ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.26, n.4, p.299-305, 2022
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v26n4p299-305

Morphophysiological aspects of ornamental sunflowers cultivated in different growing seasons under semi-arid conditions[1]

Aspectos morfofisiológicos de girassol ornamental cultivado em diferentes épocas de cultivo sob condições semiáridas

Sheila D. P. da Silva[2], Gracielle P. de Souza[3], Agnaldo R. de M. Chaves[4], Marcelle A. da Silva[5], Rafaela R. de Souza[3] & Márkilla Z. Beckmann-Cavalcante[3]*

[1] Research developed at Petrolina, PE, Brazil
[2] Universidade Federal do Vale do São Francisco/Programa de Pós-Graduação em Agronomia-Produção Vegetal/Campus de Ciências Agrárias, Petrolina, PE, Brazil
[3] Universidade Federal do Vale do São Francisco/Curso de Engenharia Agronômica/Campus de Ciências Agrárias, Petrolina, PE, Brazil
[4] Embrapa Semiárido, Petrolina, PE, Brazil
[5] Universidade Federal do Vale do São Francisco/Curso de Ciências Biológicas/Campus de Ciências Agrárias, Petrolina, PE, Brazil

HIGHLIGHTS:

The morphophysiological traits of ornamental sunflowers grown under semi-arid conditions are affected by the growing season.
All cultivars evaluated showed higher leaf surface areas when grown in seasonally moderate climatic conditions, except 'Sol Noturno'.
The cultivation of ornamental sunflowers in semi-arid regions is recommended in the growing season in a moderate climate.

ABSTRACT: Knowledge of how climatic conditions affect plant morphophysiology is essential for understanding how to manage the growth cycles of different crops. The aim of this study was to evaluate the effects of the growing seasons in a semi-arid area on the morphophysiological variables of ornamental sunflower plants. The experiment was carried out in a randomized block design in a split-plot arrangement with four replicates. Six cultivars ('Bonito de Outono Sortido', 'Sol Noturno', 'Sol Vermelho', 'Jardim Amarelo Alto', 'Girassol F1 Sunbright Supreme' and 'Girassol F1 Vincents Choice') were evaluated in the main plots and two different growing seasons (GS) in the subplots (GS1 - warm climate and GS2 - mild climate). Evaluations of gas exchange, chlorophyll indices, and leaf surface area were carried out at the reproductive stage (R5.5). The cultivation of ornamental sunflowers in semi-arid regions was significantly affected by the growing season. Changes in gas exchange variables and the morphophysiology of ornamental sunflower plants in the two growing seasons reflected the high phenotypic plasticity characteristic of this species. The cultivation of ornamental sunflowers under semi-arid conditions in the growing season, when air temperature and solar radiation are high, could be limited due to elevated transpiration rates. Therefore, it is recommended that they are grown mainly during the moderate climatic season in semi-arid regions.

Key words: *Helianthus annuus* L., cutting flower, photosynthesis, seasonal changes

RESUMO: O conhecimento de como as condições climáticas afetam a morfofisiologia das plantas é essencial para compreender como manejar os ciclos de crescimento das diferentes culturas. O objetivo deste estudo foi avaliar o efeito de épocas de cultivo em condições semiáridas sobre os parâmetros morfofisiológicos e de trocas gasosas de plantas de girassol ornamental. O experimento foi conduzido no delineamento em blocos casualizados arranjado em esquema de parcelas subdivididas com quatro repetições. Foram avaliados seis cultivares ('Bonito de Outono Sortido', 'Sol Noturno', 'Sol Vermelho', 'Jardim Amarelo Alto', 'Girassol F1 Sunbright Supreme' e 'Girassol F1 Vincents Choice') na parcela principal e duas diferente épocas de cultivo (GS) nas subparcelas (GS1 - clima quente e GS2 - clima ameno). As avaliações de trocas gasosas, índices de clorofilas e área foliar foram realizadas na fase reprodutiva (R5.5). O cultivo de girassol de corte no semiárido é afetado significativamente pela época de cultivo. Mudanças nas variáveis de trocas gasosas e morfofisiologia das plantas de girassol ornamental em duas epócas de cultivo, refletem uma característica de alta plasticidade fenotípica dessa espécie. O cultivo de girassol ornamental sobre condições semiáridas em época de cultivo quando a temperatura do ar e radiação solar são altas, pode ser limitada devido às altas taxas de transpiração. Recomenda-se o cultivo de girassol ornamental em épocas de clima moderado em regiões semiáridas.

Palavras-chave: *Helianthus annuus* L., flores de corte, fotossíntese, sazonalidade

• Ref. 254500 – Received 21 Jun, 2021
* Corresponding author - E-mail: markilla.beckmann@univasf.edu.br
• Accepted 05 Nov, 2021 • Published 11 Nov, 2021
Editors: Lauriane Almeida dos Anjos Soares & Walter Esfrain Pereira

Introduction

Floriculture in Brazil has exhibited expansive growth, with turnover in 2020 being around R$ 9,570.00 billion. Currently, Brazil cultivates more than 2,500 species of flowers and ornamental plants, and 29% of the area cultivated with flowers and ornamental plants is occupied by flowers used for arrangements (IBRAFLOR, 2021). The ornamental sunflower (*Helianthus annuus* L.) stands out because of its beauty, rustic appearance, and easy handling, enabling it to be cultivated in different regions. It is also an excellent crop for small-scale rural farmers (Alves et al., 2014; Nascimento et al., 2019).

Sunflowers are a temperate zone crop which performs well in a wide range of climatic conditions (Debaeke et al., 2017); it grows easily in regions in which water resources are limited (Azevedo et al., 2016). Understanding the physiological behavior of plants in different environments may highlight important aspects of the dynamics of their growth and development, as well as their ability to acclimatize to different environmental conditions, as well as identifying a more effective method of horticultural management (Birck et al., 2016; Romanowski et al., 2021).

To cultivate ornamental sunflowers in Brazilian regions that have a semi-arid climate, the high luminosity and temperatures associated with this environment must be considered. Under these conditions, excess light energy associated with heat negatively affects photosynthesis; consequently, crop growth, productivity, and postharvest quality are restricted (Souza et al., 2016a; Simões et al., 2018). Furthermore, climatic changes that occur during the year are responsible for major losses in ornamental flower crops, especially when grown in open fields (Munir et al., 2015; Becker et al., 2021).

For ornamental sunflowers, site-specific technology can be developed to optimize, support, and help farmers in their decisions. The choice of cultivar and growing season requires knowledge about the physiological behavior and acclimatization characteristics of the species. Better management of genetic diversity helps reduce genotype-phenotype incompatibilities due to increased production and ensures the stability of the target population in the chosen environment (Killi et al., 2017). In this context, the aim of the present study was to evaluate the effects of different growing seasons in semi-arid conditions on ornamental sunflower plants and their morphophysiological variables.

Material and Methods

The study was carried out between October 2015 and May 2016 in an experimental field located in the Floriculture Sector of the Universidade Federal do Vale do São Francisco (UNIVASF), Petrolina-PE, Brazil, in the sub-medium region of São Francisco River Valley (09° 19' 14" S and 40° 32' 40" W). According to Köppen, the region is classified as Bswh, a tropical semi-arid climate, with an average annual temperature of 26.5 °C.

The experiment took place in a randomized block design in a split-plot arrangement with four replicates and 24 plots. Six cultivars were evaluated in the main plot ('Bonito de Outono Sortido, 'Sol Noturno', 'Sol Vermelho', 'Jardim Amarelo Alto', 'Sunflower F1 Sunbright Supreme' and 'Sunflower F1 Vincents Choice'), and two growing seasons in the subplot: growing season 1 (GS1 = from October to December, characterized by warm weather with low relative humidity, high light intensity, and an accumulated precipitation of 92 mm) and growing season 2 (GS2 = from March to May, which comprised a period of mild climatic conditions, with lower temperatures, higher relative humidity and cloudy conditions with accumulated precipitation of 116.8 mm). Each experimental unit contained four planting rows with a spacing of 0.3 m between rows and 0.3 m between plants, in which only the two central rows were considered as useful areas for assessments.

The soil of the experimental area was classified as Quartzipsamments, with the following physical characteristics: 826.8 g kg^1 of sand, 95.7 g kg^{-1} of silt and 77.5 g kg^{-1} of clay. For each cycle, a soil chemical analysis was performed in the soil analysis laboratory (Table 1). Based on the results, fertilizer was applied two days before sowing, with 500 kg ha^{-1} of NPK 6-24-12 in the first growing season and 333 kg ha^{-1} of the same formulation in the second, as recommended by Ribeiro et al. (1999).

Seeds from the same commercial lots purchased from specialized companies were used in each season. Direct seeding (without tillage) was carried out, maintaining one plant per hole after germination. Plants were irrigated daily early in the morning using a drip system arranged as per the crop spacing, ensuring all plots were watered simultaneously (Cavalcante Júnior et al., 2013).

During the experimental period, the average temperature, relative air humidity, and global solar radiation data were collected at a climatological station located close to the experimental area (Figure 1). All evaluations were performed when plants were at phenological stage R5.5, at which, on average, 50% of the disc florets were open; this stage was reached 54 and 52 days after sowing, for seasons GS1 and GS2, respectively.

Leaf gas exchange was measured using a portable photosynthesis system (IRGA, Mod. Li-COR® 6400 XT, USA), from 09:00 to 11:30 a.m. on days with full sun. The values of net

Table 1. Chemical soil composition of the experimental area in the 0-20 cm layer, in both growing season 1 (GS1 = from October to December, characterized by hot weather with low relative humidity, and high luminous intensity) and in growing season 2 (GS2 = from March to May, which comprised a period of mild climatic conditions, with lower temperatures, higher relative humidity and greater cloudiness)

Growing season	pH 1:2.5 H_2O	Ca^{2+}	Mg^{2+}	Na^+	K^+	SB	H+Al	T	Al^{3+}	V	P	O.M.
		($cmol_c$ dm^{-3})								(%)	(mg dm^{-3})	(g dag^{-1})
GS1	5.90	2.20	1.40	0.16	0.74	4.50	1.82	6.31	0.0	71.0	94.60	1.61
GS2	5.80	1.80	1.00	0.03	0.38	3.21	1.98	5.19	0.00	62.0	55.55	2.00

Ca^{2+} - Calcium; Mg^{2+} - Magnesium; Na^+ - Sodium; K^+ - Potassium; SB - Sum of basis = Ca^{2+} + Mg^{2+} + K^+ + Na^+); H + AL - Potential acidity in pH 7.0; T - Cation-exchange capacity in pH 7.0; Al^{3+} - Exchangeable acidity; V - Saturation of bases; P - Available phosphorus; and, O.M. - Organic matter

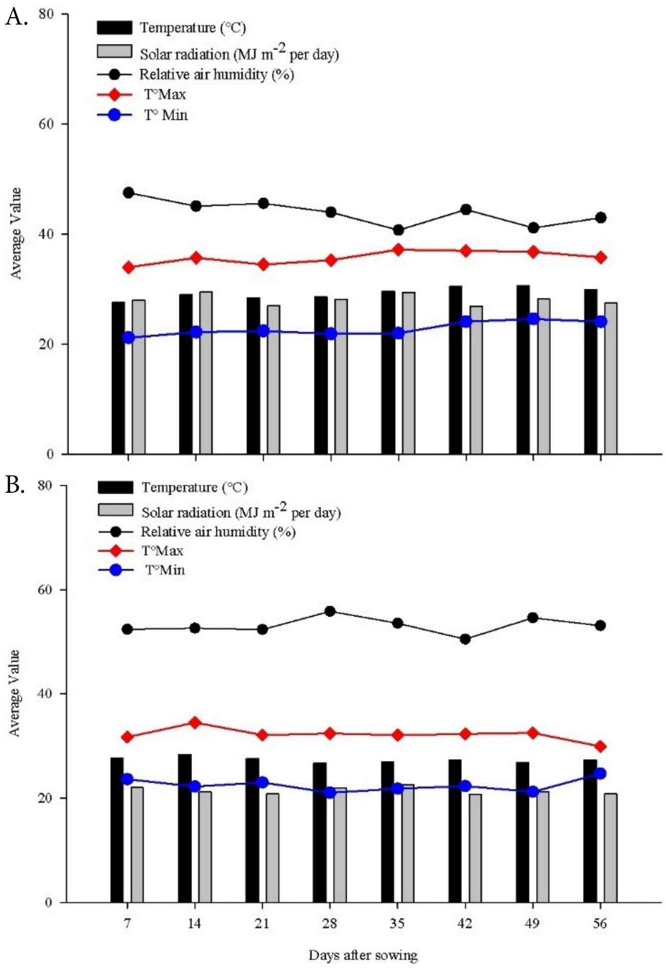


Figure 1. Weather-related records during the experiment in both growing seasons GS1 (from October to December, characterized by hot weather, with low relative humidity and high luminous availability) (A) and GS2 (from March to May, which comprised a period of mild climatic conditions, with comparatively lower temperatures, higher relative humidity and greater cloudiness) (B)

assimilation rate of CO_2 (A, µmol CO_2 m^{-2} s^{-1}), transpiration (E, mol H_2O m^{-2} s^{-1}), stomatal conductance (g_s, mol H_2O m^{-2} s^{-1}), leaf temperature (T_l, °C), and leaf-to-air vapor pressure deficit (VPD, kPa) were measured under a constant CO_2 concentration (400 µmol CO_2 mol^{-1} air) and PPFD (1500 µmol photons m^{-2} s^{-1}. The internal CO_2 concentration (Ci, ppm) was measured to calculate the ratio between the intracellular CO_2 concentration and environmental concentration (C_i/C_a). The instantaneous and intrinsic water use efficiencies, estimated from the ratio of A/E to A/g_s, were calculated.

The chlorophyll index (a, b and total) was measured using a portable chlorophyll meter (Falker®, Brazil) on two pairs of fully expanded leaves in the middle third of the plant in the early morning, and the leaf surface area (LA, cm^2 per plant) was measured using a destructive method, considering only the leaf limb, using an electronic leaf area meter (Li-COR®, model L1-3100C).

The data were subjected to analysis of variance, and the mean values were compared using the Scott–Knott test ($p \leq 0.05$). The analyses were performed using ASSISTAT software (Silva & Azevedo, 2002).

Results and Discussion

Gas exchange variables were not influenced by the interaction between ornamental sunflower cultivars and growing seasons (Table 2). However, the growing season culture showed a significant effect on all gas exchange variables, except the assimilation rate of CO_2 (A) (Table 2). This indicates that the different climatic conditions (Figure 1) in the GS1 and GS2 growing seasons promoted changes in the gas exchange responses in different ornamental sunflower cultivars, without changing A.

The growing seasons also significantly influenced the variables of instantaneous water use efficiency (A/E), intrinsic water use efficiency (A/g_s), and leaf area (LA) (Table 3). The relative content of Chl a, Chl b, and Chl total showed differences only between the cultivars (Table 3).

Plants are highly adaptable organisms, capable of adjusting morphophysiological processes that enable growth, optimum photosynthesis and survival in a changing environment (Souza et al., 2016a; Romanowski et al., 2021). Therefore, any change in the cultivation environment triggers changes in the patterns of transpiration and photosynthesis, with temperature and solar radiation intensity as the main factors governing the growth rate and productivity of crops (Baydar & Erbas, 2005; Souza et al., 2016a).

The GS1 environment was marked by average temperatures throughout the experimental period of approximately 29 °C, relative humidity of 44%, and global solar radiation of 28 MJ m^{-2} per day (Figure 1A), whereas GS2 showed a temperature of 27 °C, 53% relative humidity, and 21 MJ m^{-2} per day solar radiation on average (Figure 1B). In this context, GS1 was characterized by

Table 2. Summary of analysis of variance and means of assimilation rate of CO_2 (A, µmol CO_2 m^{-2} s^{-1}), stomatal conductance (g_s, mol H_2O m^{-2} s^{-1}), transpiration rate (E, mmol H2O m^{-2} s^{-1}), leaf temperature (T_l, °C), vapor pressure deficit between leaf and air (VPD, kPa) and ratio between intracellular CO_2 concentration and environmental concentration (Ci/Ca) of ornamental sunflower cultivars in two growing seasons (GS1 and GS2) in semi-arid conditions

Source of variation	A	g_s	E	T_l	VPD	C_i/C_a
Blocks	0.66^{ns}	0.72^{ns}	1.39^{ns}	9.35**	10.08**	0.34^{ns}
Cultivars (C)	1.00^{ns}	1.91^{ns}	2.10^{ns}	3.99*	3.76*	2.71^{ns}
Growing seasons (GS)	2.87^{ns}	66.22**	354.76**	46.94**	207.53**	75.94**
GS1	40.58 a	0.73 b	13.68 a	31.13 a	1.38 a	0.70 b
GS2	38.12 a	1.15 a	8.19 b	29.93 b	0.77 b	0.80 a
C x GS	1.33^{ns}	1.56^{ns}	2.27^{ns}	2.54^{ns}	0.70^{ns}	1.06^{ns}
CV1 (%)	13.89	13.71	9.19	1.59	5.98	4.10
CV2 (%)	12.75	19.06	9.24	1.96	13.69	5.16

ns - Non-significant; CV - Coefficient of variation. Means followed by the same letter in the column do not differ by Skott-Knott's test ($p > 0.05$); * and ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F-test, respectively

Table 3. Summary of analysis of variance and means of instant water use efficiency (A/E), intrinsic water use efficiency (A/g_s) and leaf area (LA, cm^2 per plant), chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll (Chl total) of ornamental sunflower cultivars in two growing seasons in semi-arid conditions

Source of variation	A/E	A/g_s	LA	Chl a	Chl b	Chl total
Blocks	3.93*	0.42^{ns}	0.42^{ns}	2.49^{ns}	0.71^{ns}	1.28^{ns}
Cultivars (C)	1.86^{ns}	2.52^{ns}	2.52^{ns}	16.43**	5.01**	10.72**
Growing seasons (GS)	386.12**	98.61**	61.95**	0.07^{ns}	0.65^{ns}	0.02^{ns}
GS1	2.96 b	57.69 a	2266.06 b	28.12	6.26	34.38 a
GS2	4.65 a	34.26 b	3113.68 a	28.24	6.11	34.35 a
C x GS	1.30^{ns}	1.30^{ns}	5.23**	0.83^{ns}	2.10^{ns}	1.20^{ns}
CV1 (%)	10.48	14.38	18.3	3.07	11.15	4.44
CV2 (%) (GS)	8.04	17.77	13.87	5.33	10.19	6.04

ns - Non-significant; CV - Coefficient of variation. Means followed by the same letter in the column do not differ by Skott-Knott's test ($p > 0.05$); * and ** - Significant at $p \leq 0.05$ and $p \leq 0.01$ by F-test, respectively

conditions of higher temperature associated with a higher solar irradiance, and low humidity which favored a reduction in g_s, Ci/Ca, and A/E. However, E, T_l, VPD, and A/g_s were increased. In GS2, with lower temperatures, lower solar irradiance, and higher relative air humidity, the opposite occurred (Tables 2 and 3).

A reduction in g_s usually decreases the availability of CO_2 for photosynthesis, causing a reduction in A and, consequently, growth. In addition, stomatal closure in well-watered C3 and C4 species is triggered by high light intensity associated with high VPD (Killi et al., 2020; Eyland et al., 2021), which explains the lower g_s and higher VPD in ornamental sunflower plants grown in GS1. It is important to highlight that a reduction in g_s does not always correspond to a reduction in A, as observed in our study (Table 2). This indicates that the temperature in GS1 did not reach adequate levels to reduce the net CO_2 assimilation rate, probably because the degree of stomatal opening did not limit the diffusion of CO_2 in the intercellular spaces of the mesophyll, ensuring the efficiency of photosystem II (Eyland et al., 2021).

Similar results were also observed by Silva et al. (2013), who aimed at evaluating the responses of sunflower plant gas exchange at different phenological stages and found that even with a decline of 1.42 to 0.9 mol m^{-2} s^{-1} in g_s there was no significant reduction in A. Hence, these authors reported that when cellular turgor is maintained, g_s and A are partially or fully sustained. The results obtained by Kaleem et al. (2009) also showed that g_s was progressively increased due to the gradual increase of temperature up to 40 days after the emergence of sunflower hybrids during the spring season, but from 50 days after the emergence, it started decreasing, probably due to extreme temperatures during this peak growth period. In this context, the decrease in relative humidity associated with high temperatures provides T_l and VPD increases with a consequent reduction in stomatal opening (Costa & Marenco, 2007), which corroborates the results obtained in GS1.

Regarding the E variable, an increase was observed in GS1 even with a decrease in g_s, which may have occurred because of the higher T_l, which also provides an increase in VPD (Table 2). This result is a consequence of greater evaporation rates. Additionally, it was verified in this study that, although there was higher g_s in GS2, this did not result in higher E, due to the higher relative humidity in this period (Figure 1B).

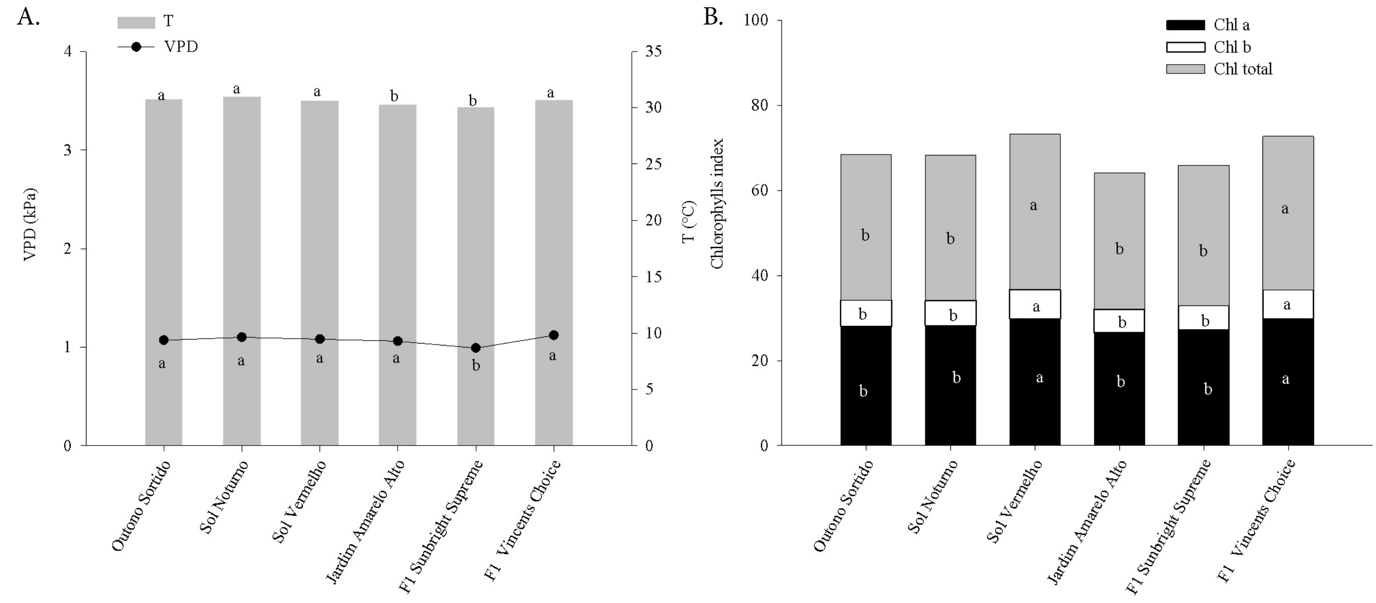
The 1.2 °C average increase in T_l during GS1 was sufficient to increase the VPD by 44.20% when compared with GS2; although the value is higher in GS1, it may be considered low according to Erismann et al. (2006), which is probably why it did not cause greater reductions in g_s. These authors also reported that at full flowering, the VPD was low, with values between 0.8 and 2.2 kPa, which did not compromise the net assimilation rate by ensuring a stomatal conductance close to 0.9 mol m^{-2} s^{-1}. Additionally, the higher A/E in GS2 indicates that more CO_2 was absorbed due to less water loss. Strategically, plants use water more efficiently when climatic conditions result in greater evaporation.

Leaf temperature (T_l) and VPD showed significant differences between the ornamental sunflower cultivars studied (Table 2). The 'Sunflower F1 Sunbright Supreme' cultivar showed significantly lower VPD and T_l values than the other cultivars (Figure 2A).

This result may be related to the plant structure, as more compact plants, with relatively small leaves and shorter internodes, tend to have a lower VPD, as there is less air circulation, as well as less luminosity in the leaves, so that they retain moisture and their temperature is reduced for longer. Wind causes transpiration from the leaf surface, accentuating the VPD, which is directly proportional to T_l (Romanowski et al., 2021). The highest T_l values for 'Bonito de Outono Sortido', 'Sol Noturno', 'Sol Vermelho' and 'Sunflower F1 Vincents Choice' (Figure 2A) could be related to the leaf arrangement, which is perpendicular to the incidence of solar radiation.

The cultivars also showed significant differences in the chlorophyll index (Table 3), where it was observed that the ornamental sunflowers 'Girassol F1 Vincents Choice' and 'Sol Vermelho' presented significantly higher values for Chl a, Chl b, and Chl total compared to the other cultivars studied (Figure 2B). Chlorophyll concentration is a variable that usually has a direct relationship to photosynthetic efficiency and is strongly influenced by environmental and genetic conditions (Souza et al., 2021). Therefore, increasing or maintaining the chlorophyll concentration allows plants to achieve photosynthetic efficiency, high growth rates, and productivity under different environmental conditions. In this context, the cultivars 'Girassol F1 Vincents Choice' and 'Sol Vermelho' may present growth advantages under different environmental conditions compared to the other cultivars studied.

Silva et al. (2018) evaluated the growth of ornamental sunflowers in two growing seasons under semi-arid conditions and found that the cultivars 'Sol Vermelho' and 'Sunflower F1 Vincents Choice' presented better agronomic performance, thus exhibiting better acclimatization to the region. This could be related to genetic characteristics allowing the activation of mechanisms which increase and maintain chlorophyll concentrations under different environmental conditions.

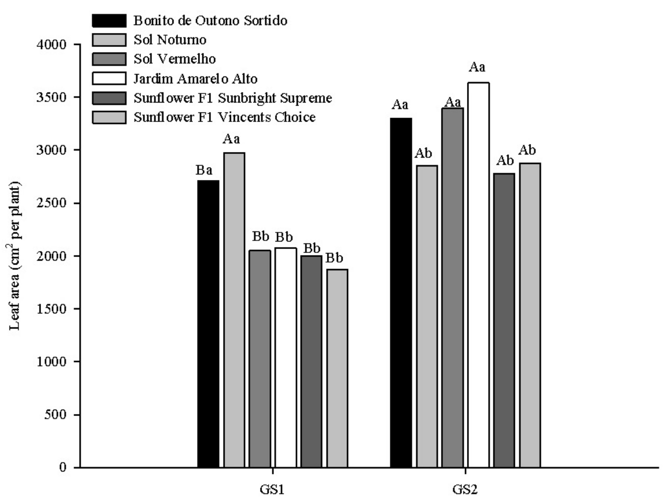


Means values of cultivars followed by the same letters do not differ by Scott Knott test at p ≤ 0.01

Figure 2. Leaf temperature (T) vapor pressure deficit between leaf and air (VPD) (A), and chlorophyll a (Chl a), chlorophyll b (Chl b) and total chlorophyll (Chl total) of ornamental sunflower cultivars grown in semi-arid conditions

As for the morphological aspects, which are influenced by genetic and environmental conditions, leaf surface area (LA) was an obvious factor, with significant interaction between cultivars and growing season (Table 3). Significant differences were observed among sunflower cultivars for LA in both growing seasons (Figure 3). When the plants were grown in GS1, the highest LA reading was recorded for 'Sol Noturno', which was statistically on a par with 'Bonito de Outono Sortido'; the values of both were higher than those of the other cultivars. In GS2 the cultivars 'Jardim Amarelo Alto', 'Sol Vermelho' and 'Bonito de Outono Sortido' were statistically similar to each other and higher than 'Sol Noturno', 'Sunflower F1 Sunbright Supreme' and 'Sunflower F1 Vincents Choice' (Figure 3).

It was also observed that only the cultivar 'Sol Noturno' presented the same behavior concerning LA in both growing seasons. All other cultivars studied showed a higher LA when cultivation occurred in GS2 (Figure 3). This result reinforces the evidence that the leaf is a highly adaptable structure, where shape and size are not predetermined, but are influenced by external factors and signals such as light. These adaptive qualities are extremely important for survival, as leaves play a key role in regulating temperature, gas exchange, and light absorption (Souza et al., 2016b; Romanowski et al., 2021).



Uppercase letters compare growing season, while lowercase letters compare ornamental sunflower cultivars. Bars followed by the same letter do not differ by Scott-Knott test at p ≤ 0.01

Figure 3. Leaf area of ornamental sunflower cultivars cultivated in two seasons in the semi-arid region

The highest average of LA value recorded for 'Jardim Amarelo Alto' is supported by its large leaves, despite being a small cultivar. 'Bonito de Outono Sortido' and 'Sol Vermelho' are taller cultivars which have numerous if relatively small leaves, explaining their high average values. According to Carvalho et al. (2012), the leaf area is related to the cultivar and the number and size of leaves, as the smaller number of leaves is balanced by a larger surface area per leaf. The lowest LA values were observed for all the cultivars in GS1. An exception was 'Sol Noturno', which had similar values in both GSI and GS2. This is probably related to the climate during this period, which exhibited higher global solar radiation incidence, higher temperatures, especially maximum temperatures, and lower relative humidity. This significantly increased the plant E rate and thereby resulted in an LA decrease. In contrast, for most cultivars, the LA was significantly higher in GS2. Thus, all ornamental sunflower cultivars were more sensitive to GS1 conditions, except for the 'Sol Noturno' cultivar. Leaf area reduction is one of the main acclimatization strategies of sunflower plants to environmental stress. Shafiq et al. (2021) reported that under abiotic stress conditions, a decrease in cell expansion is a mechanism for avoiding high solar irradiance and preserving the photosynthetic system. This may have occurred in this experiment because the conditions were insufficient to reduce the photosynthetic rate, although they had a significant influence on LA.

Environmental conditions, such as temperature, relative humidity, and solar radiation, affect gas exchange, plant physiology, morphology, growth, and development. The results of the present study show that the cultivation of ornamental sunflower cultivars in the semi-arid region and different growing seasons is affected by changes in climatic conditions. In addition, the differences in gas exchange behavior and plant morphophysiology resulting from environmental changes for different growing seasons reflect the high phenotypic adaptability of this species. The results of this study have practical applications for cultivation strategies in the Brazilian semi-arid region, mainly to enable small farmers to produce ornamental sunflowers and thus guarantee access to locally produced flowers.

Conclusions

1. Changes in the variables of gas exchange and morphophysiology of ornamental sunflower plants in the two growing seasons reflect the high phenotypic plasticity of this species, allowing them to resist environmental changes.

2. Cultivation of ornamental sunflowers under semi-arid conditions in the growing season, when temperatures and solar radiation are high, may be limited due to high transpiration rates. However, the cultivar 'Sol Noturno' showed less sensitivity to seasonality and could be cultivated in both growing seasons.

3. In semi-arid regions and especially during a moderate growing season, the ornamental sunflowers 'Bonito de Outono Sortido', 'Sol Noturno', 'Sol Vermelho', 'Jardim Amarelo Alto', 'Sunflower F1 Sunbright Supreme' and 'Sunflower F1 Vincents Choice' are recommended.

Acknowledgments

The authors acknowledge the financial grants from Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq, grant number 456690/2014-0) and to Fundação de Amparo a Ciência e Tecnologia do Estado de Pernambuco (FACEPE) for granting a scholarship to the first author under grant number IBPG-1358-5.01/14.

Literature Cited

Alves, S. M.; Rebouças, J. R.; Ferreira Neto, M.; Batista, R. O.; di Souza, L. Fertirrigação de girassol ornamental com esgoto doméstico tratado em sistema de hidroponia. Irriga, v.19, p.714-726, 2014. https://doi.org/10.15809/irriga.2014v19n4p714

Azevedo, B. M. de; Vasconcelos, D. V.; Bomfim, G. V. do; Viana, T. V. de A.; Nascimento Neto, J. R. do; Oliveira, K. M. A. S. de. Production and yield response factor of sunflower under different irrigation depths. Revista Brasileira de Engenharia Agrícola e Ambiental, v.20, p.427-433, 2016. https://doi.org/10.1590/1807-1929/agriambi.v20n5p427-433

Baydar, H.; Erbas, S. Influence of seed development and seed position on oil, fatty acids and total tocopherol contents in sunflower (*Helianthus annuus* L.). Turkish Journal of Agriculture and Forestry, v.29, p.179-186, 2005.

Becker, C. C.; Streck, N. A.; Uhlmann, L. O.; Cera, J. C.; Ferraz, S. E. T.; Silveira, W. B.; Balest, D. S.; Silva, L. F. da. Assessing climate change effects on gladiola in Southern Brazil, Scientiae Agricola, v.78, p.1-11, 2021. https://doi.org/10.1590/1678-992x-2018-0275

Birck, M.; Dalchiavon, F. C.; Stasiak, D.; Iocca, A. F. S.; Hiolanda, R.; Carvalho, C. G. P. Performance of sunflower cultivars at different seeding periods in central Brazil. Ciência e Agrotecnologia, v.41, p.42-51, 2016. https://doi.org/10.1590/1413-70542017411021216

Carvalho, D. R.; Nascimento, P. G. M. do; Silva, M. G. O. da; Mesquita, H. C. de; Cunha, J. L. X. L. Comparação de métodos para estimativa da área foliar do *Myrciaria tenella* O. Berg. R. Agropecuária Científica no Semiárido, v.8, p.1-6, 2012.

Cavalcante Júnior, E. G. C.; Medeiros, J. F. de; Melo, T. K. de; Espinola Sobrinho, J.; Bristot, G.; Almeida, B. M. de. Necessidade hídrica da cultura do girassol irrigado na chapada do Apodi. Revista Brasileira de Engenharia Agrícola e Ambiental, v.17, p.261-267, 2013. https://doi.org/10.1590/S1415-43662013000300003

Costa, G. F. da; Marenco, R. A. Fotossíntese, condutância estomática e potencial hídrico foliar em árvores jovens de andiroba (*Carapa guianensis*). Acta Amazônica, v.37, p.229-234, 2007. https://doi.org/10.1590/S0044-59672007000200008

Debaeke, P.; Casadebaig, P.; Flenet, F.; Langlade, N. Sunflower crop and climate change: vulnerability, adaptation, and mitigation potential from case-studies in Europe. OCL - Oilseeds and fats, Crops and Lipids, v.24, p.1-15, 2017. https://doi.org/10.1051/ocl/2016052

Erismann, N. M. de; Machado, E. C.; Godoy, I. J. de. Capacidade fotossintética de genótipos de amendoim em ambiente natural e controlado. Pesquisa Agropecuária Brasileira, v.41, p.1099-1108, 2006. https://doi.org/10.1590/S0100-204X2006000700005

Eyland, D.; Wesemael, J. V.; Lawson, T.; Carpentier, S. The impact of slow stomatal kinetics on photosynthesis and water use efficiency under fluctuating light. Plant Physiology, v.186, p.998-1012, 2021. https://doi.org/10.1093/plphys/kiab114

IBRAFLOR. Instituto Brasileiro de Floricultura. 2021. Available on: <https://www.ibraflor.com.br/> Accessed on: Oct. 2021.

Kaleem, S.; Hassan, F.; Saleem, A. Influence of environmental variations on physiological attributes of sunflower. African Journal Biotechnology, v.8, p.3531-3539, 2009.

Killi, D.; Bussotti, F.; Raschi, A.; Haworth, M. Adaptation to high temperature mitigates the impact of water deficit during combined heat and drought stress in C3 sunflower and C4 maize varieties with contrasting drought tolerance. Physiologia Plantarum, v.159, p.130-147, 2017. https://doi.org/10.1111/ppl.12490

Killi, D.; Raschi, A.; Bussotti, F. Lipid peroxidation and chlorophyll fluorescence of photosystem II performance during drought and heat stress is associated with the antioxidant capacities of C3 sunflower and C4 maize varieties. International Journal of Molecular Sciences, v.21, p.1-21, 2020. https://doi.org/10.3390/ijms21144846

Munir, M.; Hadley, P.; Carew, J.; Adams, S.; Pearson, S.; Sudhakar, B. Effect of constant temperatures and natural daylength on flowering time and leaf number of Antirrhinum using the photo-thermal model. Pakistan Journal of Botany, v.47, p.1717-1720, 2015.

Nascimento, A. M. P. do; Paiva, P. D. de O.; Manfredini, G. M.; Sales, T. S. Harvest stages and pulsing in ornamental sunflower 'Sunbright Supreme'. Ornamental Horticulture, v.25, p.149-157, 2019. https://doi.org/10.14295/oh.v25i2.1991

Ribeiro, A. C.; Guimarães, P. T. G.; Alvarez, V. V. H. Recomendação para o uso de corretivos e fertilizantes em Minas Gerais: 5° Aproximação. Comissão de Fertilidade do Solo do Estado de Minas Gerais, Viçosa, Minas Gerais, Brazil, 1999. 360p.

Romanowski, A.; Furniss, J. J.; Hussain, E.; Halliday, K. J. Phytochrome regulates cellular response plasticity and the basic molecular machinery of leaf development. Plant Physiology, v.186, p.1220-1239, 2021. https://doi.org/10.1093/plphys/kiab112

Shafiq, I.; Hussain, S.; Raza, M. A.; Iqbal, N.; Asghar, M. A.; Raza, A.; Fan, Y.; Mumtaz, M.; Shoaib, M.; Ansar, M.; Manaf, A.; Yang, W.; Yang, F. Crop photosynthetic response to light quality and light intensity. Journal of Integrative Agriculture, v.20, p.4-23, 2021. https://doi.org/10.1016/S2095-3119(20)63227-0

Silva, A. R. A. da; Bezerra, F. M. L.; Lacerda Filho, C. F. de; Pereira Filho, J. V.; Freitas, C. A. S. de. Trocas gasosas em plantas de girassol submetidas à deficiência hídrica em diferentes estádios fenológicos. Revista Ciência Agronômica, v.44, p.86-93, 2013. https://doi.org/10.1590/S1806-66902013000100011

Silva, F. A. S.; Azevedo, C. A. V. de. Versão do programa computacional Assistat para o sistema operacional Windows. Revista Brasileira de Produtos Agroindustriais, v.4, p.71-78, 2002. https://doi.org/10.15871/1517-8595/rbpa.v4n1p71-78

Silva, S. D. P. da; Beckmann-Cavalcante, M. Z.; Souza, G. P. de; Oliveira, T. S. de; Lima, R. da R.; Chaves, A. R. de M. Growth of ornamental sunflowers in two growing seasons under semiarid conditions. Emirates Journal of Food and Agriculture, v.30, p.381-388, 2018. https://doi.org/10.9755/ejfa.2018.v30.i5.1681

Simões, W. L.; Drumond, M. A.; Oliveira, A. R. de; Gonçalves, S. L.; Guimarães, M. J. M. Morphophysiological and productive responses of sunflower varieties to irrigation. Revista Caatinga, v.31, p.143-150, 2018. https://doi.org/10.1590/1983-21252018v31n117rc

Souza, R. R. de; Cavalcante, M. Z. B.; 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, 2016b. https://doi.org/10.1590/1807-1929/agriambi.v20n2p128-132

Souza, R. R. de; Cavalcante, M. Z. B.; Silva, E. M. da; Amaral, G. C.; Brito, L. P. da S.; Avelino, R. C. Alterações morfofisiológicas e crescimento de helicônias em função de diferentes ambientes de sombreamento. Comunicata Scientiae, v.7, p.214-222, 2016a. https://doi.org/10.14295/cs.v7i2.884

Souza, R. R. de; Paiva, P. D. de O.; Souza, A. R. de; Silva, R. R. de; Silva, D. P. C. da; Reis, M. V. dos; Paiva, R. Morpho-anatomical changes and antioxidant enzyme activity during the acclimatization of *Genipa americana*. Acta Physiologiae Plantarum, v.43, p.1-10, 2021. https://doi.org/10.1007/s11738-021-03263-9