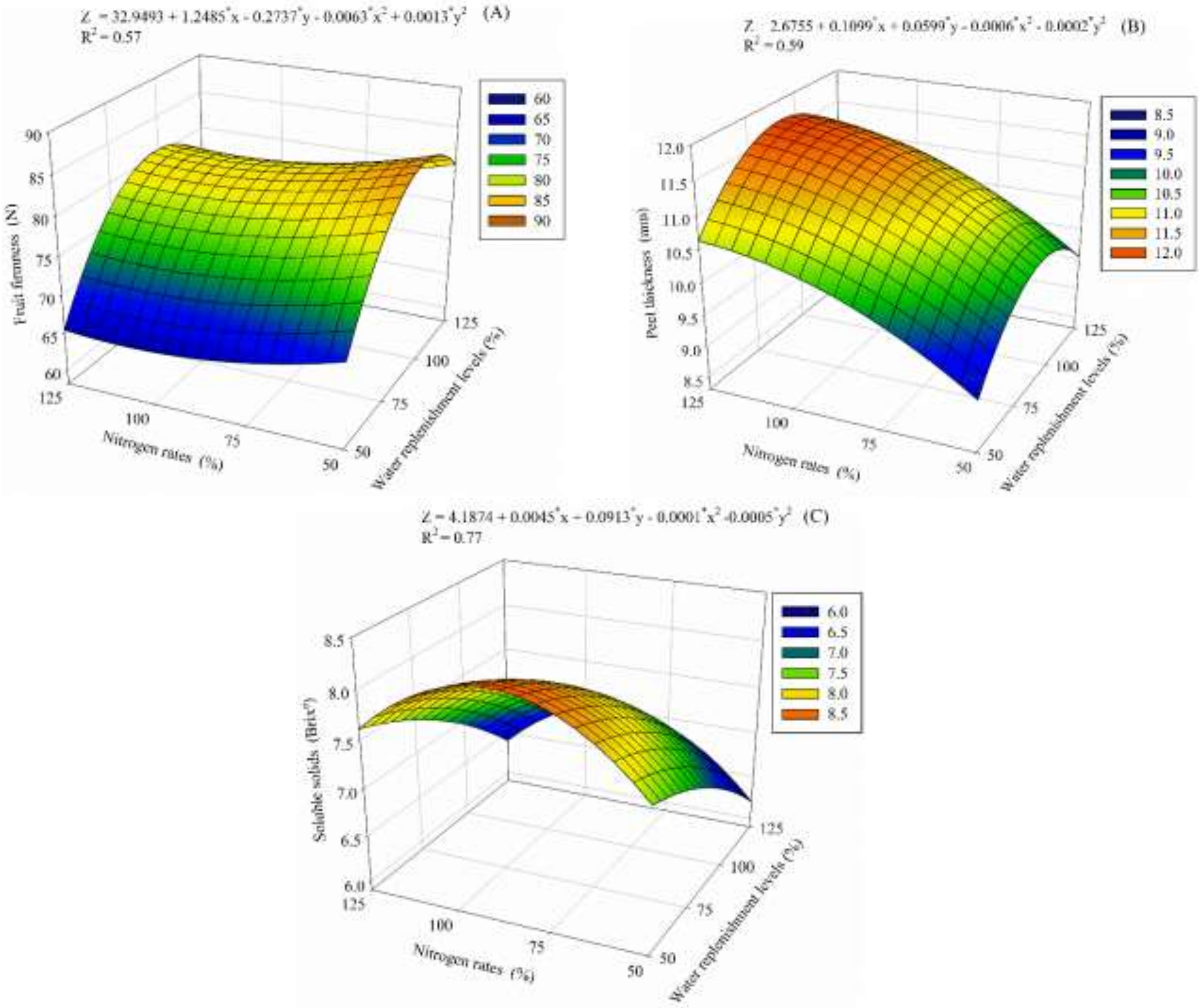

Figure 8. Fruit firmness (A), peel thickness (B), and soluble solids (C) in mini-watermelon plants as a function of the interaction between water replenishment levels and nitrogen rates, at 76 days after sowing.
X and Y - Nitrogen rates and Water replenishment levels, respectively.

Regarding peel thickness (Figure 8B), the highest measurement (9.64 mm) was observed in mini-watermelon plants irrigated at 92% ETr and fertilized with 125% of the recommended nitrogen rate. This contrasts with the lowest measurement of 9.11 mm recorded under the water replenishment and nitrogen levels of 50%, resulting in an increase of 0.53 mm. The enhancement in peel thickness directly impacts fruit firmness, imparting increased resistance to physical damage. According to Campos et al. (2021), elevated nitrogen rates contribute to increased fiber content within the peel, consequently resulting in greater thickness and firmness. The influence of nitrogen on fruit quality is intertwined with plant development, reshaping the source-sink dynamics by redistributing assimilated compounds between vegetative and reproductive components (Pôrto et al., 2012).

Soluble solids content in the fruit (Figure 8C) attained its highest level (8.23 °Brix) in plants subjected to 50% ETr irrigation coupled with a 92% nitrogen application rate. Conversely, the lowest measurement (6.20 °Brix) was recorded in plants under 125% ETr irrigation combined with nitrogen at 50% of the recommended level. The soluble solids content in mini-watermelon fruits holds significant value, particularly in regions such as Brazil, where it serves as an essential parameter in fruit selection (Barros et al., 2012). In this study, the recorded values conform to quality standards, as the maximum value of 8.23 °Brix surpasses the recommended value of 8 °Brix for commercial sale (Instrução Normativa, 2018). The rise in soluble solids content correlates with the role of sugars as osmotic regulators in plants subjected to water stress conditions (Matos & Carvalho, 2020).

An increase in water replenishment levels led to a corresponding elevation in the pH of mini-watermelon pulp of fruits (Figure 9). The highest pH value of 4.56 was recorded in plants irrigated at 100% ETr, while the lowest pH value of 4.45 was recorded in plants receiving 50% ETr irrigation. Maintaining fruit pH within the acidic range is crucial for industrial processes, as it can facilitate pulp preservation without necessitating extensive heat treatment, resulting in lower nutrient loss (Benevides et al., 2008). However, the pH values observed in this study fall below the recommendation set by the Ministry of Agriculture (ideal pH of 5.4), with the recorded value being 4.56 (Instrução Normativa, 2018). This contrasts with the findings of Soares et al. (2013) in their study on tomato crop under varying water stress levels (60, 80, 100, and 120% ETr), where they noted a decline in fruit pH with increased irrigation amounts.

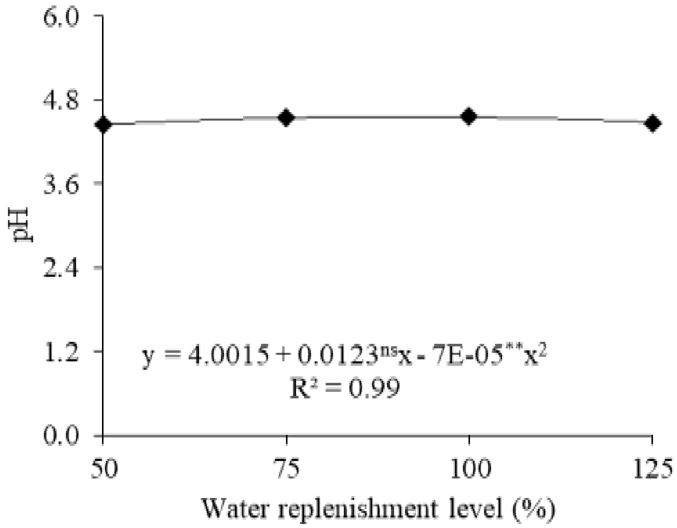

Figure 9. Potential of hydrogen (pH) of mini-watermelon plants as a function of water replenishment levels, at 76 days after sowing.

The interaction between water replenishment levels and nitrogen rates exhibited significance in terms of leaf dry biomass in mini-watermelon plants (Table 6). Independently, water replenishment levels had a significant effect on dry biomass of root, stem, total, and shoot, while nitrogen rates exhibited no substantial influence on the measured variables.

Table 6
Summary of analysis of variance for dry biomass of root (RDB), stem (SDB), leaf (LDB), total (TDB), and shoot (ShDB), and root/shoot ratio (R/S) of mini-watermelon under water replenishment levels and nitrogen doses, at 76 days after sowing

Source of variation	DF	Mean square					
		RDB	SDB	LDB	TDB	ShDB	R/S
Water replenishment (WR)	3	0.542*	8.590**	99.924**	182.881**	165.422**	0.000^{ns}
Linear regression	1	1.545**	23.057**	220.280**	436.401**	385.979**	0.000^{ns}
Quadratic regression	1	0.002^{ns}	1.417^{ns}	63.365^{ns}	82.766^{ns}	83.740^{ns}	0.000^{ns}
Nitrogen rates (NR)	3	0.116^{ns}	0.042^{ns}	3.127^{ns}	2.560^{ns}	2.866^{ns}	0.000^{ns}
Linear regression	1	0.300^{ns}	0.120^{ns}	2.530^{ns}	0.770^{ns}	1.550^{ns}	0.000^{ns}
Quadratic regression	1	0.000^{ns}	0.000^{ns}	4.590^{ns}	4.450^{ns}	4.880^{ns}	0.001^{ns}
Interaction (WR × NR)	9	0.112^{ns}	0.830^{ns}	6.418*	6.989^{ns}	6.523^{ns}	0.000^{ns}
CV (%)		42.36	13.63	17.92	12.74	13.40	44.40

ns, *, **, not significant, significant at $p \leq 0.05$ and $p \leq 0.01$, respectively. CV = coefficient of variation.

Increasing water replenishment levels led to a linear augmentation in stem, root, total, and shoot dry biomass of mini-watermelon plants (Figures 10A, 10B, 10C, and 10D), corresponding to a 4.10, 0.88, 1.88, and 1.81% increase in ETr, respectively. When comparing stem, root, total, and shoot dry biomass of plants irrigated at 125% ETr to those under 50% ETr, the increases amounted to 53.13%, 32.63%, 42.10%, and 41.57%, respectively. As noted by Hong et al. (2022), dry matter accumulation in watermelon plants tends to rise with increased water availability until reaching a point of stability with rising irrigation levels, which aligns with the biomass accumulation outcomes of our study.

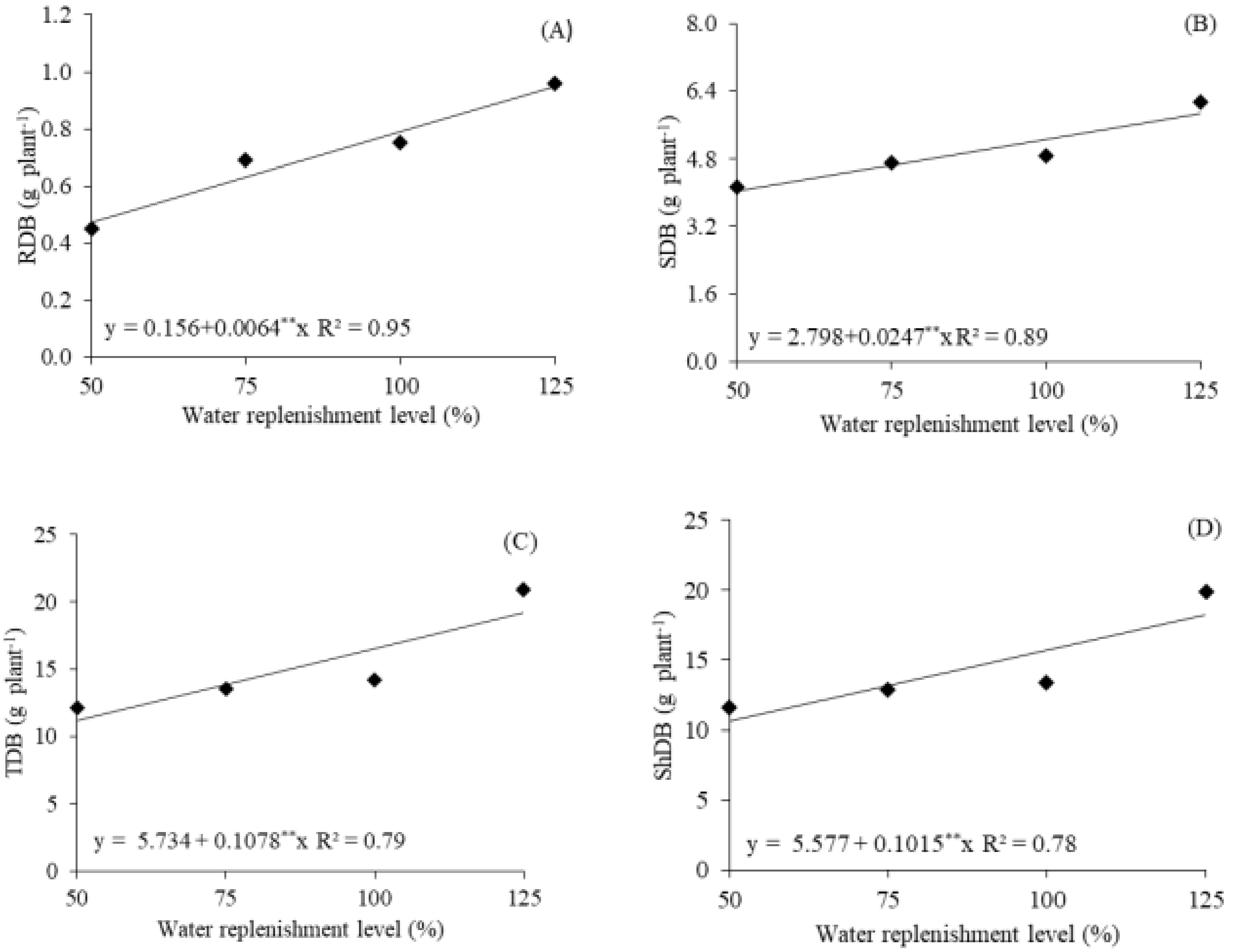

Figure 10. Dry biomass of root (RDB, A), stem (SDB, B), total (TDB, C), and shoot (ShDB, D) of mini-watermelon plants as a function of water replenishment levels, at 76 days after sowing.

The escalation in biomass accumulation in mini-watermelon plants, driven by increased water availability, is directly linked to its role in numerous physiological and biochemical processes. These include increased turgor pressure, enhanced nutrient transport, and subsequent plant growth (Ahmad et al., 2021). Notably, irrigation at 125% ETr yielded higher photosynthesis rates, resulting in greater biomass accumulation within plant organs. Similar findings were reported by M. E. B. Brito et al. (2015) in their investigation of tomato crop subjected to varying irrigation levels (60, 80, 100, and 120% ETr), where increased irrigation levels fostered growth in root and stem dry biomass.

A study by A. S. de Lima et al. (2017) on watermelon seedling production under irrigation amounts of 100% and 50% ETr found that plants irrigated at 50% ETr exhibited the lowest total dry biomass accumulation. Similarly, Aragão et al. (2011) noted an increase in the measured shoot's dry biomass with irrigation levels elevated from 50% to 125% ETr.

For leaf dry biomass (Figure 11), plants cultivated under 125% ETr irrigation and a nitrogen rate of 50% of the recommendation attained the maximum value of 14.26 g per plant. Conversely, the lowest leaf dry biomass (6.83 g per plant) was observed in plants subjected to 69% ETr irrigation and a nitrogen rate of 97%. The increased accumulation of leaf dry biomass is a direct consequence of augmented water availability and nitrogen rates, influencing cell growth, turgor pressure, and increased photosynthetic activity. This is evident through stomatal opening, carbon fixation, and consequently, biomass accumulation (Díaz-Pérez & Hook, 2017).

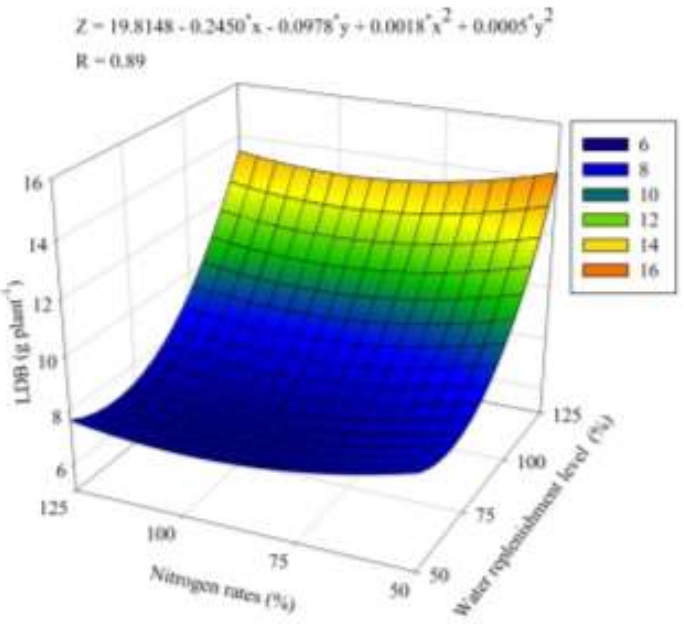

Figure 11. Leaf dry biomass of mini-watermelon plants as a function of the interaction between water replenishment levels and nitrogen rates, at 76 days after sowing.
X and Y- Nitrogen rates and Water replenishment levels, respectively.

Conclusions

Deficit irrigation at 50% of actual evapotranspiration inhibits gas exchange, the synthesis of photosynthetic pigments, growth, and fruit quality in 'Sugar Baby' mini-watermelon, regardless of nitrogen rate.

Irrigating at 125% of evapotranspiration in combination with fertilization at 100% of the recommended nitrogen rate yields higher values for total chlorophyll content; number of leaves, dry biomass of root, stem, total, and shoot as well as the pH of 'Sugar Baby' mini-watermelon fruit pulp.

References

Ahmad, S., Muhammad, I., Wang, G. Y., Zeeshan, M., Yang, L., Ali, I., & Zhou, X. B. (2021). Ameliorative effect of melatonin improves drought tolerance by regulating growth, photosynthetic traits and leaf ultrastructure of maize seedlings. *BMC Plant Biology, 21*(1), 1-14. doi: 10.1186/s12870-021-03160-w

Andrade, A. D., Cruz, A. D. S., Cavalcante, E. D. S., Albuquerque, J. D., & Souza, W. D. (2013). Estimativa da evapotranspiração e dos coeficientes de cultura para diferentes fases de desenvolvimento da melancia. *Revista Brasileira de Geografia Física, 6*(5), 1417-1429.

Anjos, R. A., Santos, M. A. R., Oliveira, M. X. de, Jr., Bezerra, F. V., Neto, Bezerra, F. V., Neto, Amaral, A. M., & Santos, M. Â. C. M. dos. (2022). Qualidade de frutos de melancia sob diferentes dosagens de adubação nitrogenada. *Research, Society and Development, 11*(2), 1-7. doi: 10.33448/rsd-v11i2.25993

Aragão, V. F., Fernandes, P. D., Gomes, R. R., Fº., Santos, A. M. dos, Neto, Carvalho, C. M., & Feitosa, H. O. (2011). Efeito de diferentes lâminas de irrigação e níveis de nitrogênio em ambiente protegido. *Revista Brasileira de Agricultura Irrigada, 5*(4), 361-375. doi: 10.7127/rbai.v5n400043

Barros, M. M., Araújo, W. F., Neves, L. T. B. C., Campos, A. J. de, & Tosin, J. M. (2012). Produção e qualidade da melancia submetida a adubação nitrogenada. *Revista Brasileira de Engenharia Agrícola e Ambiental, 16*(10), 1078-1084. doi: 10.1590/S1415-43662012001000007

Benevides, S. D., Ramos, A. M., & Stringheta, P. C. (2008). Qualidade da manga e polpa de manga Ubá. *Ciência e Tecnologia de Alimentos, 28*(1), 571-578. doi: 10.1590/S0101-20612008000300011

Bernardo, S., Mantovani, E. C., Silva, D. D. da, & Soares, A. A. (2019). *Manual de irrigação* (9a ed.). UFV.

Bezerra, R. U. (2017). *Cultivo da abóbora maranhão sob dosagens de nitrogênio e lâminas de irrigação diferenciadas.* Dissertação de mestrado, Universidade Federal do Ceará, Fortaleza, CE, Brasil.

Bezerra, R. U., Viana, T. V. de A., Azevedo, B. M. de, Pereira, J. V., Fº., & Lima, A. D. (2020). Produção e qualidade da abóbora maranhão sob influência de lâminas de irrigação e doses de nitrogênio. *Irriga, 25*(1), 87-101. doi: 10.15809/irriga.2020v25n1p87-101

Brito, H. C., Brito, Y. M. A. de, & Rufino, I. A. A. (2022). O índice de segurança hídrica do Brasil e o semiárido brasileiro: desafios e riscos futuros. *Revista Brasileira de Cartografia, 74*(1), 1-15. doi: 10.14393/rbcv 74n1-60928

Brito, M. E. B., Soares, L. A. dos A., Lima, G. S. de, Sá, F. V. da S., Araújo, T. T., & Silva, E. C. B. da. (2015). Crescimento e formação de fitomassa do tomateiro sob estresse hídrico nas fases fenológicas. *Irriga, 20*(1), 139-153. doi: 10.15809/irriga.2015v20n1p139

Campos, A. J. de M., Santos, S. M., & Nacarath, I. R. F. F. (2021). Estresse hídrico em plantas: uma revisão. *Research, Society and Development, 10*(15), 1-10. doi: 10.33448/rsd-v10i15.23155

Carnicel, J. L. da S., Oliveira, E. L., Mota, I. F. de, Peixoto, F. da C., Souza, T. S. de, Rangel, R. P., & Santos, J. D. (2020). Implantação de unidades experimentais do cultivo protegido de melancia no projeto de assentamentos agroecológicos do extremo sul da Bahia. *Cadernos de Agroecologia, 15*(2), 1-4.

Cavalcante, R. R., Tavares, A. T., Mendes, F. C., Cerqueira, F. B., & Nascimento, I. R. (2017). Características pós-colheita de frutos partenocárpicos de melancia obtidos com uso de 2,4-D. *Brazilian Journal of Applied Technology for Agricultural Science, 10*(1), 51-57. doi: 10.5935/PAeT.V10.N1.05

Correia, C. M., Pereira, J. M. M., Coutinho, J. F., Bjorn, L. O., & Torres-Pereira, J. M. G. (2005). Ultraviolet-B radiation and nitrogen affect the photosynthesis of maize: a Mediterranean field study. *European Journal of Agronomy, 22*(3), 337-347. doi: 10.1016/j.eja.2004.05.002

Dal Mora, M. R., Rocha, R. R., Diamante, M. S., Guedes, S. F., & Seabra, S., Jr. (2021). Atributos físico-químicos e bioquímicos de melancia vermelha e amarela minimamente processada, durante o armazenamento. *Scientific Electronic Archives, 14*(12), 13-21. doi: 10.36560/141220211455

Dias, A. S., Lima, G. S. de, Pinheiro, F. W. A., Gheyi, H. R., & Soares, L. A. dos A. (2019). Gas exchanges, quantum yield and photosynthetic pigments of West Indian cherry under salt stress and potassium fertilization. *Revista Caatinga, 32*(2), 429-439. doi: 10.1590/1983-21252019v32n216rc

Díaz-Pérez, J. C., & Hook, J. E. (2017). Plastic-mulched bell pepper (Capsicum annuum L.) plant growth and fruit yield and quality as influenced by irrigation rate and calcium fertilization. *American Society for Horticultural Science, 52*(5), 774-781. doi: 10.21273/HORTSCI11830-17

Fageria, N. K., & Carvalho, M. C. S. (2014). Comparison of conventional and polymer coated urea as nitrogen sources for lowland rice production. *Journal of Plant Nutrition, 37*(1), 1358-1371. doi: 10.1080/019041 67.2014.888736

Fátima, R. T. de, Jesus, E. G. de, Guerrero, A. C., Rocha, J. L. A., & Brito, M. E. B. (2019). Adubação silicatada como atenuante do estresse hídrico no crescimento e trocas gasosas do alface. *Revista Engenharia na Agricultura, 27*(2), 170-178. doi: 10.13083/reveng.v27i2.892

Fernandes, E. A., Soares, L. A. dos A., Lima, G. S. de, Silva, A. M. de S., Neta, Roque, I. A., Silva, F. A. da, Fernandes, P. D., & Lacerda, C. N. de. (2021). Cell damage, gas exchange, and growth of *Annona squamosa* L. under saline water irrigation and potassium fertilization. *Semina: Ciências Agrárias, 42*(3), 999-1018. doi: 10.5433/1679-0359.2021v42n3p999

Ferreira, D. F. (2019). Sisvar: a computer analysis system to fixed effects split-plot type designs. *Revista Brasileira de Biometria, 37*(4), 529-535. doi: 10.28951/rbb.v37i4.450

Hong, T., Cai, Z., Li, R., Liu, J., Li, J., Wang, Z., & Zhang, Z. (2022). Effects of water and nitrogen coupling on watermelon growth, photosynthesis and yield under CO_2 enrichment. *Agricultural Water Management, 256*(1), 107229. doi: 10.10 16/j.agwat.2021.107229

Instrução Normativa nº 37. Ministério as Agricultura e do Abastecimento (2018). *Regulamento técnico geral para fixação dos padrões de identidade e qualidade para polpa de fruta.* https://www.in.gov.br/materia/-/asset_publisher/Kujrw0TZC2Mb/content/id/44304988/do1-2018-10-08-instrucao-normativa-n-37

Jacinto, S. G., Jr., Moraes, J. G. L., Silva, F. do B. D., Silva, B. do N., Sousa, G. G. de, Oliveira, L. L. B. de, & Mesquita, R. O. (2019). Respostas fisiológicas de genótipos de fava (*Phaseolus lunatus* L.) submetidas ao estresse hídrico cultivadas no Estado do Ceará. *Revista Brasileira de Meteorologia, 34*(3), 413-422. doi: 10.1590/0102-778 6343047

Kluge, R. A., Tezotto-Uliana, J. V., & Silva, P. P. da. (2015). Aspectos fisiológicos e ambientais da fotossíntese. *Revista Virtual de Química, 7*(1), 56-73. doi: 10.5935/1984-6835.20150004

Kováčik, J., Dresler, S., Peterková, V., & Babula, P. (2020). A nutrição nitrogenada modula o estresse oxidativo e a produção de metabólitos em *Hypericum perforatum. Protoplasma, 25*(1), 439-447. doi: 10. 1007/s00709-019-01448-1

Li, H., Liu, H., Pang, J., Li, S., Cui, Y., & Sun, J. (2023). Effects of water and nitrogen interaction on growth and nutrient accumulation of potted tomatoes. *Transactions of the Chinese Society for Agricultural Machinery, 9*(1), 272-279.

Lichtenthaler, H. K. (1987). Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. *Plant Cell Membranes, 148*(1), 350-382. doi: 10.1016/0076-68 79(87)48036-1

Lima, A. S. de, Alves, J. de M., Silva, F. L. de, Santos, J. da M., Mesquita, E. F., & Guerra, H. O. C. (2017). Substratos e níveis de reposição de água na produção de mudas de melancia. *Revista Brasileira de Agricultura Irrigada, 11*(7), 2010-2021. doi: 10.7127/rbai.v11n700670

Lima, G. S. de, Dias, A. S., Gheyi, H. R., Soares, L. A. dos A., & Andrade, E. M. G. (2018). Saline water irrigation and nitrogen fertilization on the cultivation of colored fiber cotton. *Revista Caatinga, 31*(1), 151-160. doi: 10.1590/1983-21252018v31n118rc

Lima, G. S. de, Félix, C. M., Silva, S. S. da, Soares, L. A. dos A., Gheyi, H. R., Soares, M. D. M., Sousa, P. F. do N., & Fernandes, P. D. (2020). Gas exchange, growth, and production of mini-watermelon under saline water irrigation and phosphate fertilization. *Semina: Ciências Agrárias, 41*(6), 3039-3052. doi: 10.5433/1679- 03 59.2020v41n6Supl2p3039

Lima, G. S. de, Nobre, R. G., Gheyi, H. R., Soares, L. A. dos A., & Silva, S. S. da. (2014). Respostas morfofisiológicas da mamoneira, em função da salinidade da água de irrigação e adubação nitrogenada. *Irriga, 19*(1), 130-136. doi: 10.15809/irriga.2014v19n1p130

Malavolta, E. (2006). *Manual de nutrição mineral de plantas.* Ceres.

Martins, A. C. (2018). *Alterações fisiológicas e bioquímicas em plantas de Macroptilium lathyroides (L.) Urb submetidas ao déficit hídrico e diferentes fontes de nitrogênio.* Tese de doutorado, Universidade Federal de Pelotas, Pelotas, RS, Brasil.

Matos, H. A., Fº., & Carvalho, R. de C. M. (2020). Análise de carboidratos solúveis em plantas de arroz. *Científic@ Multidisciplinary Journal, 7*(1), 1-8. doi: 10.29247/2358-260X.2020v7i1.4118

Melo, R. E. de, Silva, A. E. B. da, & Silva, J. R. da. (2022). Turnos de rega e polímero hidro retentor na qualidade de frutos de melancia em condições de semiárido. *Revista Eletrônica Científica Inovação e Tecnologia, 12*(31), 22-33. doi: 10.3895/recit.v12i31.15027

Mendes, B. S. da S., Willadino, L., Cunha, P. C. da, Oliveira, R. A. de, Fº., & Camara, T. R. (2011). Mecanismos fisiológicos e bioquímicos do abacaxi ornamental sob estresse salino. *Revista Caatinga, 24*(3), 71-77.

Mesquita, A. C., Ferreira, K. M., Souza, V. de, Campos, L. D. A., & Yuri, J. E. (2017). Crescimento do meloeiro sob diferentes lâminas de irrigação e doses de nitrogênio. *Anais do Congresso Brasileiro de Agrometeorologia; Simpósio de Mudanças Climáticas e Desertificação no Semiárido Brasileiro,* Juazeiro, BA, Brasil, 20, 5.

Nascimento, N. V. D. (2016). *Déficit hídrico em diferentes estádios fisiológicos da melancieira: efeitos em seu crescimento, produção e qualidade dos frutos.* Tese de doutorado, Universidade Federal de Campina Grande, Campina Grande, PB, Brasil.

Nóbrega, J. S., Bezerra, A. C., Ribeiro, J. E. da S., Silva, E. C. da, Silva, T. I. da, Costa, R. N. M., Silva, A. V. da, Lopes, A. S., & Dias, T. J. (2021). Growth and gas exchange of purple basil submitted to salinity and foliar nitrogen fertilization. *Journal of Plant Nutrition, 44*(18), 2729-2738. doi: 10.1080/01904167.2021. 1927080

Novais, R. F., Neves, J. C. L., & Barros, N. F. (1991). Ensaio em ambiente controlado. In A. J. Oliveira, *Métodos de pesquisa em fertilidade do solo* (pp. 189-253). Brasília: EMBRAPA Informação Tecnológica.

Oliveira, R. F. de, Silva, E. S. da, Carmo, I. L. G. da S., Monteiro, J. L. L., Neto, Medeiros, R. D. de, & Abanto-Rodriguez, C. (2018). Plantas de cobertura e doses de nitrogênio no cultivo da melancia na savana de Roraima, Brasil. *Scientia Agropecuaria, 9*(4), 477-484. doi: 10.17268/sci.agropecu.2018.04.02

Oliveira, R. M. de, Oliveira, R. A. de, Vidigal, S. M., Oliveira, E. M. de, Guimarães, L. B., & Cecon, P. R. (2019). Produção e produtividade da água do couve-flor sob lâminas de irrigação e doses de nitrogênio. *Revista Brasileira de Engenharia Agrícola e Ambiental, 23*(8), 561-565. doi: 10.1590/1807-1929/agriambi.v23n8p561-565

Oliveira, Z. V. S. R., Mesquita, A. C., Simões, W. L., Salviano, A. M., Silva, J. S. da, & Felix, A. T. R. (2022). Trocas gasosas e análises bioquímicas em variedades de melancia sob cultivo orgânico no semiárido nordestino. *Scientia Plena, 18*(9), 1-14. doi: 10.14808/sci.plena.2022.090202

Pacheco, H., & Rodrigues, L. N. (2022). Reúso de água de piscicultura na irrigação de melancia (*Citrullus lanatus* Thunb.) cultivada em sistema de produção de base ecológica. *Research, Society and Development, 11*(3), 1-16. doi: 10.33448/rsd-v11i3.326710

Pereira, W. de B., Possídio, C. E. F., Sousa, J. S. C. de, Simões, W. L., & Santos, C. M. G. (2021). Produção e qualidade de melões sob diferentes arranjos do sistema de irrigação e coberturas do solo. *Revista*

Brasileira de Meteorologia, 36(2), 285-294. doi: 10.1590/0102-7786362012

Pinheiro, F. W. A., Lima, G. S. de, Gheyi, H. R., Soares, L. A. dos A., Oliveira, S. G. de, & Silva, F. A. da (2022). Gas exchange and yellow passion fruit production under irrigation strategies using brackish water and potassium. *Revista Ciência Agronômica, 53*(1), e20217816. doi: 10.5935/1806-6690.20220009

Pompeu, R. C. F. F., Cândido, M. J. D., Lopes, M. N., Gomes, F. H. T., Lacerda, C. F. de, Aquino, B. F., & Magalhães, J. A. (2010). Características morfofisiológicas do capim-aruana sob diferentes doses de nitrogênio. *Revista Brasileira de Saúde e Produção Animal, 11*(4), 1187-1210.

Pôrto, M. L. A., Puiatti, M., Fontes, P. C. R., Cecon, P. R., Alves, J. do C., & Arruda, J. A. de. (2012). Produtividade e acúmulo de nitrato nos frutos de abobrinha em função da adubação nitrogenada. *Bragantia, 71*(2), 190-195. doi: 10.1590/S0006-87052012005000020

Rocha, I. T. M., Silva, A. V. da, Freire, F. J., Oliveira, E. C. A. de, Souza, E. R. de, & Endres, L. (2023). Biochemical differences in the initial growth of sugarcane varieties cultivated under different potassium doses and water conditions. *Revista Caatinga, 36*(1), 61-69. doi: 10.1590/1983-21252023v36n107rc

Rocha, P. H. F., Barbacena, D. R., França, L. C., Gonçalves, R. C., Nascimento, C. A. C., Leal, F., & Adorian, G. C. (2020). Crescimento e marcha de acúmulo de nutrientes em melancia cv. Top gun em varzéa irrigada no Tocantins. *Agri-environmental Sciences, 6*(1), 1-10. doi: 10.36725/agries.v6i0.1723

Sá, F. V. da S., Gheyi, H. R., Lima, G. S. de, Paiva, E. P. de, Silva, L. de A., Moreira, R. C. L., Fernandes, P. D., & Dias, A. S. (2019a). Ecophysiology of West Indian cherry irrigated with saline water under phosphorus and nitrogen doses. *Bioscience Journal, 35*(1), 211-221. doi: 10.14393/BJ-v35n1a2019-41 742

Sá, F. V. da S., Mesquita, E. F. de, Souza, F. M. de, Ferreira, D. da S., Ferreira, A. R. de S., & Alves, A. de S. (2019b). Crescimento de mudas de pepino sob restrição hídrica e doses de esterco bovino. *Revista Brasileira de Agricultura Irrigada, 13*(4), 3568-3577. doi: 10.7127/RBAI.V13N4001084

Santos, J. B. dos, Centeno, C. R. M., Azevedo, C. A. V. de, Gheyi, H. R., Lima, G. S. de, & Lira, V. M de (2017). Crecimiento del girasol (*Helianthus annuus* L.) en función de la salinidad del agua de riego con fertilización nitrogenada. *Agrociência, 51*(6), 649-660.

Santos, P. L. F. dos, Castilho, R. M. M. de, & Gazola, R. P. D. (2019). Pigmentos fotossintéticos e sua correlação com nitrogênio e magnésio foliar em grama bermuda cultivada em substratos. *Acta Iguazu, 8*(1), 92-101. doi: 10.48075/actaiguaz.v8i1.18357

Saud, S., Fahad, S., Yajun, C., Ihsan, M. Z., Hammad, H. M., Nasim, W., Alharby, H., Arif, M., & Alharby, H. (2017). Effects of nitrogen supply on water stress and recovery mechanisms in Kentucky bluegrass plants. *Frontiers in Plant Science, 8*(983), 1-18. doi: 10.3389/fpls.2017.00983

Scotti-Campos, P., Pham-Thi, A., Semedo, J. N., Pais, I. P., Ramalho, J. C., & Matos, M. do C. (2013). Physiological responses and membrane integrity in three Vigna genotypes with contrasting drought tolerance. *Emirates Journal of Food and Agriculture, 25*(12), 1002-1013. doi: 10.9755/ejfa.v25i12.16733

Silva, A. A. R. da, Sousa, P. F. do N., Lima, G. S. de, Soares, L. A. dos A., Gheyi, H. R., & Azevedo, C. A. V. de. (2022b). Hydrogen peroxide reduces the effect of salt stress on growth and postharvest quality of hydroponic mini watermelon. *Water, Air, & Soil Pollution, 233*(1), e198. doi: 10.1007/s11270-022-0566 9-8

Silva, D. R. M., Cunha, C. S. M., & Felipe, E. A. (2014). Aspectos vegetativos e reprodutivos para a cultura da melancia sob diferentes coberturas de solo e níveis de irrigação em Teresina-PI. *Agropecuária Científica no Semiárido, 10*(2), 96-103.

Silva, J. R. I., Souza, E. S. de, Souza, R., Santos, E. S. dos, & Antonino, A. C. D. (2019a). Efeito de diferentes usos do solo na erosão hídrica em região semiárida. *Revista Engenharia na Agricultura, 27*(3), 272-283. doi: 10.13083/reveng.v27i3.867

Silva, S. S. da, Lima, G. S. de, Lima, V. L. A. de, Gheyi, H. R., Soares, L. A. dos A., & Oliveira, J. P. M. (2022a). Production and post-harvest quality of mini-watermelon crop under irrigation management strategies and potassium fertilization. *Revista Brasileira de Engenharia Agrícola e Ambiental, 26*(1), 51-58. doi: 10.1590/1807-1929/agriambi.v26n1p51-58

Silva, S. S. de, Lima, G. S. de, Lima, V. L. A. de, Soares, L. A. dos A., Gheyi, H. R., & Fernandes, P. D. (2021). Quantum yield, photosynthetic pigments and biomass of mini watermelon under irrigation strategies and potassium. *Revista Caatinga, 34*(3), 659-669. doi: 10.1590/1983-21252021v34n318rc

Silva, S. S., Lima, G. S. de, Lima, V. L. A. de, Gheyi, H. R., Soares, L. A. dos A., & Lucena, R. C. M. (2019b). Gas exchanges and production of watermelon plant under salinity management and nitrogen fertilization. *Pesquisa Agropecuária Tropical, 49*(1), e54822. doi: 10.1590/1983-40632019v4954822

Soares, L. A. dos A., Brito, M. E. B., Araújo, T. T. de, Sá, F. V. da S., & Silva, E. C. B. (2013). Morfofisiologia e qualidade pós-colheita do tomateiro sob estresse hídrico nas fases fenológicas. *Revista Verde de Agroecologia e Desenvolvimento Sustentável, 8*(1), 239-246. doi: 10.18378/rvads.v8i1.2001

Soares, L. A. dos A., Felix, C. M., Lima, G. S. de, Gheyi, H. R., Silva, L. de A., & Fernandes, P. D. (2023). Gas exchange, growth, and production of cotton genotypes under water deficit in phenological stages. *Revista Caatinga, 36*(1), 145-157. doi: 10.1590/1983-21252023v36n116rxc

Soares, L. A. dos A., Fernandes, P. D., Lima, G. S. de, Suassuna, J. F., & Pereira, R. F. (2018). Gas exchanges and production of colored cotton irrigated with saline water at different phenological stages. *Revista Ciência Agronômica, 49*(2), 239-248. doi: 10.5935/1806-6690.20180027

Soares, L. A. dos A., Lima, G. S. de, Chaves, L. H. G., Xavier, D. A., Fernandes, P. D., & Gheyi, H. R. (2015). Fitomassa e produção do girassol cultivado sob diferentes níveis de reposição hídrica e adubação potássica. *Revista Brasileira de Engenharia Agrícola e Ambiental, 19*(4), 336-342. doi: 10.1590/1807-1929/agriambi.v19n4p336-342

Sullivan, C. Y. (1972). Mechanisms of heat and drought resistance in grain sorghum and methods of measurement. In N. G. P. Rao, & L. R. House (Eds.), *Sorghum in the seventies* (v.1, cap.1, pp. 247-264). New Delhi, NCP: Oxford & IBH Publishing Co.

Taiz, L., Zeiger, E., Moller, I., & Murphy, A. (2017). *Fisiologia e desenvolvimento vegetal* (6a ed.). Artmed.

Teixeira, P. C., Donagemma, G. K., Fontana, A., & Teixeira, W. G. (2017). *Manual de métodos de análise de solo.* EMBRAPA.

Ullah, H., Santiago-Arenas, R., Ferdous, Z., Attia, A., & Datta, A. (2019). Improving water use efficiency, nitrogen use efficiency, and radiation use efficiency in field crops under drought stress: a review. *Advances in Agronomy, 156*(1), 109-157. doi: 10.1016/bs.agron.2019.02.002

Weatherley, P. E. (1950). Studies in the water relations of the cotton plant. I - The field measurements of water deficits in leaves. *New Phytologist, 49*(1), 81-97. doi: 10.1111/j.1469-8137.1950.tb05146.x