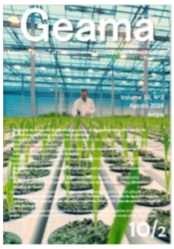

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Impact of cropping season temperature combined with water deficit on sorghum cultivar development

Impacto da temperatura na época de plantio combinado com déficit hídrico no desenvolvimento de cultivares de sorgo

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Keyword
Sorghum bicolor (L.) Moench
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resilient cultivars

ABSTRACT

Increased temperatures and altered precipitation patterns with severe drought are among the main challenges in agriculture. Hence, this study evaluated the impact of cropping season temperature combined with water deficit on the vegetative performance of sorghum cultivars. The experimental design was randomized blocks in a 2x6x4 factorial arrangement, performed in two annual cropping seasons (one in June - moderate temperatures; and one in January - high temperatures, in Brazilian climate conditions), using six sorghum cultivars (AGRI002E, BRS 506, BRS 716, SF 15, Santa Elisa, and BRS Ponta Negra) at four soil water availabilities (25, 50, 75, and 100% field capacity), with four repetitions. The biometric assessments of plant development (plant height, the number of leaves, stem diameter, and the number of tillers) occurred at the beginning of the maturation phase. The data were subjected to the analysis of variance by the Scott-Knott test and regression for water availability. Sorghum cultivars responded differently to the combined stress of increased air temperatures in different cropping seasons and water deficit. The warmest season was more beneficial to plant height, the number of leaves, and stem diameter. The combined effect of water restriction and temperature harmed the biometric responses of sorghum plants, potentially reducing plant development and final yield.

Palavras-Chave
Sorghum bicolor (L) Moench
mudanças climáticas
estresse abiótico
cultivares resilientes

RESUMO

O aumento da temperatura e as alterações no padrão de precipitação, com secas severas, representam um dos principais desafios para a agricultura. Diante disso, objetivou-se avaliar o impacto da temperatura na época de plantio combinado com o déficit hídrico no desempenho vegetativo de cultivares de sorgo. O delineamento experimental foi em blocos casualizados, no arranjo fatorial 2x6x4, sendo duas épocas distintas do ano (uma com plantio realizado em junho – temperatura moderada, e outra em plantio realizado em janeiro – temperatura alta, nas condições do Brasil), seis cultivares de sorgo (AGRI002E, BRS 506, BRS 716, SF 15, Santa Elisa e BRS Ponta Negra) e quatro disponibilidade hídrica do solo (25; 50; 75 e 100% da capacidade do campo – CC), com quatro repetições. As Avaliações biométricas do desenvolvimento da planta (altura da planta, número de folhas, diâmetro do colmo e número de perfilhos) foram realizadas no início da fase de maturação. Os dados foram submetidos à análise de variância pelo teste Scott-Knott e regressão para a disponibilidade hídrica. As cultivares de sorgo apresentaram respostas diferenciadas frente ao estresse combinado de aumento da temperatura do ar em diferentes épocas de plantio e o déficit hídrico. A época mais quente para o plantio mostrou-se mais vantajoso para os parâmetros de altura da planta, número de folhas e diâmetro do colmo. O efeito combinado entre a restrição hídrica e a temperatura afeta negativamente as respostas biométricas das plantas de sorgo, o que pode reduzir o desenvolvimento das plantas e, consequentemente, o rendimento final.

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Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2022) has indicated increased temperatures and altered precipitation patterns with severe drought among the main challenges for agriculture and food safety (YADAV et al., 2020). Impacts on physiological and biochemical plant mechanisms stand out as direct impacts of these conditions (FGHIRE et al., 2015; YADAV et al., 2020; ISLAM et al., 2021), considering that turgor pressure, which influences cell growth, promotes leaf wilting, leaf abscission, and decreased leaf area and transpiration. These factors reduce plant height, harming their growth and development (FGHIRE et al., 2015; YADAV et al., 2020; ISLAM et al., 2021).

Leaf area and plant height are essential to assess plant growth and development during the vegetative phase (MITTLER, 2006). In this context, biometry may evaluate the effects of combined plant stresses at different phenological stages, focusing on a precise quantification of measures and physical characteristics (LUCCHESI, 1984). Biometric characterization identifies genotype responses to environmental, temperature, and water deficit variations (RAO et al., 1999; SANKARAPANDIAN, 2013; PERAZZO et al., 2017), allowing the selection of tolerant materials (BEGNA, 2022).

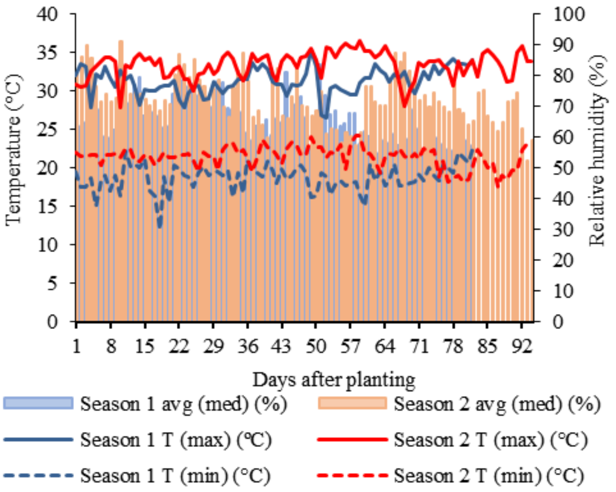
Sorghum [*Sorghum bicolor* (L.) Moench.] has multiple uses, such as producing high-quality grains, silage (TABOSA et al., 2020), and human food (KANTI MEENA et al., 2022) and as biomass with potential for biofuel burning and production (PIMENTEL et al., 2017; SILVA et al., 2018). Hence, biometric characteristics are relevant for selecting tolerant sorghum cultivars for higher air temperatures (NASCIMENTO, 2022).

However, extreme temperatures and water deficits in the environment are simultaneous, and the threats of combined stresses are even more severe than individual stresses (JAVED et al., 2020; SHABBIR et al., 2022; PRIYA et al., 2023). Therefore, this study evaluated the impact of cropping season temperature combined with water deficit on the vegetative performance of sorghum cultivars.

Material and Methods

The experiment was performed in a field at Embrapa Semi-Arid, in Petrolina, PE, Brazil (9° 8' 8.9" S, 40° 18' 33.6" W). The analysis of sorghum cultivars tolerant to abiotic stresses was based on the combination of thermal and water stresses. Planting occurred in two seasons: June 2021, when maximum temperatures were between 26.6 and 34.2°C (moderate) and relative humidity was 65.87%, and January 2022, when temperatures were between 27.9 and 36.6°C (high) and relative humidity was 73.35%. Figure 1 presents the climate data.

Figure 1. Maximum temperature (Ta max (°C)), minimum temperature (Ta min (°C)), and mean relative humidity (Rh mean (%)).



Source: Authors (2023)

The experimental design was randomized blocks in a 2x6x4 factorial arrangement, performed in two annual cropping seasons Season 1 in June of 2021, with maximum temperatures ranging from 26.6 to 34.2 °C, and Season 2 in January of 2022, with maximum temperatures ranging from 27.9 to 36.6 °C**,** using six sorghum cultivars for biomass production (AGRI002E, BRS 506, BRS 716, SF 15, Santa Elisa, and BRS Ponta Negra) at four soil water availabilities (WA) (25, 50, 75, and 100% field capacity), with four repetitions.

Sorghum cultivars were planted in 26L vases and placed outdoors. The soil was a red-yellow eutrophic plinthic acrisol (EMBRAPA, 2013). Base fertilization was applied three days before planting according to soil chemical analyses and crop recommendations (CAVALCANTI, 2008).

Ten seeds per vase were planted in 5 cm-deep pits, and thinning occurred after 15 days, leaving only one plant per vase. Irrigation management was based on the maximum water retention capacity of the soil in the vase (field capacity), using the Time Domain Reflectometry (TDR) device, model TDR100, by Campbell. Coaxial cable sensors with three rods and TDR calibration were used following the protocols by Batista (2016). Irrigation occurred every two days based on a soil water balance, replacing the amount of water for maintaining humidity according to previously established treatments.

Biometric assessments were performed when the plants started the maturation phase (82 and 94 days after planting in seasons 1 and 2, respectively). This stage shows complete internode extensions, which define the final plant height. The evaluated biometric characteristics were plant height - measured in centimeters (cm) with a measuring tape from the soil level to the neck of the last expanded leaf; stem diameter - measured in millimeters (mm) with a digital caliper at the corresponding height of 10 cm from the stem base; the number of leaves - quantified by counting complete green leaves (expanded) in each plant; and the number of tillers - determined by a simple count in each plant.

The data were subjected to the analysis of variance (ANOVA), and the means were compared with the Scott-Knott test at 5% significance for the interaction between seasons and cultivars using the SISVAR 5.6 program. When significance occurred, a regression analysis was performed to assess the influence of water availability.

Results and Discussion

The combination of abiotic stresses (cropping season temperature and water deficit) and sorghum cultivars was significant for all analyzed variables (Tables 1, 2, 3, and 4). The January crop (season 2 - high temperatures) was a determinant for sorghum development, especially when combined with water deficit, and all cultivars were higher in that season (Table 1), indicating a potential adaptation to increased temperatures. The BRS 716 cultivar was highly resilient, increasing height by 90% compared to the June crop (season 1 - moderate temperatures) with 75 and 100% soil water availability (WA). The rate of 75% WA stands out because, even under moderate stress, plant height was 208 cm (Table 1), higher than other cultivars planted in the same season.

Table 1. Plant height of sorghum cultivars according to the combination of thermal stress (cropping season temperature) and water stress (soil water availability).

Plant height (cm)

Season 1 (moderate temperatures)

Cultivar	Water availability (%) 25	50	75	100	Equation*	R^2
AGRI002E	26.50bB	68.00bB	89.32cB	89.22dB	$-0.0166x^2 + 2.918x – 36.1125$	1
BRS 506	42.37aB	96.00aB	132.00aA	156.33aA	$-0.0117x^2 + 2.9761x - 24.406$	0.99
BRS 716	25.75bB	74.00bB	108.50bB	123.75bB	$-0.0132x^2 + 2.964x - 40.375$	0.99
SF 15	27.00bB	26.50cB	80.50cB	104.25cB	$0.0097x^2 – 0.0695x + 18.4375$	0.92
Santa Elisa	25.33bB	62.00bB	107.00bB	118.00bB	$-0.0102x^2 + 2.5753x -34.7518$	0.98
BRS Ponta Negra	27.33bB	64.66bB	101.66bB	116.66bB	$-0.0089x^2 + 2.3367x – 26.5862$	0.99

Season 2 (high temperatures)

Cultivar	Water availability (%) 25	50	75	100	Equation*	R^2
AGRI002E	77.00bA	153.00aA	180.66bA	195.00cA	$-0.0247x^2 + 4.61x - 21.083$	0.99
BRS 506	108.00aA	114.75cA	132.25dA	160.00dA	$0.0084x^2 - 0.356x + 111.63$	1
BRS 716	108.12aA	152.66aA	208.00aA	234.66aA	$-0.0072x^2 + 2.6336x + 44.781$	0.99
SF 15	81.66bA	130.50bA	166.75cA	198.66cA	$-0.0068x^2 + 2.3948x + 26.437$	0.99
Santa Elisa	76.00bA	160.00aA	175.66bA	213.33bA	$-0.0188x^2 + 4.058x – 9.0833$	0.95
BRS Ponta Negra	87.75bA	156.75aA	165.00cA	190.66cA	$-0.0173x^2 + 3.4347x + 16.625$	0.94

Means followed by the same lower-case letter in the column for the same cropping season among cultivars and upper-case letters in the column between cropping seasons for the same cultivar do not differ by the Scott-Knott test at a 5% probability. * The equations describe the relationship between water availability (x) and the morphological characteristics of sorghum (y) for each cultivar and season.

Source: Authors (2023)

The optimal temperature for sorghum development is between 33 and 34 °C (RIBAS, 2003). However, our study showed that a maximum air temperature of 36.5 °C may favor the growth of the analyzed sorghum cultivars (Table 1). This response demonstrates the adaptability of plants to higher temperatures, corroborating Nascimento (2022). Conversely, temperature was not beneficial (season 2) when combined with water stress, significantly decreasing plant growth with 25% WA and showing cultivar heights between 77 and 108.12 cm (Table 1). Hence, water is a determinant for sorghum plants to achieve their height potential, noting that plant height is one of the relevant characteristics among biometric variables for sorghum cultivar selection. Plant height may also predict agronomic characteristics (PERAZZO et al., 2013; GUIMARÃES et al., 2016) because larger sorghum genotypes tend to produce more dry matter (SILVA et al., 2022).

Overall, the number of leaves was higher for plants maintained with 100% WA combined with cropping season 2 (high temperatures) for all cultivars (Table 2). except for SF 15 (. which planting in the moderate-temperature season favored a higher number of cultivar leaves.

Table 2. The number of leaves in sorghum cultivars according to the combination of thermal stress (cropping season temperature) and water stress (soil water availability).

Number of leaves						
Season 1 (moderate temperatures)						
Cultivar	Water availability (%)				Equation*	R^2
	25	50	75	100		
AGRI002E	6.25bA	7.50cB	8.00baB	8.00bB	$0.023x + 6$	0.80
BRS 506	8.25aA	9.25bA	8.25aA	8.25bB	$\hat{y} = \bar{y} = 8.5$	---
BRS 716	8.00aA	6.50cB	8.75aB	8.25bB	$\hat{y} = \bar{y} = 7.87$	---
SF 15	5.75bA	10.25aA	9.50aA	11.25aA	$-0.0011x^2 + 0.2005x + 1.8125$	0.82
Santa Elisa	8.25aA	8.50bB	7.75aB	8.50bB	$\hat{y} = \bar{y} = 8.25$	---
BRS Ponta Negra	6.25bB	8.75bB	8.75aB	9.50bB	$-0.0007x^2 + 0.1265x + 3.6875$	0.91
Season 2 (high temperature)						
Cultivar	Water availability (%)				Equation*	R^2
	25	50	75	100		
AGRI002E	6.25bA	9.33bA	10.50bA	13.00bA	$0.0857x + 4.4167$	0.97
BRS 506	5.62bA	8.33bA	9.00cA	9.66cA	$-0.0008x^2 + 0.1533x + 2.4062$	0.97
BRS 716	7.75aA	9.00bA	10.75bA	12.25bA	$0.061x + 6.125$	0.99
SF 15	6.5bA	7.00cB	9.50cA	10.75cB	$0.061x + 4.625$	0,94
Santa Elisa	6.75bB	11.25aA	12.75aA	14.25aA	$-0.0012x^2 + 0.246x + 1.5$	0,98
BRS Ponta Negra	8.00aA	10.25aA	11.25bA	12.50bA	$0.058x + 6.875$	0.96

Means followed by the same lower-case letter in the column for the same cropping season among cultivars and upper-case letters in the column between cropping seasons for the same cultivar do not differ by the Scott-Knott test at a 5% probability. * The equations describe the relationship between water availability (x) and the morphological characteristics of sorghum (y) for each cultivar and season.

Source: Authors (2023)

The regression of the June crop was not adjusted according to soil water availability for the number of leaves of BRS 506, BRS 716, and Santa Elisa cultivars, which were represented by mean values (Table 2). The absence of significant variations among water availability levels for the number of leaves of these cultivars may be due to wax deposits in the pod-leaf junction typical of sorghum leaves. These wax deposits are vital for plant water conservation, reducing water loss during transpiration, especially under water stress (BUROW et al., 2009).

The number of leaves among cultivars was higher when planting the Santa Elisa cultivar in the high-temperature season combined with 100% WA, presenting 14.25 leaves. However, even when combined with moderate water stress (50 and 75% WA), the cultivar performed well, with 11.25 and 12.75 leaves, respectively, overcoming the other cultivars with the same water availability (Table 2).

Oliveira et al. (2021), verified that the number of leaves directly affects sorghum productivity, and water deficit is responsible for premature leaf senescence, decreasing production (RODRIGUES et al., 2021). Thus, the high number of leaves may have favored the Santa Elisa cultivar yield.

Conversely, water deficit reduces leaf nitrogen, unbalancing carbon and nitrogen in mature leaves and inducing leaf senescence (CHEN et al., 2015). Moreover, plant damage is more intense when combined with thermal stress, hindering photosynthetic efficiency, increasing respiration rates, damaging cell membranes. denaturing proteins, inducing oxidative stress, and inhibiting growth. These factors compromise plant vitality, development, and productivity and may directly affect the formation and maintenance of the number of leaves (JUMRANI and BHATIA, 2018; SHABBIR et al., 2022).

Plants subjected to severe water stress (25% WA) emitted fewer leaves and more leaf senescence, except for BRS 506, BRS 716, and Santa Elisa cultivars combined with moderate temperatures (June crop), not being affected by water availability (Table 2).

Stem diameter is crucial for plant resistance against breakage and bedding and was also affected by combined stress (Table 3). AGRI002E, BRS 716, and Santa Elisa cultivars showed significantly larger stem diameters in the highest water availability (100%) combined with high temperatures (season 2), increasing these diameters by approximately 60, 69.4, and 93%, respectively, compared to season 1 (moderate temperatures) (Table 3).

Table 3. Stem diameters in sorghum cultivars according to the combination of thermal stress (cropping season temperature) and water stress (soil water availability).

Stem diameters (mm)						
Season 1 (moderate temperatures)						
Cultivar	Water availability (%)				Equation	R^2
	25	50	75	100		
AGRI002E	12.22aB	16.02bB	13.91bB	16.69bB	$0.0451x + 11.8912$	0.51
BRS 506	9.63aB	17.59aA	18.06aB	17.99bB	$-0.0032x^2 +0.5041x – 0.6112$	0.95
BRS 716	12.31aB	14.55bB	14.89bB	15.89bB	$0.0442x + 11.6487$	0.89
SF 15	12.85aB	18.61aA	17.21aB	21.16aB	$0.0941x + 11.5775$	0.76
Santa Elisa	11.78aB	14.05bB	12.85bB	14.26bB	$\hat{y} = \bar{y}= 13.23$	---
BRS Ponta Negra	11.72aB	17.04aB	17.40aB	17.67bB	$-0.002x^2 + 0.3256x + 5.0862$	0.95
Season 2 (high temperature)						
Cultivar	Water availability (%)				Equation	R^2
	25	50	75	100		
AGRI002E	16.98aA	21.39bA	23.91aA	26.19aA	$0.1206x + 14.58$	0.97
BRS 506	16.96aA	1990bA	21.31bA	23.59bA	$0,0852x + 15.11$	0.98
BRS 716	19.50aA	23.39aA	25.57aA	26.91aA	$0.0976x + 17.7387$	0.94
SF 15	15.72aA	19.43bA	22.10bA	24.46bA	$0.1155x + 13.2125$	0.98
Santa Elisa	17.77aA	22.40aA	24.44aA	27.51aA	$0.125x + 15.22$	0.97
BRS Ponta Negra	17.20aA	21.01bA	22.96bA	23.48bA	$0.0832x + 15.9662$	0.88

Means followed by the same lower-case letter in the column for the same cropping season among cultivars and upper-case letters in the column between cropping seasons for the same cultivar do not differ by the Scott-Knott test at a 5% probability. * The equations describe the relationship between water availability (x) and the morphological characteristics of sorghum (y) for each cultivar and season.

Source: Authors (2023)

The same cultivars also presented considerable yield under moderate stress (75% WA) combined with high temperatures (season 2), increasing stem diameter by approximately 71% for AGRI002E and BRS 716 cultivars and 90% of the Santa Elisa cultivar compared to the effect combined with the moderate-temperature season. BRS 716 and Santa Elisa cultivars stood out because, even at 50% WA stress, their stem diameters increased by around 60% compared to the combination with season 1 (moderate temperatures).

SF 15 cultivar plants showed a larger stem diameter (21.16 mm) with 100% WA combined with moderate temperatures among the other cultivars in the same season (Table 3).

Silva et al. (2014), showed that stem diameter is relevant for analyzing plant susceptibility to bedding and breakage that harms crop harvesting and reduces final yield. Therefore, selecting genotypes with larger stem diameters is significant because it is directly related to fresh and dry matter production (KIRCHNER et al., 2019).

The largest stem diameter is evidenced by cell turgidity caused by the ideal water supply responsible for plant growth and cell elongation up to the optimal water range.

It is worth noting that excess leads to smaller stems because of low root oxygenation (JHAN et al., 2023). The findings highlight the tolerance of cultivars to increased temperatures even when combined with water shortage. The significant increase in stem diameter, especially during the high-temperature season (season 2), demonstrates the adaptability of AGRI002E, BRS 506, BRS 716, SF 15, Santa Elisa, and BRS Ponta Negra cultivars. Therefore, knowing the combined effects of high temperatures and water stress on cultures is vital to understanding plant responses, mainly considering climate change impacts (JUMRANI and BHATIA, 2018).

The number of tillers (Table 4) was considerably sensitive to combined stress variations. The moderate-temperature season (June crop) provided more tillers for all cultivars (Table 4), showing that moderate temperatures and shorter days (<12h20min) promote tillering and biomass accumulation. However, the January crop with high temperatures and longer days (>12h20min) significantly reduced the number of tillers, especially in the SF 15 cultivar. Moreover, the water availability level affected each cultivar differently. This pattern indicates an intrinsic relationship between water stress and cropping season temperature, directly impacting tillering.

Table 4. The number of tillers in sorghum cultivars according to the combination of thermal stress (cropping season temperature) and water stress (soil water availability)

Number of tillers						
Season 1 (moderate temperatures)						
Cultivar	Water availability (%)				Equation	R^2
	25	50	75	100		
AGRI002E	3.00aA	4.00bA	6.75aA	3.50cA	$-0.0017x^2 + 0.2295x - 2.0625$	0.99
BRS 506	1.75aA	1.75cA	1.50cA	1.75dA	$\hat{y} = \bar{y} = 1.69$	0.96
BRS 716	2.5aA	4.25bA	4.25bA	3.25cA	$-0.0011x^2 + 0.1465x - 0.4375$	0.92
SF 15	1.75aA	6.50aA	5.25bA	7.75aA	$-0.0009x^2 + 0.1795x - 1.6875$	0.95
Santa Elisa	2.50aA	5.25aA	4.75bA	5.25bA	$-0.0009x^2 + 0.1435x - 0.3125$	0.92
BRS Ponta Negra	2.25aA	3.00cA	4.75bA	4.50cA	$0.034x + 1.5$	0.97
Season 2 (high temperature)						
Cultivar	Water availability (%)				Equation	R^2
	25	50	75	100		
AGRI002E	0aB	1.75aB	2aB	3.25aA	$0.04x - 0.75$	0.95
BRS 506	0aB	0bB	0bB	0bB	$\hat{y} = \bar{y} = 0$	0.94
BRS 716	0aB	0bB	0bB	0bB	$\hat{y} = \bar{y} = 0$	0.55
SF 15	0.75aA	1.50aB	1.00bB	2.25aB	$\hat{y} = \bar{y} = 1.37$	0.91
Santa Elisa	0aB	0bB	2.5aB	1.75aB	$0.031x - 0.875$	0.77
BRS Ponta Negra	0aB	0bB	1.5aB	1.25aB	$0.021x - 0.625$	---

Means followed by the same lower-case letter in the column for the same cropping season among cultivars and upper-case letters in the column between cropping seasons for the same cultivar do not differ by the Scott-Knott test at a 5% probability. * The equations describe the relationship between water availability (x) and the morphological characteristics of sorghum (y) for each cultivar and season.

Source: Authors (2023)

The SF 15 cultivar stood out with a mean of 7.75 tillers when irrigated with 100% WA. In the January crop, the SF 15 cultivar also showed more tillers, but increased temperatures caused a 71% reduction compared to the moderate-temperature season (Table 4).

The combined stress effect between moderate temperatures and 67% WA promoted a higher number of tillers for AGRI002E and BRS 716 cultivars, with means of 5.68 and 4.44 tillers, respectively (Table 4). The combined effect between stresses did not interfere with tiller formation in the BRS 506 cultivar, presenting a mean of 1.69 tillers in the moderate-temperature season and not tillering at high temperatures, showing that only increased temperatures affected tiller formation in the cultivar. The BRS 716 cultivar also did not present interferences from the combined stress between high temperatures and water availability, not forming tillers in season 2.

This data variation may be related to genetic, environmental and hormonal factors that regulate apical dominance that directly affect sorghum plant tillering (ROTILI et al., 2021). Short days (shorter than 12 hours and 20 minutes) (RODRIGUES, 2021) and moderately low temperatures (16.7 and 26 °C) (ALAM et al., 2014) favored sorghum tillering compared to planting with temperatures between 20.2 and 31.9 °C, promoting higher biomass accumulation (PERAZZO et al., 2013). These influences agree with the responses from the evaluated cultivars, considering the higher number of tillers in the moderate-temperature season (Table 4).

Rotili et al. (2021) stated that higher temperatures are associated with higher leaf expansion because of the capture of solar radiation but also increase night respiration, limiting available carbohydrates for tiller formation. However, lower temperatures (moderate) compromise photosynthesis, reducing plant growth rates and raising carbon allocation to axillary meristems, consequently favoring tiller formation (ROTILI et al., 2021). Moreover, temperature influences overall development speed, affecting total carbon allocation to axillary meristems, regardless of daily carbon assimilation. Therefore, higher temperatures in field conditions accelerate development, reducing the time of tiller formation from axillary meristems, and lower temperatures typical of moderate environments provide more favorable conditions for tiller formation.

This study highlights the relevance of considering the combined effects of environmental stress on plants. The mean increase in air temperature of 1.9 °C between cropping seasons and water availability variations significantly affected the biometry of the analyzed sorghum cultivars.

Although 100% WA favored sorghum production, positive responses also occurred with lower water availability. These responses are essential for understanding the effects of climate change on the physical characteristics of plants and their productive potential.

Conclusion

The warmest cropping season benefited plant height, the number of leaves, and stem diameter of the evaluated cultivars, and the higher number of tillers occurred in plants cultivated in the moderate-temperature season. The combined effect of water restrictions and moderate temperatures harmed the biometric responses of sorghum plants, potentially reducing plant development and final yield.

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