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Impact of solar irradiance on gas exchange and growth of heliconia grown in a semi-arid region[1]

Impacto da irradiância solar nas trocas gasosas e crescimento de helicônias cultivadas em região semiárida

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HIGHLIGHTS:

The photosynthetic behavior of the studied heliconia genotypes is not influenced by the light condition.
Plants of H. psittacorum *cv. Golden Torch and cv. Red Opal are tolerant to high solar irradiations.*
The shaded environment offers suitable conditions for the growth of heliconia during the vegetative stage.

ABSTRACT: Light is essential for providing energy for photosynthetic reactions and has a complex and not yet fully understood effect on heliconia growth and yield. Thus, the objective of this study was to evaluate the effect of light intensity on the growth and photosynthesis of heliconia under semi-arid conditions and to screen potential genotypes tolerant to high solar irradiation levels during the vegetative stage. The experiment was conducted in Petrolina, PE, Brazil, whose geographic coordinates are 09° 19' 14" S, 40° 32' 40" W, with an average altitude of 387 m. The experimental design used was in randomized blocks, arranged in a split-plot scheme, and the treatments were composed of two light intensities (full sun and 50% shading) and five genotypes (*Heliconia psittacorum* x *H. spathocircinata* cv. Golden Torch; *H. psittacorum* cv. Red Opal; *H. bihai* cv. Lobster Claw Two; *H. rauliniana* and *H. rostrata*). Growth and gas exchange assessments were conducted on the 100th day after the trial initiation. Light intensity (full sun and 50% shading) did not influence the rates of photosynthesis (A), stomatal conductance (gs), or transpiration (E) of plants. However, the isolated effect of the genotype revealed that plants of cv. Red Opal, *H. bihai*, *H. rauliniana*, and cv. Golden Torch had higher values of A, gs, and E. Overall, shading improved plant growth. We conclude that the genotypes *H. psittacorum* cv. Red Opal, and *H. psittacorum* cv. Golden Torch exhibited the greatest tolerances to high solar irradiance conditions.

Key words: *Heliconia* spp., photosynthesis, tropical floriculture, light stress

RESUMO: A luz é essencial por fornecer energia para as reações fotossintéticas e tem uma influência complexa e não totalmente compreendida no crescimento e produção de helicônias. Assim, objetivou-se avaliar o efeito da intensidade de luz sobre o crescimento e fotossíntese de helicônias em condições semiáridas e a triagem de genótipos potenciais tolerantes as condições de altos níveis de irradiação solar durante o estágio vegetativo. O experimento foi conduzido em Petrolina-PE, Brasil, cujas coordenadas geográficas são: 09° 19' 14" S, 40° 32' 40" O, com altitude média de 387 m. O delineamento experimental utilizado foi em blocos casualizados, arranjados em esquema de parcelas subdivididas, e os tratamentos foram compostos por duas intensidades de luz (pleno sol e sombreamento de 50%) e cinco genótipos (*Heliconia psittacorum* x *H. spathocircinata* cv. Golden Torch; *H. psittacorum* cv. Red Opal; *H. bihai* cv. Lobster Claw Two; *H. rauliniana* e *H. rostrata*). No 100° dia após o início do experimento foram realizadas avaliações de crescimento e trocas gasosas. As intensidades de luz (pleno sol e sombreamento 50%) não influenciaram a taxa fotossintética (A), condutância estomática (gs) e transpiração (E) das plantas. Porém, o efeito isolado do genótipo revela que plantas de cv. Red Opal, *H. bihai*, *H. rauliniana* e cv. Golden Torch apresentaram maiores valores de A, gs e E. Em geral, o sombreamento favoreceu maior incremento no crescimento das plantas. Conclui-se que os genótipos *H. psittacorum* cv. Red Opal e *H. psittacorum* cv. Golden Torch exibem maior tolerância às condições de elevada irradiância solar.

Palavras-chave: *Heliconia* spp., fotossíntese, floricultura tropical, estresse luminoso

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Introduction

The State of Pernambuco is one of Brazil's main producers of tropical flowers in Brazil, mainly heliconia (Marulanda et al., 2018). The demand for these species has increased; however, production does not meet this demand (Linares-Gabriel et al., 2020). Therefore, there is a demand to expand the cultivation of these species to other regions, such as the São Francisco Valley, presenting an opportunity for economic diversification in the region.

Solar radiation is a component of climate that plays a key role in crop productivity. In addition, 90% of plant biomass production is generated in response to photosynthetic activity. However, when luminosity or amount of solar radiation exceeds the plant demand, it can cause photoinhibition and restrict growth (Brelsford et al., 2019). Previous studies have shown that high levels of light irradiation are common in semi-arid regions and impair' the growth, development, and productivity of some species (Souza et al., 2016; Silva et al., 2018; Nihad et al., 2019).

In this sense, the evaluation of gas exchange and growth parameters is fundamental because they will enable an understanding of the mechanisms of adjustment to different light conditions, the selection of better genotypes, and the implementation of techniques and management that allow cultivation in regions with high levels of solar irradiation, such as the region of São Francisco Valley (Santos et al., 2022; Silva et al., 2022).

The objective of this study was to evaluate the effect of light intensity on the growth and photosynthesis of heliconia under semi-arid conditions and to screen potential genotypes tolerant to high solar irradiation levels during the vegetative stage.

Material and Methods

The experiment was conducted in Petrolina, PE, Brazil, whose geographic coordinates are 09° 19' 14" S, 40° 32' 40" W, with an average altitude of 387 m. According to the Köppen classification, the regional climate is BSwh (Alvares et al., 2013). The meteorological data obtained during the experimental period (August to December 2021) were recorded by a meteorological station and are shown in Figures 1A and 1B.

The treatments comprised two light environments (full sun and 50% shade) and five Heliconia genotypes (*H. psittacorum* x *H. spathocircinata* cv. Golden Torch, *H. psittacorum* cv. Red Opal, *H. bihai* cv. Lobster Claw Two, *H. rauliniana*, and *H. rostrata*). The experimental design was a randomized block in a split-plot scheme with six repetitions and one plant per plot.

For seedling production, rhizomes were washed and disinfected with water and sodium hypochlorite (NaCl, 1% active chlorine) and standardized to a length of 20 cm, with two buds per rhizome. Subsequently, they were grown in plastic pots (5 L) with a mixture of sand and bovine manure (1:1) as the substrate, irrigated daily using micro-sprinklers, and kept under a 50% shaded roof.

Soil samples were collected from the 0–20 cm layer of the respective treatments. The results of the analysis are presented in Table 1.

The seedlings were transplanted to the respective treatment plots after three months when they exhibited two or three fully expanded leaves. They were placed in holes with dimensions of 20 × 20 × 20 cm (width × length × depth), with a spacing of 1.5 m between plants and 2.0 m between rows, and received basal fertilization by supplying 45 g of phosphorus (P) (Monoammonium Phosphate, 61% P_2O_5) and 2 L of the substrate used to prepare the seedlings per pit. A micro-sprinkler irrigation system with a nominal flow of 60 L h^{-1} was used, and irrigation was carried out daily until field capacity was reached.

Top dressing fertilization with nitrogen (N) and potassium (K) was performed according to the recommendations of

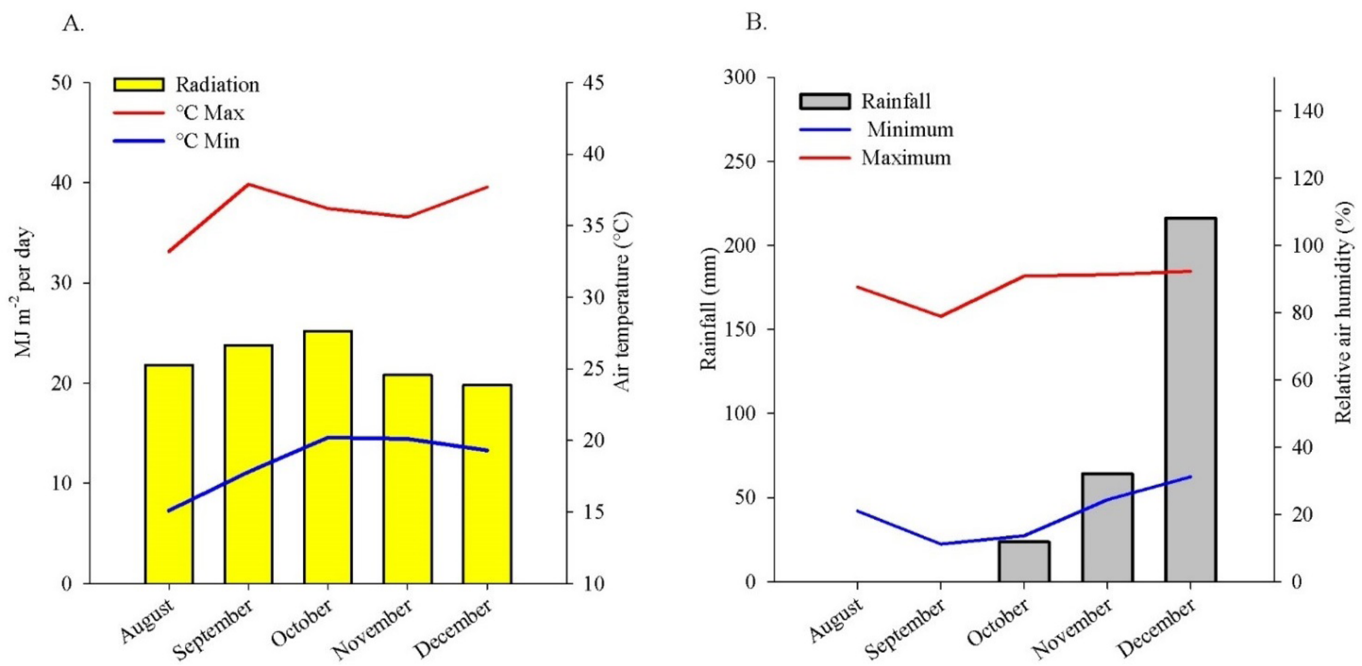


Figure 1. Average values of air temperature and global solar radiation (A) and relative air humidity and rainfall (B) during the experimental period

Table 1. Chemical composition of the soil in the experimental areas cultivated with heliconia species under different light intensities (full sun and 50% shading)

Areas	pH H_2O	K^+	Ca^{2+}	Mg^{2+}	Al^{3+}	H + Al	SB	T
		(cmol$_c$ dm^{-3})						
Full sun	6.06	0.50	1.64	0.97	0.0	0.86	3.39	4.25
Shading	5.92	0.30	2.25	0.77	0.0	0.82	3.43	4.25
	V (%)	P	Fe^{2+}	Mn^{2+}	Cu^{2+}	Zn^{2+}	OM (g kg^{-1})	
		(mg dm^{-3})						
Full sun	79.82	39.6	97.8	12.6	0.1	6.8	17.0	
Shading	80.78	26.5	110.0	22.4	0.1	2.5	17.8	

Abbreviations: K^+ - Potassium; Ca^{2+} - Calcium; Mg^{2+} - Magnesium; Al^{3+} - Exchangeable acidity; H + Al - Potential acidity at pH 7.0; SB - Sum of exchangeable bases; T - Cation exchange capacity at pH 7.0; P - Extraction with anion exchange resin; Fe^{2+} - Iron; Mn^{2+} - Manganese; Cu^{2+} - Copper; Zn^{2+} - Zinc; V - Base saturation; and, OM - Organic matter

Beckmann-Cavalcante et al. (2016), in which 120 g of N (calcium nitrate, 21% N and ammonium sulfate, 15.5% N) and 120 g of K (potassium sulfate, 50% K_2O) were applied three months after transplanting using a sowing rows, without incorporation. Furthermore, as a supplementary form and for the supply of micronutrients (boron, copper, manganese, and zinc), foliar fertilizer NIPHOKAM 10-08-08 (0.75 g L^{-1}) was sprayed, and manual weeding was performed to control weeds.

Growth and gas exchange assessments were conducted 100 days after transplanting (DAT). The number of leaves (NL), average tiller height (HEI, cm), and the number of tillers per clump (NT) were determined. The total leaf area per clump (TLA) was calculated using Eq. 1, as proposed by Zucoloto et al. (2008).

$$\mathrm{TLAe} = 0.5187\left(\mathrm{W}\times\mathrm{L}\times\mathrm{N}\right)+9,603.5 \quad (1)$$

where TLAe is the estimated total leaf area, W is the width, L is the length, and N is the total number of leaves.

Gas exchange assessments were performed using a portable infrared gas analyzer (IRGA, LI 6400 XT, LI-COR Biosciences, Lincoln, NE, USA). The photosynthetic photon flux density (PPFD) values of 1,800 μmol m^2 s^{-1} in full sun and 900 μmol m^2 s^{-1} in the shade indicated that the shade net reduced solar radiation by 50%. The IRGA was calibrated at a constant CO_2 concentration (300 ppm), and the light intensity used simulated the conditions of each environment, with values of 1800 and 900 μmol m $^{-2}$ s $^{-1}$, respectively, for environments in full sun and 50% shading to determine net photosynthesis (A), transpiration (E), stomatal conductance (gs), intercellular CO_2 concentration (Ci), apparent electron transport rate (ETR), vapor pressure deficit (VPD), and leaf temperature (LT). Measurements were taken between 9:00 and 11:00 a.m., and three plants of each species per treatment and three fully expanded leaves from the middle third of the plant were randomly used.

The data were subjected to analysis of variance (ANOVA), and the means were compared using Tukey's test at a significance level of 0.05. All tests were performed using Sisvar software (Ferreira, 2014), and graphs were created using SigmaPlot 11.0.

Results and Discussion

The variance analysis results did not indicate a significant interaction between light intensity and genotype (A × B) for any of the gas exchange parameters evaluated (Table 2).

The heliconia genotypes exhibited contrasting photosynthetic parameter responses independent of light conditions, with higher values of A and, consequently, gs and E obtained in plants of cv. Red Opal, followed by *H. bihai*, *H. rauliniana*, and cv. Golden Torch. In contrast, *H. rostrata* had the lowest A, gs, and E values (Table 2). In addition, we observed that cv. Red Opal, cv. Golden Torch, *H. bihai*, and *H. rostrata* showed lower values of VPD and, consequently, LT than *H. rauliniana* (Table 2). This result may be related to alterations or intrinsic morphoanatomical characteristics of these species, such as the accumulation of chemical compounds and the number and shape of stomata, which, according to Hertel et al. (2021), favor the leaf surface cooling process.

The light intensities affected only Ci, VPD, LT, and the Ci/Ca ratio (Table 2). Thus, it can be seen that plants grown in a shaded environment showed higher average LT and VPD than plants grown in full sun (Figures 2A and B).

A possible explanation for this response stems from the fact that shaded environments restrict air movement around plants. This causes a decrease in heat and gas conductance in the leaf boundary layer resulting in higher leaf temperature and, consequently, higher VPD (Grossiord et al., 2020).

The intercellular CO_2 concentration (C_i) (Figure 2C) and internal/external carbon concentration ratio (C_i/Ca) (Figure 2D) were higher in plants grown under the full sun than in plants grown in partial shade. Such responses demonstrate that, under these conditions, the plants may have activated morphoanatomical adjustment mechanisms that allowed a greater accumulation of CO_2 inside the leaf tissues, contributing to the maintenance of photosynthesis at rates similar to those in the shaded environment. For example, studies have demonstrated that species with a greater potential for acclimatization to conditions of high irradiance invest in morphoanatomical mechanisms such as increased palisade parenchyma, which enables greater accumulation of CO_2 and consequently increases photosynthesis (Hertel et al., 2021).

Regarding growth parameters, a significant interaction between light intensity and genotype (A × B) was observed only for the average tiller height (HEI) variable. We also found that the genotype evaluated alone significantly affected all parameters evaluated. The same was observed for light intensity, except for of the number of tillers (NT) (Table 3).

The plants of cv. Golden Torch and cv. Red Opal presented similar HEI results in both environments, whereas *H. bihai*, *H. rauliniana*, and *H. rostrata* showed significant reductions in growth under full sun conditions (Table 3). Another result that should be highlighted is that under full sun conditions, the genotypes evaluated alone had similar HEI values (Figure 3).

Table 2. Summary of the analysis of variance for photosynthetic parameters: net photosynthesis (A), stomatal conductance (gs), internal CO_2 concentration (Ci), apparent electron transport rate (ETR), vapor pressure deficit (VPD), leaf temperature (LT), transpiration (E), internal/external carbon concentration ratio (Ci/Ca), instantaneous carboxylation efficiency (A/Ci), and water use efficiency (A/gs) in heliconia species under different light intensities (full sun and shading-50%)

SV	Mean squares				
	A	gs	Ci	ETR	VPD
Light intensities (A)	2.44^{ns}	0.0070^{ns}	4318.77*	1.51^{ns}	1.18*
Blocks	8.02^{ns}	0.0019^{ns}	44.55^{ns}	1.20^{ns}	0.01*
Residue (A)	18.16	0.0058	125.55	2.41	0.00
Genotype (B)	43.37*	0.0161*	693.36^{ns}	3.89^{ns}	0.07*
A × B	21.94^{ns}	0.0057^{ns}	1,290.55^{ns}	2.33^{ns}	0.02^{ns}
Residue (B)	15.72	0.0026	467.16	2.04	0.01
CV $_{(a)}$ %	28.60	17.81	4.68	14.44	0.19
CV $_{(b)}$ %	26.60	12.08	9.02	13.29	2.76
	Genotypes averages				
	(mmol m^{-2} s^{-1})	(mol m^{-2} s^{-1})	(mmol m^{-1})	(mmol m^{-2} s^{-1})	(kPa)
H. rauliniana	16.35 ab	0.46 a	248.30 a	11.27 a	3.14 abc
cv. Golden Torch	14.14 ab	0.39 ab	224.43 a	10.73 a	3.17 ab
cv. Red Opal	18.02 a	0.48 a	241.07 a	11.51 a	3.00 c
H. bihai	15.15 ab	0.45 a	250.50 a	10.85 a	3.07 bc
H. rostrata	10.85 b	0.35 b	233.65 a	9.43 a	3.28 a
MSD	7.01	0.09	38.24	2.53	0.15
	Mean squares				
	LT	E	Ci/Ca	A/Ci	A/gs
Light intensities (A)	12.41*	0.076^{ns}	0.027**	0.0004^{ns}	1,412.2^{ns}
Blocks	0.05^{ns}	0.72^{ns}	0.001^{ns}	0.0001^{ns}	26.95^{ns}
Residue (A)	0.1519	3.89	0.002	0.0003	86.67
Genotype (B)	0.2601**	9.034*	0.020^{ns}	0.0007^{ns}	345.94^{ns}
A × B	0.19^{ns}	3.608^{ns}	0.031^{ns}	0.0006^{ns}	451.34^{ns}
Residue (B)	0.073	1.71	0.045	0.0003^{ns}	169.12
CV $_{(a)}$ %	1.09	32.17	5.30	28.97	11.33
CV $_{(b)}$ %	0.75	21.33	8.67	31.15	15.82
	Genotypes averages				
	(°C)	(mmol m^{-2} s^{-1})	(--)	(mol m^{-2} s^{-1} Pa^{-1})	(--)
H. rauliniana	36.10 a	7.16 a	0.637 a	0.067 a	75.81 a
cv. Golden Torch	35.77 ab	5.14 ab	0.573 a	0.064 a	92.40 a
cv. Red Opal	35.58 b	7.17 a	0.620 a	0.076 a	80.02 a
H. bihai	35.77 ab	6.67 ab	0.642 a	0.062 a	75.05 a
H. rostrata	36.01 ab	4.515 b	0.594 a	0.046 a	87.66 a
MSD	0.47	2.20	0.0941	0.0348	23.0096

SV – Sources of variation; CV – Coefficient of variation; DF – Degrees of freedom; * – Significant at 0.05; ns – Not significant. Averages followed by the same letter do not differ at a significance level of 0.05 using Tukey's test; MSD – minimum significant difference

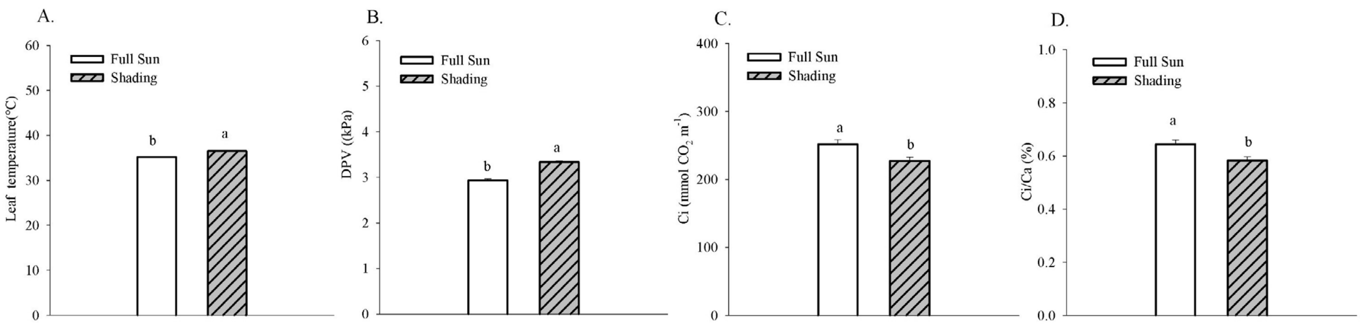


Figure 2. Leaf temperature (LT) (A), vapor pressure deficit (VPD) (B), intercellular CO_2 concentration (Ci) (C), and internal/external carbon concentration ratio (Ci/Ca) (D) of heliconia leaves grown under different light intensities (full sun and 50% shading)

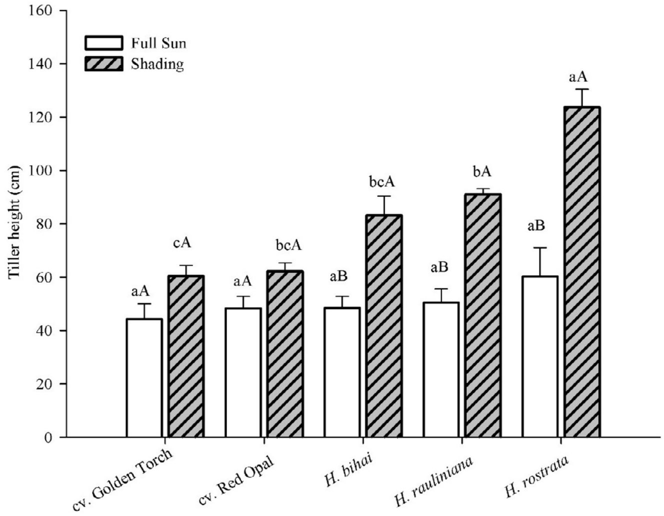
The absence of a significant effect of intensity on the height of the cv. Golden Torch and cv. Red Opal demonstrated that these genotypes were less sensitive to high-irradiance conditions than the other genotypes. Although the plants of these genotypes presented lower HEI values, this result is due to their genetic characteristics, as they are classified as being of small size, whereas the genotypes *H. bihai*, *H. rauliniana*, and *H. rostrata* are classified as high-growing (Castro et al., 2011). Although these genotypes are considered to be tall, it can be seen that they presented a drastic reduction in growth in full sun, indicating greater sensitivity to high irradiation conditions.

Overall, the largest increments in growth variables were observed in plants grown in the shade (Figures 4A-D), with the exception of NT and leaf number (Figures 4B and C, respectively).

Table 3. Summary of the analyses of variance for the number of leaves (NL), average tiller height (HEI), number of tillers (NT), and total leaf area (TLA) in heliconia species under different light intensities (full sun and 50% shading)

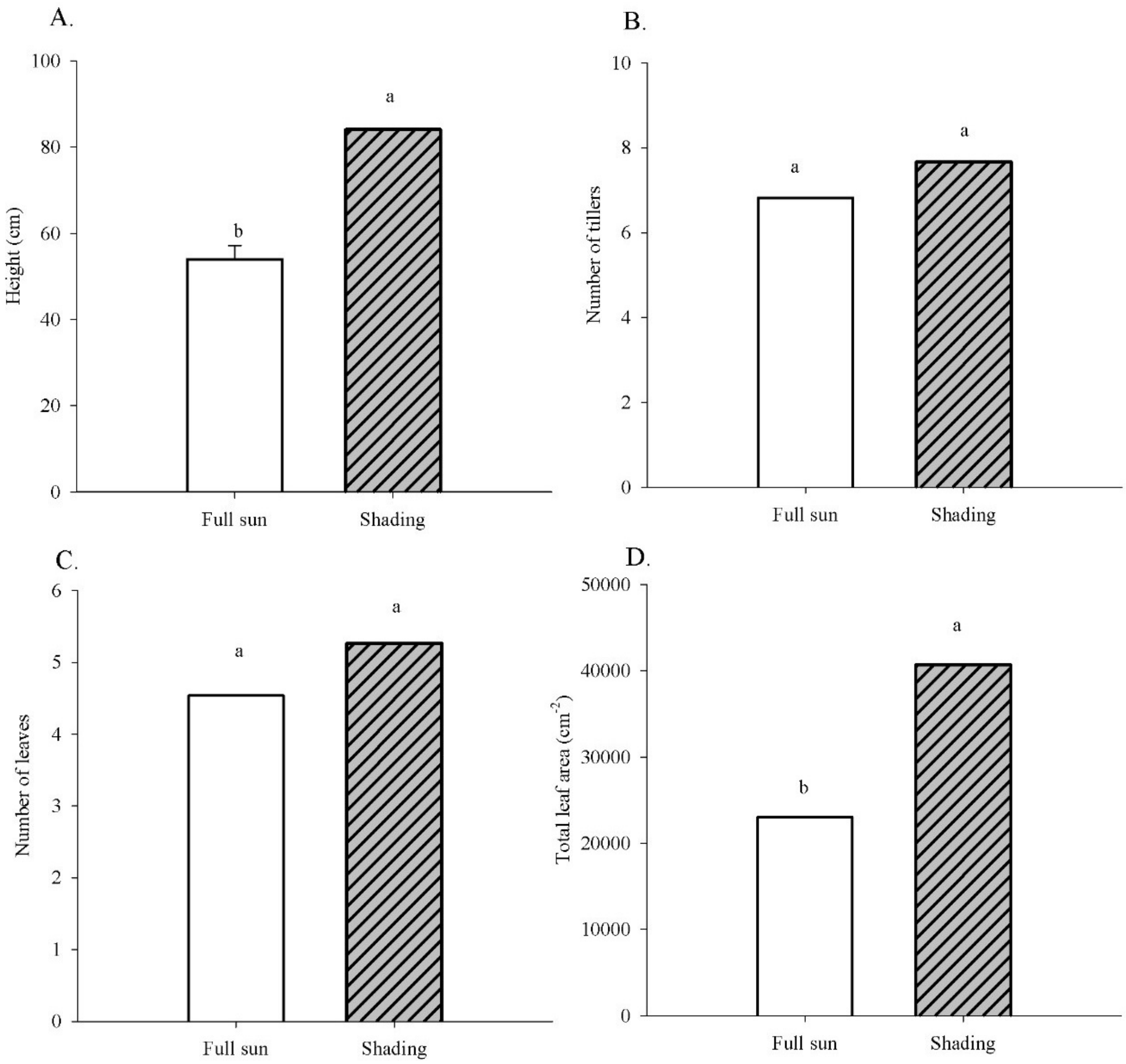
SV	Mean squares			
	NL	HEI	NT	TLA
Light intensities (A)	1.57^{*}	$17{,}035.35^{*}$	25.35^{ns}	$5.54E^{-9*}$
Blocks	0.19^{ns}	249.07^{ns}	22.50^{*}	$0.66E^{-9*}$
Residue (A)	0.11	295.55	3.91	$0.08E^{-9}$
Genotype (B)	1.22^{*}	$2{,}831.29^{*}$	79.14^{*}	$5.01E^{-9*}$
A × B	0.12^{ns}	$1{,}361.81^{*}$	3.47^{ns}	$0.60E^{-9ns}$
Residue (B)	0.26	338.26	5.43	$4.89E^{-9}$
$CV_{(a)}$ %	15.71	25.56	28.18	12.97
$CV_{(b)}$ %	24.02	27.35	33.20	35.58
	Genotypes averages			
	NL	HEI	NT	TLA
H. rauliniana	2.13 ab	70.75 ab	6.42 b	38,433.34 ab
cv. Golden Torch	2.31 a	54.42 b	6.42 b	33,435.21 ab
cv. Red Opal	2.49 a	55.33 b	9.17 a	40,838.53 a
H. bihai	1.92 ab	63.75 b	9.75 a	27,505.82 bc
H. rostrata	1.68 b	92.00 a	3.33 c	15,258.17 c
MSD	0.59	21.45	2.72	12,902.86

SV – Sources of variation; CV – Coefficient of variation; DF – Degrees of freedom; * – Significant at 0.05; ns – Not significant. Averages followed by the same letter do not differ at a significance level of 0.05 using Tukey's test; MSD - minimum significant difference



Bars with the same letter do not differ at a significance level of 0.05 using Tukey's test. Upper-case letters compare different environments for the same cultivar, and lower-case letters compare genotypes for the same environment

Figure 3. Average tiller height (HEI) of *H. psittacorum* x *H. spathocircinata* cv. Golden Torch, *H. psittacorum* cv. Red Opal, *H. bihai* cv. Lobster Claw Two, *H. rauliniana*, and *H. rostrata* grown in different light intensities (full sun and 50% shading)



Bars with the same letter did not differ at a significance level of 0.05 using Tukey's test

Figure 4. Parameter averages: average tiller height (HEI) (A), number of tillers per pit (NT) (B), number of leaves (NL) (C), and total leaf area (TLA) (D) of heliconia in the different light intensities (full sun and 50% shading)

The absence of an effect on NT and NL is also due to the genetic characteristics of each genotype that define productive potential since each tiller originates from a floral stem. Plants grown in shaded environments showed a marked increase in total leaf area compared with that of plants grown in full sun. An increase in leaf area can provide a greater capacity for plants to absorb light and assimilate carbon. This result was also observed by Santos et al. (2022) in *Euphorbia milii* where the leaf areas increased proportionally to the increase in shading in the growing environment. In contrast, the plants grown in full sun showed a drastic reduction in growth parameters, despite having the same A as the shade plants (Table 2 and Figure 4). This result indicates that heliconia plants grown under full sun conditions may have directed photoassimilates to repair damage and/or induce plant defense mechanisms against the damaging effects of excess light radiation, which requires greater energy expenditure (Hertel et al., 2021). In addition, plants grown in the shade may have a higher quantum efficiency of photosynthesis because of the decreased ratio of the respiration rate (CO_2 consumption) to the photosynthetic rate (Lennon et al., 2021). Thus, shade provides suitable conditions for the optimal growth of heliconia in regions with high solar irradiance availability. Similar results were obtained by Souza et al. (2016), who evaluated the effects of different levels of shading on the growth and productivity of *H. psittacorum* cv. Golden Torch and *H. bihai* cv. Humilis, and proposed that 50% shading improves the performance and growth of these species.

The results demonstrated that Heliconia genotypes exhibited contrasting responses in photosynthetic rate and growth. In addition, *H. psittacorum* cv. Red Opal and *H. psittacorum* cv. Golden Torch exhibited greater tolerance to growing in full sun under high solar irradiation conditions than the other genotypes. This tolerance was associated with a smaller reduction in growth parameters such as height and leaf area, which allowed the plants to survive and maintain their growth patterns under such conditions.

Conclusions

H. psittacorum var. Red Opal, and *H. psittacorum* cv. Golden Torch exhibited greater tolerance to high solar irradiance conditions than the other genotypes. Additionally, light conditions, such as full sun and 50% shade, did not affect the leaf photosynthetic rate of heliconia. However, all the genotypes studied showed better initial growth under shading conditions.

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Literature Cited

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. L. de M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2013. https://doi.org/10.1127/0941-2948/2013/0507

Beckmann-Cavalcante, M. Z.; Amaral, G. C.; Silva, A. de S.; Brito, L. P. da S.; Lima, A. M. N.; Cavalcante, I. H. L. Nitrogen and potassium fertilization in yield and macronutrients contents of heliconia cv. Golden Torch. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.337-342, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n4p337-342

Brelsford, C. C.; Morales, L. O.; Nezval, J.; Kotilainen, T. K.; Hartikainen, S. M.; Aphalo, P. J.; Robson, T. M. Do UV-A radiation and blue light during growth prime leaves to cope with acute high light in photoreceptor mutants of *Arabidopsis thaliana*? Physiologia Plantarum, v.165, p.537-554, 2019. https://doi.org/10.1111/ppl.12749

Castro, C. E. F. de; Gonçalves, C.; Moreira, S. R.; Faria, O. A. Helicônias brasileiras: características, ocorrência e usos. Revista Brasileira de Horticultura Ornamental. v.17, p.5-24, 2011. https://doi.org/10.14295/rbho.v17i1.725

Ferreira, D. F. Sisvar: A guide for its bootstrap procedures in multiple comparisons. Ciência e Agrotecnologia, v.38, p.109-112, 2014. https://doi.org/10.1590/S1413-70542014000200001

Grossiord, C.; Buckley, T. N.; Cernusak, L. A.; Novick, K. A.; Poulter, B.; Siegwolf, R. T. W.; Sperry, J. S.; McDowel, N. G. Plant responses to rising vapor pressure deficit. New Phytologist, v.226, p.1550-1566, 2020. https://doi.org/10.1111/nph.16485

Hertel, M. F.; Araújo, H. H.; Stolf-Moreira, R.; Pereira, J. D.; Pimenta, J. A.; Bianchini, E.; Oliveira, H. C. Different leaf traits provide light-acclimation responses in two neotropical woody species. Theoretical and Experimental Plant Physiology, v.33, p.313-327, 2021. https://doi.org/10.1007/s40626-021-00213-1

Lennon, A. M.; Lewis, V. R.; Farrell, A. D. Pathmanathan Umaharan. Photochemical responses to light in sun and shade leaves of *Theobroma cacao* L. (West African Amelonado). Scientia Horticulturae, v.276, p.1-9, 2021. https://doi.org/10.1016/j.scienta.2020.109747

Linares-Gabriel, A.; Gallardo-López, F.; Villarreal, M.; Landeros-Sánchez; López-Romero, G. Global vision of heliconias research as cut flower: A review. Ornamental Horticulture, v.26, p.633-646, 2020. https://doi.org/10.1590/2447-536X.v26i3.2172

Marulanda, M. L.; Isaza, L.; López, P. A. Caracterización de la diversidad genética de cultivares comerciales de heliconias en el centro occidente de Colombia. Agronomía Costarricense, v.42, p.7-20, 2018. http://dx.doi.org/10.15517/rac.v42i1.32195

Nihad, K.; Berwal, M.K.; Hebbar, K.B.; Bhat, R.; Haris, A.A.; Ramesh, S.V. Photochemical and biochemical responses of heliconia (*Heliconia stricta* "Iris") to different light intensities in a humid coastal environment. Horticulture, Environment, and Biotechnology, v.60, p.799-808, 2019. https://doi.org/10.1007/s13580-019-00173-1

Santos, J. W. G. dos; Lacerda, C. F. de; Oliveira, A. C. de; Mesquita, R. O.; Bezerra, A. M. E.; Neves, A. L. R.; Marques, E. da S.Quantitative and qualitative responses of *Euphorbia milii* and *Zamioculcas zamiifolia* exposed to different levels of salinity and luminosity. Revista Ciência Agronômica, v.53, p.1-10, 2022. https://doi.org/10.5935/1806-6690.20220033

Silva, A.A.; Beckmann-Cavalcante, M.Z.; Silva, E.M.; Pavan B.E.; Lobo, J.T.; Silva, M.L.N. Heliconia cv. Golden Torch cultivated under different irrigation depths in protected environment. Ornamental Horticulture, v.24, p.63-69. 2018. https://doi.org/10.14295/oh.v24i1.1127

Silva, S. D. P. da; Souza, G. P. de; Chaves, A. R. de M; Silva, M. A. da; Souza, R. R.de; Beckmann-Cavalcante, M. Z. Morphophysiological aspects of ornamental sunflowers cultivated in different growing seasons under semi-arid conditions. Revista Brasileira de Engenharia Agrícola e Ambiental. v.26, p.299-305, 2022. http://dx.doi.org/10.1590/1807-1929/agriambi.v26n4p299-305

Souza, R. R. de; Beckmann-Cavalcante, M. Z.; Silva, A. A. Silva, E. M. da; Brito, L. P. da S.; Silva, A. O. Yield and quality of inflorescences of 'Golden Torch' heliconia in different shaded environments. Revista Brasileira de Engenharia Agrícola e Ambiental. v.20, p.128-132, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n2p128-132

Zucoloto, M.; Lima, J. S. de S.; Coelho, R. I. Modelo matemático para estimativa da área foliar total de bananeira 'Prata-Anã'. Revista Brasileira de Fruticultura, v.30, p.1152-1154, 2008. https://doi.org/10.1590/S0100-29452008000400050