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Responses of African mahogany seedlings to temperature, vapor pressure deficit and water availability

Respostas de mudas de mogno africano à temperatura, déficit de pressão de vapor e disponibilidade de água

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Abstract

The genus *Khaya* holds significant value in the national and international forest market due to its noble wood. However, the limited understanding of species-climate interactions hinders its expansion in Brazil. To address this, we investigated the effects of different microclimates on the growth of *Khaya ivorensis*, *Khaya senegalensis*, and *Khaya anthotheca* seedlings, considering variations in mean air temperature (T), vapor pressure deficit (VPD), and water availability. Seedlings were cultivated in controlled environments representing three microclimates (I: 24.7 °C, 0.30 kPa VPD; II: 28.6 °C, 0.95 kPa VPD; III: 29.8 °C, 1.80 kPa VPD) with varying water availability levels (20%, 40%, 60%, and 90% of maximum water holding capacity). Growth variables were assessed. Our findings indicate that water restriction reduced seedling growth across all microclimates, leading to lower total dry mass production. Specifically, *K. ivorensis* exhibited robust growth under microclimates with higher water availability. *K. senegalensis* displayed optimal initial growth in microclimate III (29.8 °C, 1.80 KPa), particularly when subjected to higher water availability levels in the substrate.

Keywords: Ecophysiology; *K. anthotheca*; *K. ivorensis*; *K. senegalensis*; Microclimate.

Resumo

O gênero *Khaya* possui madeira nobre e, portanto, é relevante para o mercado florestal nacional e internacional. No entanto, a falta de informações sobre as interações das espécies com o clima é a principal limitação para sua expansão no Brasil. Assim, investigamos os efeitos de diferentes microclimas no crescimento de mudas de *K. ivorensis*, *K. senegalensis* e *K. anthotheca* combinando diferentes faixas de temperatura média do ar (T), déficit de pressão de vapor (DPV) e disponibilidade hídrica. Para isso, as mudas foram cultivadas em três diferentes ambientes controlados, caracterizados como: microclima I (temperatura do ar 24,7 °C e DPV 0,30 kPa), microclima II (temperatura do ar 28,6 °C e DPV 0,95 kPa) e microclima III (temperatura do ar 29,8°C e DPV 1,80 kPa); todos os microclimas apresentaram quatro níveis de disponibilidade hídrica: 20%, 40%, 60% e 90% da capacidade máxima de retenção de água do substrato, respectivamente. Variáveis de crescimento foram avaliadas. Nossos resultados revelaram que as mudas reduziram seu crescimento quando submetidas à restrição hídrica em todos os microclimas, resultando em menor produção de massa seca total. A espécie *K. ivorensis* apresentou alto crescimento nos microclimas estudados em condições de maior disponibilidade hídrica. A espécie *K. senegalensis*

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apresentou o maior crescimento inicial no microclima III (29,8°C; 1,80 Kpa) quando submetida aos maiores níveis de disponibilidade hídrica no substrato.

Palavras-chave: Ecofisiologia; *K. anthotheca*; *K. ivorensis*; *K. senegalensis*; Microclima.

INTRODUCTION

Brazil, the sixth largest exporter of forest products globally, presents favorable tropical and subtropical climates that contribute to its thriving national forest production. In 2019, the sector witnessed a remarkable 12.6% growth (Indústria Brasileira de Árvores, 2020), with exports surpassing 11 billion dollars annually (Food and Agriculture Organization, 2021). Notably, African mahogany (*Khaya anthotheca* Welw, *Khaya ivorensis* A. Chev., and *Khaya senegalensis* A. Juss) plantations have gained prominence in the northern and southeastern regions of the country (Pinheiro & Chaves, 2011; Ribeiro et al., 2017; Reis et al., 2019), covering an area of over 37 thousand hectares (Reis et al., 2019). Renowned for its rapid growth rate and prized, high-value wood (Reis et al., 2019; Guimarães et al., 2004), African mahogany has sparked keen interest among farmers, corporations, governmental and research institutions, prompting efforts to expand its cultivation to other regions of Brazil.

Expanding African mahogany plantations to non-traditional areas in Brazil, such as the subtropical regions in the southeast (average annual temperature: 20ºC to 24ºC) or the tropical and semi-arid regions in the north (average annual temperature: 28ºC to 32ºC) (Elli et al., 2020), faces challenges due to limited understanding of the species' ecophysiology. Furthermore, climate change poses risks to both commercial and non-commercial forests in Brazil, with an increased occurrence of extreme weather events like heatwaves, frosts, and droughts. Projections indicate a projected 2ºC temperature rise and up to a 15% decrease in rainfall in central Brazil, the main region for commercial forest cultivation (Elli et al., 2020), potentially rendering future African mahogany cultivation unsuitable in this area.

High temperatures have been observed to stimulate respiration and photorespiration processes in most forest species, leading to a decline in photosynthetic efficiency (Yamori et al., 2014; Nóia Júnior et al., 2018a) and triggering leaf abscission (Hikosaka et al., 2006; Taiz & Zeiger, 2013). Conversely, low temperatures reduce photosynthesis rates due to decreased stomatal conductance, resulting in diffusive and metabolic limitations (Santos et al., 2011; Nóia Júnior et al., 2018b). However, the response of tropical trees to temperature is not solely determined by temperature alone. Other climatic factors, such as vapor pressure deficit (VPD) and water availability, play a significant role in shaping their response.

Research on rubber trees, eucalyptus, and jaborandi has demonstrated the influence of VPD and water availability on the response of tropical trees to temperature (Marenco et al., 2014; Chaves et al., 2009; Guo et al., 2010; Nóia Júnior et al., 2018b; Nóia Júnior et al., 2020; Amaral et al., 2021). These studies have revealed that water stress can exacerbate the negative effects of high temperatures on photosynthetic efficiency, while sufficient water availability can mitigate those effects to some extent. In the case of African mahogany, a limited understanding of its response to temperature, VPD, and water availability hampers its future cultivation and expansion into new areas in Brazil. This knowledge gap poses challenges for the development of appropriate cultivation practices and management strategies.

Given the increasing risks posed by climate change, including more frequent and severe extreme weather events, the need to comprehend the response of African mahogany to temperature and water-related stressors becomes even more pressing. The projected temperature rise and decreased rainfall in central Brazil, the primary region for commercial forest cultivation, further underscore the importance of investigating the adaptability and resilience of African mahogany in the face of changing climatic conditions.

To ensure successful cultivation and sustainable expansion, comprehensive research is warranted. Based on the above, the objective of this study was to evaluate the growth of three African mahogany species (*K. anthotheca*, *K. ivorensis* and *K. senegalensis*) subjected to different ranges of temperatures, VPD and water availability, in order to evaluate the eco-physiological potential of the species. High temperatures have been observed to increase respiration and photorespiration processes in most forest species, leading to a decline in photosynthetic efficiency (Yamori et al., 2014; Nóia Júnior et al., 2018a) and triggering leaf abscission (Hikosaka et al., 2006; Taiz & Zeiger, 2013). Conversely, low temperatures reduce photosynthesis rates due to decreased stomatal conductance, resulting in diffusive and metabolic limitations (Santos et al., 2011; Nóia Júnior et al., 2018b). Additionally, the response of tropical trees to temperature is influenced by other climatic factors such as vapor pressure deficit (VPD) and water availability, as observed in rubber trees, eucalyptus, and jaborandi (Marenco et al., 2014; Chaves et al., 2009; Guo et al., 2010; Nóia Júnior et al., 2020; Amaral et al., 2021). Water stress and drought present challenges for African mahogany. Reduced water availability affects photosynthesis and growth. Understanding the species' response is crucial for successful cultivation, including irrigation strategies, drought-tolerant varieties, and climate change adaptation. However, the understanding of such responses in African mahogany species remains limited. Therefore, the future cultivation and expansion of African mahogany in new areas of Brazil necessitate a comprehensive examination of its response to different air temperature ranges, VPD, and water availability.

Comprehensive research is crucial for successful cultivation and sustainable expansion of African mahogany. This study aims to evaluate the growth of three species (*K. anthotheca*, *K. ivorensis*, and *K. senegalensis*) under varied temperatures, VPD, and water availability. By assessing their eco-physiological potential, we can enhance our understanding and promote effective cultivation practices.

MATERIAL AND METHODS

Study site and experimental design

The experiment was conducted in commercial greenhouses (Van der Hoeven® model) with controlled temperature and relative humidity belonging to the Meteorology and Forest Ecophysiology Laboratory of the Federal University of Espírito Santo, in the municipality of Jerônimo Monteiro, Espírito Santo, Brazil.

Seedlings with an average of 100 days old produced via seeds of three African mahogany species of *Khaya ivorensis* A. Chev., *K. senegalensis* A. Juss. and *K. anthotheca* (Welw.) C. DC. were obtained from the Brazilian Institute of Forests (IBF), located in the municipality of Londrina, Paraná, Brazil. The seedlings were planted in 12 L pots filled with substrate composed of 68% soil (Red-yellow Latosol collected at a depth of 20-50 cm), 16% tanned cattle manure and 16% coffee straw. The nutritional characterization of the substrate can be seen in Table 1.

Table 1. Chemical analysis of a Red-yellow Oxisol used in an experiment in a greenhouse from October 15, 2013 to January 14, 2014 in the municipality of Jerônimo Monteiro - ES.

Chemical analysis																			
pH	P	K	Na	Ca	Mg	Al	H+Al	C	M.0.	CEC(t)	CEC(T)	S.B.	V	m	ISNa	Fe	Cu	Zn	Mn
H_2O	mg dm^{-3}			cmol$_c$ dm^{-3}				g kg^{-1}		cmol$_c$ dm^{-3}			%			mg dm^{-3}			
6.2	323	890	42	6.3	1.6	0	3.7	8.3	14.4	10.6	14.3	10.6	74.7	0.0	2.0	34	0.3	4.0	20

pH = potential Hydrogeologic; P = phosphorus; K = potassium; Na = sodium; Ca= Calcium; Mg = magnesium; Al = aluminum; H+Al = potential acidity; C = carbon; M.O = organic matter; CEC(t) = effective cation exchange capacity; CEC(T) = total cation exchange capacity; S.B = sum of bases; V = percentage of base saturation; m = percentage of saturation by aluminum; ISNa = percentage of sodium saturation; Fe = Iron; Cu = Copper; Zn = Zinc; Mn = Manganese.

Seedlings were 100 days old when planted and averaged 22.0 cm in height, 3.1 mm in stem diameter, 10.2 cm^2 of leaf area and 6.2 g of total dry mass. The seedlings were kept for 21 days in an climatized greenhouse and then were randomly distributed to environments with different microclimatic conditions. Three different treatments were defined through a combination of different temperature and VPD conditions, characterized as follows: microclimate I (air temperature 24.7 °C and VPD 0.30 kPa), microclimate II (air temperature 28.6 °C and VPD 0.95 kPa) and microclimate III (air temperature 29.8 °C and VPD 1.80 kPa). Each microclimate took place in a different greenhouse. In addition, four water availability levels were tested within each microclimate: 20%, 40%, 60% and 90% of the water available in the substrate. The experiment was carried out in a completely randomized design in a 3x3x4 factorial scheme consisting of three species of African mahogany, three microclimatic conditions, four available soil water levels with five replications, and each replicate was represented by a plant. The experiment was carried out for a period of 90 days.

Microclimatic characterization

An automatic meteorological station was installed consisting of a temperature and relative humidity sensor (Campbell Scientific, Inc., Logan, UT, USA) in order to characterize the microclimate within each of the three greenhouses. Data were stored in a CR-10x model datalogger (Campbell Scientific, Inc., Logan, UT, USA) whose data readings were performed every 10 seconds and mean values were stored every 15 minutes. The air vapor pressure deficit (VPD) values were obtained from the difference between the pressure saturation and the partial pressure of water vapor. The three microclimates were characterized over the 90 days of the experimental period. Daily temperature, VPD and RH of the three microclimates studied and their mean values are shown in Figure 1 and Table 2, respectively.

Table 2. Average values of air temperature and vapor pressure deficit at times of the day, night, maximum, minimum and general average of air temperature and vapor pressure deficit in the period from October 15, 2013 to 14 January 2014, in three heated greenhouses in the municipality of Jerônimo Monteiro - ES.

	Microclimate I	Microclimate II	Microclimate III
		Air temperature (°C)	
Maximum	27.7	32.8	34.9
Minimum	21.8	23.7	24.3
Average	24.7	28.6	29.8
		Vapor pressure deficit (Kpa)	
Maximum	0.67	1.60	2.88
Minimum	0.02	0.48	0.56
Average	0.30	0.95	1.70

The air temperature in the greenhouses was controlled by an evaporative cooling system (pad cooling) and air conditioners which were activated by temperature controllers (Full Gauge®, MT-543Ri plus). Relative air humidity values were maintained using humidity controllers (Full Gauge®, AHC-80 plus) which are based on psychrometrics, and a fogger-type misting system. The temperature and relative humidity variation programming of the control systems was controlled and maintained through the use of Sistrad® software. This software verified and changed (when necessary) the temperature of the greenhouses and relative humidity every 30 min during the day and every hour during the night to simulate the daily microclimatic conditions in each greenhouse in the study (Figure 1).

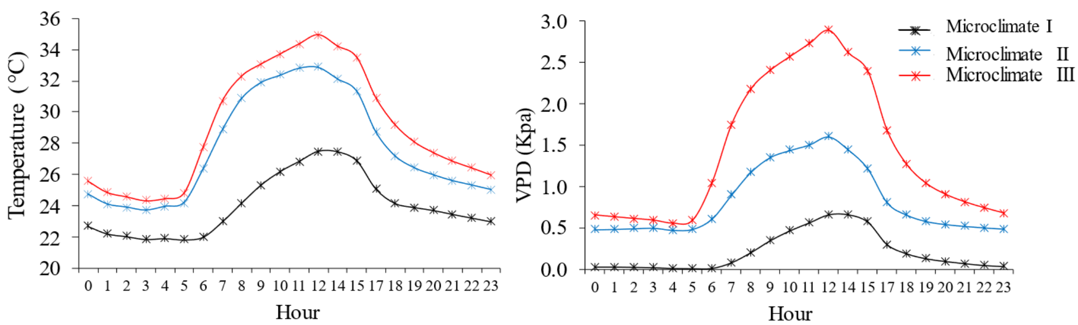

Figure 1. Average daily course of average air temperature (A) and vapor pressure deficit (B) in three heated greenhouses in the municipality of Jerônimo Monteiro - ES, from October 15, 2013 to January 14 of 2014.

Monitoring of water availability and consumption levels

Irrigation was carried out based on the daily weighing of pots with seedlings, replacing the water lost by evapotranspiration (Freire et al., 1980). Water consumption was performed at the end of 90 days of experimentation, calculated in liters for each sampling unit in all treatments. Points of the soil water retention curve were used according to Empresa Brasileira de Pesquisa Agropecuária (1997) to determine the available water values. The field capacity (FC) value was 31.80% and the permanent wilting point (PWP) value was 19.75%. The substrate density was 0.86 g cm^{-3} obtained by the Embrapa test tube method (1997).

Water application for the treatment irrigation levels occurred when soil moisture reached 20%, 40%, 60% and 90% of the available water (measured gravimetrically) to reach the maximum field capacity of the substrate (this procedure was repeated throughout the trial period).

Plant growth analysis

After the experimental period, the seedling height was measured with a millimeter ruler (accuracy of 0.1 cm), diameters with a digital caliper (accuracy of 0.01 mm) and leaf area (LA) with A LI-3100 leaf area integrator (Li-Cor Inc, Lincoln, Nebraska, USA). In addition, the dry mass (DM) for each organ was obtained after drying leaves, stems and roots at 65 °C until constant weight (precision of the equipment used to determine the dry mass was 0.0001 g).

Statistical analysis

Statistical analyses were conducted using the R ExpDes.pt software package (R Core Team, 2017). The data were subjected to one-way analysis of variance (ANOVA) to examine the interaction between microclimates, species, and water availability levels. Normality and homogeneity of the data ($p \leq 0.05$) were assessed using the Shapiro-Wilk test (Shapiro & Wilk, 1965) and Hartley's maximum F-tests (Hartley, 1950), respectively. Tukey's test ($p \leq 0.05$) was employed for mean comparisons. Furthermore, significant interactions between microclimates, species, and water availability levels were visually represented through plotted graphs.

RESULTS

The growth in height, diameter, and leaf area of *K. anthotheca*, *K. ivorensis*, and *K. senegalensis* seedlings was significantly influenced by different microclimates and water availability levels ($p \leq 0.001$, Figures 2 and 3). Higher temperatures (microclimates II and III) positively impacted height growth, with an average of 40.7 cm, while lower temperatures (microclimate I) resulted in an average height of 36.6 cm. *K. anthotheca* exhibited limited growth across all microclimates, with an average reduction of 10 cm compared to *K. ivorensis* and *K. senegalensis*. Seedlings in the 20% water availability treatment showed restricted height growth across all microclimates. The impact of water restriction varied among microclimates, with the most pronounced effect observed in *K. ivorensis* in microclimates I and III, and in *K. senegalensis* in microclimate II. The height growth reduction in the 20% water availability treatment ranged from 20 cm to 39.6 cm, depending on the species and microclimate.

Stem diameter exhibited a significant increase in response to the high temperature of microclimate III ($p \leq 0.001$, Figure 2B), particularly for *K. ivorensis* under 60% and 90% water availability. The combination of lower air temperature and VPD in microclimate I promoted diameter growth across all three species under 20% water availability. Under these conditions, the average stem diameter was 2.3 mm larger compared to seedlings in microclimate II. The most pronounced impact of water restriction was observed in microclimate III with *K. ivorensis* seedlings, where those in the 20% treatment displayed a diameter 8.6 mm smaller than those in the 60% water availability treatment.

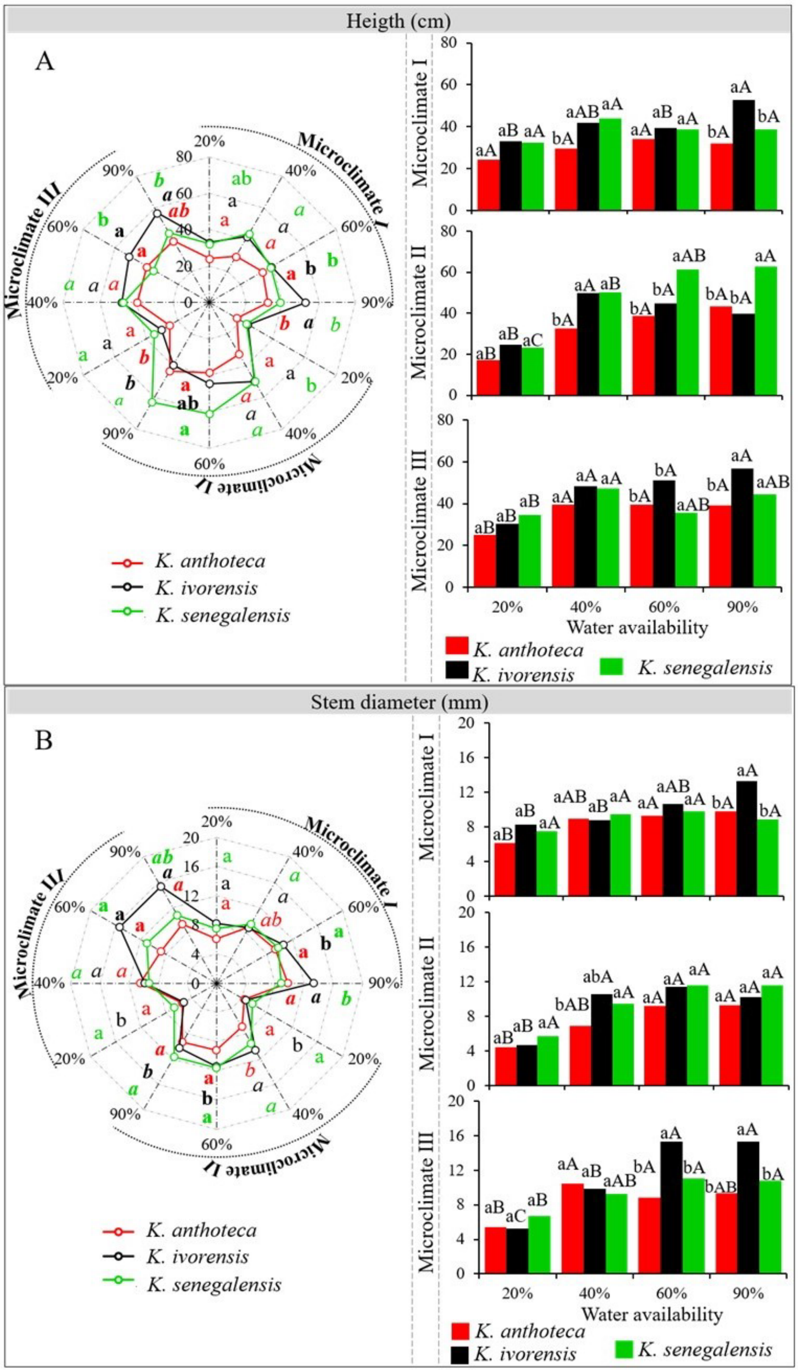

Figure 2. Height (A) and stem diameter (B) of *K. ivorensis*, *K. senegalensis* and *K. anthotheca* seedlings submitted to different temperatures, VPD and water availability. Microclimate I (24.7 °C and 0.30 Kpa), Microclimate II (28.6 °C and 0.95 Kpa) and Microclimate III (29.8 °C and 1.70 Kpa). Water availability levels (WAL): 20%, 40%, 60% and 90%. Different letters represent statistically significant differences between treatments (Tukey's test, p≤0.05). Statistical differences between microclimates (radar graph) are represented by lowercase letters (lowercase for 20% WAL, lowercase italics for 40% WAL, lowercase bold for 60% WAL and lowercase bold/italics for 90% WAL). Statistical differences (bar graphs) between species are represented by lowercase letters and uppercase water availability.

Leaf area was significantly restricted under the conditions of higher air temperatures and vapor pressure deficit (VPD) in microclimates II and III, particularly for seedlings experiencing greater water restriction (20% water availability) ($p \leq 0.001$, Figure 3). The impact of water restriction was more pronounced for *K. senegalensis* in microclimate II, with a reduction of 1870 cm^2 in leaf area observed in the 20% water availability treatment compared to the 60% treatment.

Higher total dry mass production was observed in warmer microclimates ($p<0.001$, Figure 4A). *K. senegalensis* and *K. ivorensis* seedlings displayed greater accumulation of total dry mass under high air temperatures and VPD conditions (microclimates II and III) when well-watered. The impact of water availability was most pronounced in seedlings subjected to higher air temperatures and VPD (microclimate III), with a reduction of 33.3 g in *K. senegalensis* seedlings under 20% water availability compared to 90%.

Shoot dry mass and root dry mass also exhibited positive effects of higher air temperatures and VPD (microclimates II and III) under well-irrigated conditions (60% and 90% water availability) ($p <0.001$, Figure 4B and 4C) in *K. senegalensis* and *K. ivorensis* seedlings. Seedlings in milder air temperature and VPD conditions (microclimate I) and subjected to 20% water availability showed higher values of both shoot dry mass and root dry mass compared to the same treatment in other microclimates for all three species. While *K. ivorensis* seedlings displayed the highest shoot dry mass production under well-irrigated conditions (90% water availability), microclimate III was the most limiting microclimate (25 g reduction) for seedlings under 20% water availability, and a similar pattern was observed for root dry mass with an 8.4 g reduction.

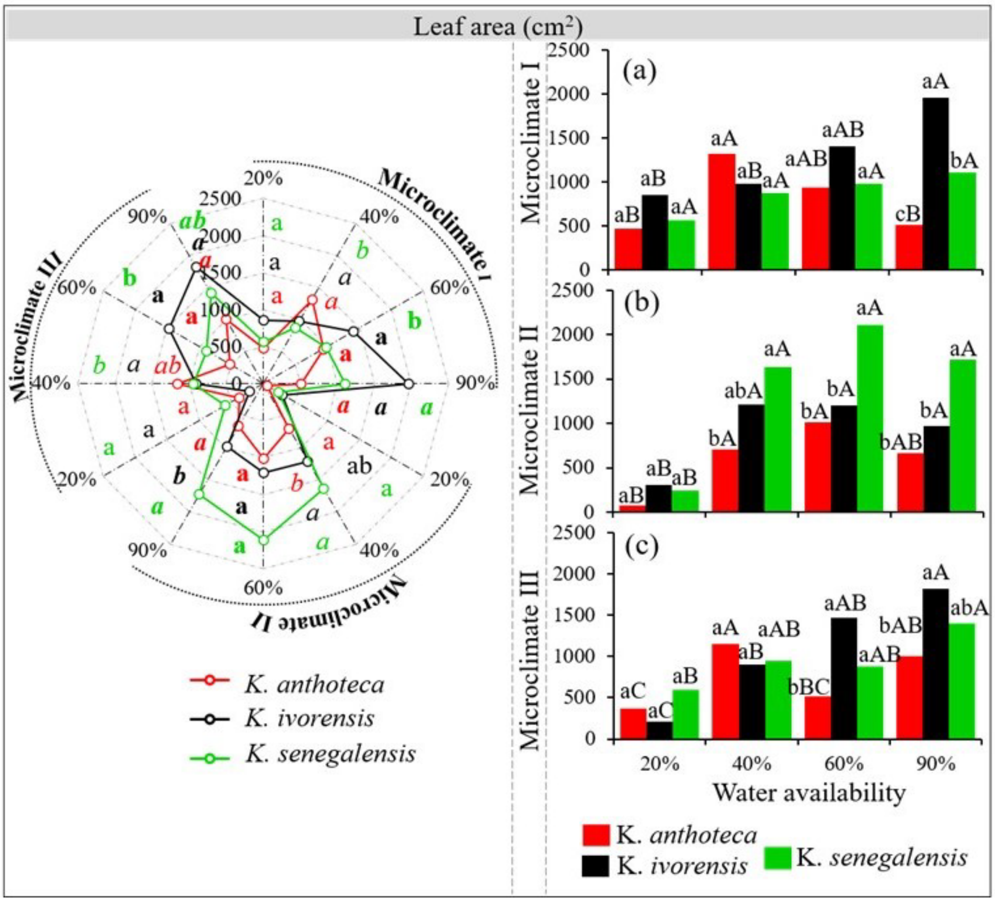

Figure 3. Leaf area of *K. ivorensis*, *K. senegalensis* and *K. anthotheca* seedlings subjected to different temperatures, VPD and water availability. Microclimate I (24.7 °C and 0.30 Kpa), Microclimate II (28.6 °C and 0.95 Kpa) and Microclimate III (29.8 °C and 1.70 Kpa). Water availability levels (WAL): 20%, 40%, 60% and 90%. Different letters represent statistically significant differences between treatments (Tukey's test, $p \leq 0.05$). Statistical differences between microclimates (radar graph) are represented by lowercase letters (lowercase for 20% WAL, lowercase italics for 40% WAL, lowercase bold for 60% WAL and lowercase bold/italics for 90% WAL). Statistical differences (bar graphs) between species are represented by lowercase letters and uppercase water availability.

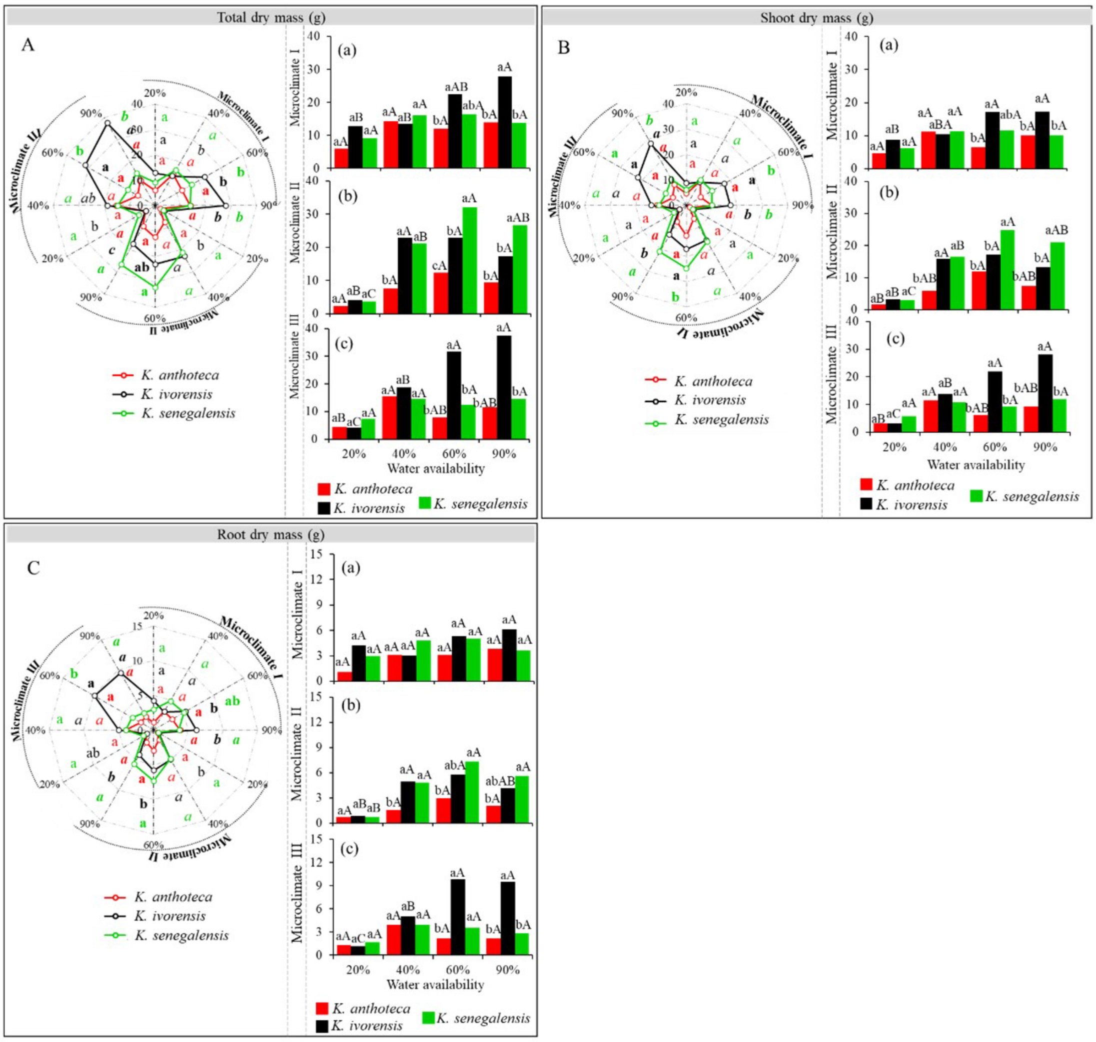

Figure 4. Total dry mass (A), shoot dry mass (B) and root dry mass (C) of *K. ivorensis*, *K. senegalensis* and *K. anthotheca* seedlings subjected to different temperatures, VPD and water availability. Microclimate I (24.7 °C and 0.30 Kpa), Microclimate II (28.6 °C and 0.95 Kpa) and Microclimate III (29.8 °C and 1.70 Kpa). Water availability levels (WAL): 20%, 40%, 60% and 90%. Different letters represent statistically significant differences between treatments (Tukey's test, $p \leq 0.05$). Statistical differences between microclimates (radar graph) are represented by lowercase letters (lowercase for 20% WAL, lowercase italics for 40% WAL, lowercase bold for 60% WAL and lowercase bold/italics for 90% WAL). Statistical differences (bar graphs) between species are represented by lowercase letters and uppercase water availability.

DISCUSSION

To meet the increasing global demand for energy, fiber, and food, it is projected that agricultural and forest production will need to double by 2050 (Food and Agriculture Organization, 2018). However, climate change poses significant challenges to achieving this goal, as high temperatures and droughts have already had detrimental effects on forests worldwide. For instance, the Russian heat wave in 2010 resulted in a 50% reduction in gross primary production, highlighting the vulnerability of forests to extreme temperature events (Teskey et al., 2015). Similarly, recent droughts have led to tree mortality in various regions of the United States. In Brazil, water deficit has been found to cause productivity losses of over 50% in eucalyptus forests (Elli et al., 2019; Freitas et al., 2021). Given these challenges, it is crucial to understand and mitigate climate-induced variations in forest production. This requires a comprehensive understanding of the eco-physiological responses of tree species to changing environmental conditions. Some species of interest are the African mahoganies, which hold significant economic and ecological value.

One of the primary factors influencing tree physiology and performance under changing climatic conditions is high temperature and vapor pressure deficit (VPD). Elevated temperatures, coupled with increased VPD, can have profound effects on various physiological processes. For example, thermal stress characterized by increased temperature amplitudes has been found to negatively impact gas exchange in rubber tree seedlings. This leads to reduced photosynthesis, stomatal conductance, and transpiration, ultimately resulting in higher intercellular CO_2 concentration and increased leaf temperature (Nóia Júnior et al., 2018). Similarly, in the case of Açaí plants, increased atmospheric CO_2 concentrations have been shown to benefit gas exchange. However, the positive effects of elevated CO_2 are counteracted by the adverse impacts of high temperature and VPD, which hinder growth and biomass accumulation (Amaral et al., 2023). Furthermore, jaborandi seedlings subjected to high temperature, elevated CO_2 concentrations, and water stress experience negative effects on their growth and physiological processes (Amaral et al., 2021). The combined challenges of high temperatures, drought, and their impact on tree physiology highlight the urgent need to investigate adaptive mechanisms and resilience in the face of climate change. The study on African mahogany contributes valuable insights into the species' responses to changing environmental conditions and adaptation strategies. Evaluating the growth of *K. ivorensis*, *K. senegalensis*, and *K. anthotheca* under varying temperature and water availability provides crucial information for sustainable farming and wood availability. Understanding the eco-physiological responses of tree species like African mahogany helps in developing effective strategies for climate-resilient forest management and conservation.

The water availability level of 90% positively influenced the growth of *K. ivorensis* under lower air temperature and VPD values in Microclimate I. These conditions enhanced the physiological processes of *K. ivorensis*, including photosynthetic efficiency, cell membrane integrity, enzymatic adjustments, and stomatal conductance. As a result, the highland areas of southeastern Brazil, with temperatures ranging from 21 to 27ºC, could be suitable for cultivating this species, provided irrigation is accessible. However, it is important to note that climatic variations in these regions, such as frost and heat waves, can occur in some years, posing additional limitations for this forest species.

The three African mahogany species exhibited a similar response to water deficit, characterized by 20% water availability in microclimate I. This finding aligns with previous studies demonstrating a significant decline in dry mass accumulation among tropical forest species under water stress conditions (Kameli & Lösel, 1996; Susiluoto & Berninger, 2007; Rad et al., 2011). The limitation in plant growth likely occurred due to reduced stomatal conductance (gs) caused by water stress, leading to decreased photosynthetic rates because of limited CO_2 availability in the leaf mesophyll (Kramer & Boyer, 1995; Amaral et al., 2023). Additionally, inadequate soil water levels can impede root absorption and sap flow, negatively impacting plant development and growth (Taiz & Zeiger, 2013).

The negative impacts of low water availability on African mahogany species were amplified under high temperatures observed in Microclimate II and III. This could be attributed to plants experiencing elevated temperatures along with limited soil moisture, which leads to increased respiration and photorespiration processes, ultimately reducing photosynthetic efficiency (Yamori et al., 2014; Marenco et al., 2014; Nóia Júnior et al., 2018b; Nóia Júnior et al., 2020). Similar findings have been observed in other native forest species of Brazil, such as *Joannesia princeps* Vell and rubber trees (Santos, 2014; Nóia Júnior et al., 2018b). High temperatures and drought often occur together and are interconnected (Stéfanon et al., 2014). Drought periods are typically associated with reduced cloud cover and lower air humidity, further exacerbating high temperatures. The increased temperature raises vapor pressure deficit (VPD), intensifying evapotranspiration and hastening soil drying, leading to severe drought conditions. Hence, our results emphasize the threat posed by projected increases in combined drought and heat events to African mahogany species in central Brazil (Intergovernmental Panel on Climate Change, 2021). Importantly, it should be noted that irrigated areas are projected to expand by 76% in Brazil, which could help mitigate the effects of water deficits in central Brazil (Agência Nacional de Águas e Saneamento Básico, 2021).

Among the commercially available African mahogany species, *K. senegalensis* is widely recognized as the most tolerant to stressful environments and is extensively cultivated in regions like Australia with high temperatures and relatively high VPD (Arnold et al., 2004). Our study further confirms the superior performance of *K. senegalensis* in environments characterized by high VPD. However, it should be noted that the growth of this species is highly sensitive to water availability, with total dry mass ranging from 5g (at 20% water availability) to 40g (at 90% water availability). Conversely, the growth of *K. anthoteca* and *K. ivorensis* did not exhibit a significant increase with 90% water availability compared to 60% availability, suggesting their higher resistance to moderate water deficits.

Forests are particularly vulnerable to the adverse effects of high temperatures and droughts. The research on African mahogany highlights the negative impacts of elevated temperature and water scarcity on the species' growth and physiological processes. Understanding how African mahogany and other tree species respond and adapt to these challenges is crucial for ensuring resilient forest management in the face of climate change. The study's findings underscore the urgent need to address the combined threats of drought and heat events and their potential consequences for forest production.

CONCLUSION

Our study demonstrates that water deficit adversely affects the growth of African mahogany seedlings, regardless of microclimate. The negative impact is intensified by high air temperature and vapor pressure deficit (VPD). However, well-watered seedlings of *K. ivorensis* and *K. senegalensis* benefit from high temperature and VPD. Therefore, regions in Brazil with high air temperatures and VPDs, coupled with adequate water availability, are most suitable for African mahogany cultivation, particularly *K. ivorensis* and *K. senegalensis*. These findings provide valuable insights for sustainable forest management and the potential impact of climate change on African mahogany and other tree species.

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