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Initial establishment of cassava plants with increasing temperature

Estabelecimento inicial de plantas de mandioca com o aumento da temperatura

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ABSTRACT

Adverse environmental conditions, such as increased air temperature, have an impact on initial plant growth, interfering with the potential yield potential of crops. Thus, the objective was to evaluate the effect of increasing temperature on the initial establishment of cassava plants. The experiment was carried out in growth chambers, with a completely randomized design in a 3x2 factorial scheme (cultivars x temperature regimes), with five replications, for 165 days. Cassava seedlings of the cultivars BRS 417, BRS 420 and BRS CS01 were used and the temperature regimes: T1 (20-26-33 °C) and T2 (24.8-30.8-37.8 °C). The physiological parameters were negatively affected by the increase in temperature. These physiological changes resulted in an increase in leaf temperature. Cultivar BRS 420 had the highest stem diameter when compared to the others, with an average of 4.63 mm. The temperature regime of 24.8-30.8-37.8 °C contributed to greater plant height of cultivars BRS 420 and BRS CS01, with an average of 104.28 and 89.54 cm respectively. The increase in temperature also contributed to greater production of aboveground biomass, with an increase in fresh mass of 41% and 52% and dry mass of 20% and 37% for BRS 420 and BRS CS01, respectively. The fresh mass of the root system was greater with increasing temperature for the three cultivars analyzed, with emphasis on BRS 420, which also showed greater production of dry mass of the roots, regardless of the temperature regime. The increase in air temperature, with a daily regime of 24.8-30.8-37.8 °C favored the growth and development of young cassava plants, contributing to their establishment, even with changes in physiological responses.

KEYWORDS: climate change; growth; M*anihot esculenta* Crantz; photosynthesis.

RESUMO

Condições ambientais adversas, como o aumento da temperatura do ar, tem impacto sobre o crescimento inicial das plantas, interferindo no potencial de rendimento dos cultivos. Assim, objetivou-se avaliar o efeito do aumento da temperatura no estabelecimento inicial de plantas de mandioca. O experimento foi realizado em câmaras de crescimento, com delineamento inteiramente casualizado em esquema fatorial 3x2 (cultivares x regimes de temperatura), com cinco repetições, durante 165 dias. Foram utilizadas mudas de mandioca das cultivares BRS 417, BRS 420 e BRS CS01 e os regimes de temperatura: T1 (20-26-33 °C) e T2 (24.8-30.8-37.8 °C). Os parâmetros fisiológicos foram afetados negativamente pelo aumento da temperatura. Essas alterações fisiológicas resultaram no aumento da temperatura foliar. A cultivar BRS 420 apresentou maior diâmetro do caule, quando comparada às demais, com uma média de 4,63 mm. O regime de temperatura de 24.8-30.8-37.8 °C contribuiu para maior altura das plantas das cultivares BRS 420 e BRS CS01, com média de 104.28 e 89.54 cm respectivamente. O aumento da temperatura também contribuiu para maior produção de biomassa da parte aérea, com um aumento de massa fresca de 41% e 52% e massa seca de 20% e 37% para BRS 420 e BRS CS01, respectivamente. A massa fresca do sistema radicular foi maior com o aumento da temperatura para as três cultivares analisadas, com destaque para BRS 420, que também apresentou maior produção de massa seca das raízes, independentemente do regime de temperatura. O aumento da temperatura do ar, com regime diário de 24.8-30.8-37.8 °C favoreceu o crescimento e desenvolvimento das plantas jovens de mandioca, contribuindo para o seu estabelecimento, mesmo com alterações nas respostas fisiológicas.

PALAVRAS-CHAVE: mudanças climáticas; crescimento; *Manihot esculenta* Crantz; fotossíntese.

INTRODUCTION

The increase in the world's population has direct implications for the demand for food production (REINCKE et al. 2018). Added to this challenge, the adverse effects of climate change put food security at risk (BRÜSSOW et al. 2017), as they make agricultural yields vulnerable due to the increased frequency of extreme events, with high temperatures and prolonged droughts (TOSCANO et al. 2016, IPCC 2021).

Temperature is one of the most important climatic elements for plant production, being decisive for the geographical distribution of crops and directly interfering with plant growth and development (CHAUDHRY & SIDHU 2021, BARROS et al. 2022). So the biometric, physiological and productive parameters depend on the temperature conditions in which the plants are growing. According to BERGAMASCHI & BERGONCI (2017), plants can alter their metabolism when subjected to high temperatures, accelerating growth and phenology, in a way that does not impair their normal development. For cassava, temperatures above 35 °C cause negative impacts on physiological processes, such as photosynthesis, respiration and transpiration, which can reduce plant growth and production (EL-SHARKAWY 2006).

The initial phase of plant growth and development is considered one of the most important, with the establishment of seedlings being a decisive step for resilience to adverse environmental conditions (CHAUDHRY & SIDHU 2021, MELO JUNIOR et al. 2018, RAI et al. 2018, BARROS et al. 2021a). The exposure of plants to high temperatures for a long period can cause serious biochemical and molecular alterations, due to the increase of stress hormones, production of reactive oxygen species, and alteration of genes involved in protection against thermal stress, in addition to physiological and morphological factors that affect early plant growth (RAI et al. 2018).

According to the Intergovernmental Panel on Climate Change (IPCC 2021) the increase in air temperature could reach 1.9 ºC by 2040, and 5.7 ºC by 2100. These scenarios represent a risk to the food system due to the loss of productivity. In this context, the search for crops that have greater adaptability to high temperatures will be strategic for food security (BRÜSSOW et al. 2017). The cultivation of cassava (*Manihot esculenta* Crantz) can be an alternative to global climate change. Cassava is called the crop of the 21st century, as in addition to tolerating adverse environmental conditions, such as high temperatures (FAO 2019), it is an important source of energy for the food industries, rich in carbohydrates, a fundamental raw material for sustainability, and can be used in the formulation of biodegradable products, replacing petroleum derivatives, from plastics to ethanol (VALLE & LORENZI 2014). Much of the world's cassava production is used for human consumption in fresh cooked or processed forms, as well as for animal feed and industrial applications (LATIF & MULLER 2014). All these attributes make cassava attractive, especially for small farmers (ADU et al. 2018).

Thus, studies on the impacts of increased temperature on the physiological responses and development of young cassava plants may contribute to the selection of cultivars that are more adapted to the new temperature climate scenarios (IPCC 2021). Thus, the objective was to evaluate the effect of increasing temperature on the initial establishment of cassava plants.

MATERIAL AND METHODS

The experiment was carried out in growth chambers, of the Fitotron type, with temperature, humidity and photoperiod control, located at Embrapa Semiarid. The experimental design was completely randomized in a 3x2 factorial scheme (cultivars x temperature), with five replications, totaling 15 plants in each growth chamber. To carry out the experiment, for industry cassava seedlings (15 cm) were used, developed by the Cassava Genetic Improvement Program of Embrapa, cultivars BRS 417, BRS 420 and BRS CS01. The industry cassava cultivars used in this research have a good productivity, cycle ranging from 12-18 months, in addition to being moderately tolerant to the main diseases (EMBRAPA 2022). The temperature regimes used (Table 1) were determined from the minimum, average and maximum temperatures in the Sub-Medium of the São Francisco Valley, Brazil, over the last 30 years, ranging from 18-22, 25-27 and 32-34 ° C, respectively. In this work, an increase of 4.8 °C was used, based on the IPCC temperature increase scenario (2021).

The seedlings with 15 cm were transplanted into a 25 x 30 x 0.20 cm plastic bag containing soil. The soil used was classified as Eutrophic Red-Yellow Argisols (BATISTA et al. 2016). Fertilization was carried out three days before transplanting, according to the results of chemical analyzes of the soil and indications for the crop (CAVALCANTI et al. 2008), using 1 gram of formulated 8-28-16 (NPK) per bag. Irrigations were performed every two days, using a graduated cylinder. A spacing of 50 cm was used between the plants and they remained in the growth chambers for a period from July to December 2022, totaling 165 days.

Table 1. Temperature regimes used in the experiment.

Temperature regimes	Time/Temperature (° C)			
	20 h to 6 h	6 h to 10 h	10 h to 15 h	15 h to 20
T1 (20-26-33 °C)	20	26	33	26
T2 (24.8-30.8-37.8 °C)	24.8	30.8	37.8	30.8

The physiological evaluation was carried out one day before the plants were harvested, starting at 08:00 am. On that occasion, gas exchanges were evaluated using the portable Infrared Gas Analyzer (IRGA), model Li-6400, using artificial light set at 2500 µmol m^{-2} s^{-1}. The analyzed variables were: photosynthesis rate (*A*), stomatal conductance (*gs*), transpiration (*E*) and leaf temperature (Lt). The reading was carried out on the leaf without injuries, with a green color and fully expanded, located in the middle third of the plant.

All plants were harvested one hundred and sixty-five days after planting, when biometric evaluations were performed (number of leaves; stem diameter (mm) with the aid of a digital caliper, where a height of 10 - 12 centimeters from ground level; plant height (cm) measured from ground level to the apex of the plant, with the aid of a millimeter ruler and productive evaluations of the plants (fresh and dry mass of the aerial part (g) and fresh and dried mass from the roots (g). The materials were packed in paper bags and kept in an oven at 65 ºC until they reached constant weight (±72h). Subsequently, the weight was carried out on an analytical scale, accurate to 0.0001g, to obtain the dry mass.

The results were submitted to analysis of variance (ANOVA), in which the isolated significant effects and interactions between the sources of variation were tested, a *p* value <0.05 was considered to indicate statistical signifcance and the means compared by the Scott Knott test, using the SISVAR Version 5.6 program.

RESULTS AND DISCUSSION

For the physiological responses, the cassava cultivars BRS 417, BRS 420 and BRS CS01 did not differ among themselves with increasing temperature. However, temperature regimes significantly affected photosynthetic parameters.

In the environment with a temperature regime of 20-26-33 °C, the plants showed greater stomatal conductance (Figure 1a), increased transpiration (Figure 1b), as well as a higher photosynthetic rate, with an average of 9.14 µmol of CO_2 m^{-2} s^{-1} (Figure 1c). The increase of 4.8 °C reduced stomatal opening and transpiration rate by 28% and 20%, respectively (Figures 1a and 1b). This reduction in stomatal conductance caused a 69% drop in photosynthetic rate (Figure 1a), as well as an increase of approximately 3 °C in leaf temperature (Figures 1c and 1d).

The yield potential of a crop is related to plant physiology and phenology, which in turn are influenced by genotype and environment (BYJU & SUJA 2020). Physiological responses depend on the temperature at which the plants are growing (HATFIELD & PRUEGER 2015). When tropical plants are exposed for long periods of time to temperatures above 35 °C there is an impact on CO_2 fixation, because there is a reduction in the stomatal opening, decreasing transpiration and, consequently, causing an increase in the leaf temperature (REYNOLDS-HENNE et al. 2010), resulting in the excessive production of reactive oxygen species, severely damaging the photosynthetic rate, and the index of chlorophyll (RAI et al. 2018, BARROS et al. 2021a).

According to EL-SHARKAWY (2006), cassava can develop in a wide temperature range, ranging from 25 to 40 °C, however, the optimal temperature for photosynthesis of cassava plants varies between 25 - 35 °C. Above or below this temperature, the rate of photosynthesis is reduced, as shown by the results found in this research.

The variables: plant height, fresh and dry mass of the superior part and fresh mass of the root showed a significant influence of the temperature x cultivar interaction (Table 2), where stem diameter and root dry mass differed only between cultivars.

The increase of 4.8 °C in the average air temperature did not significantly influence the stem diameter of the cassava plants (Figure 2a), but there was a difference between the cultivars, with emphasis on the cultivar BRS 420 with an average of 4.63 mm.

For plant height, the temperature regime of 24.8-30.8-37.8 °C contributed to greater length of cultivars BRS 420 and BRS CS01, with an increase of 39 and 66%, respectively (Figure 2b). Cultivar BRS 417 showed no difference with increasing temperature.

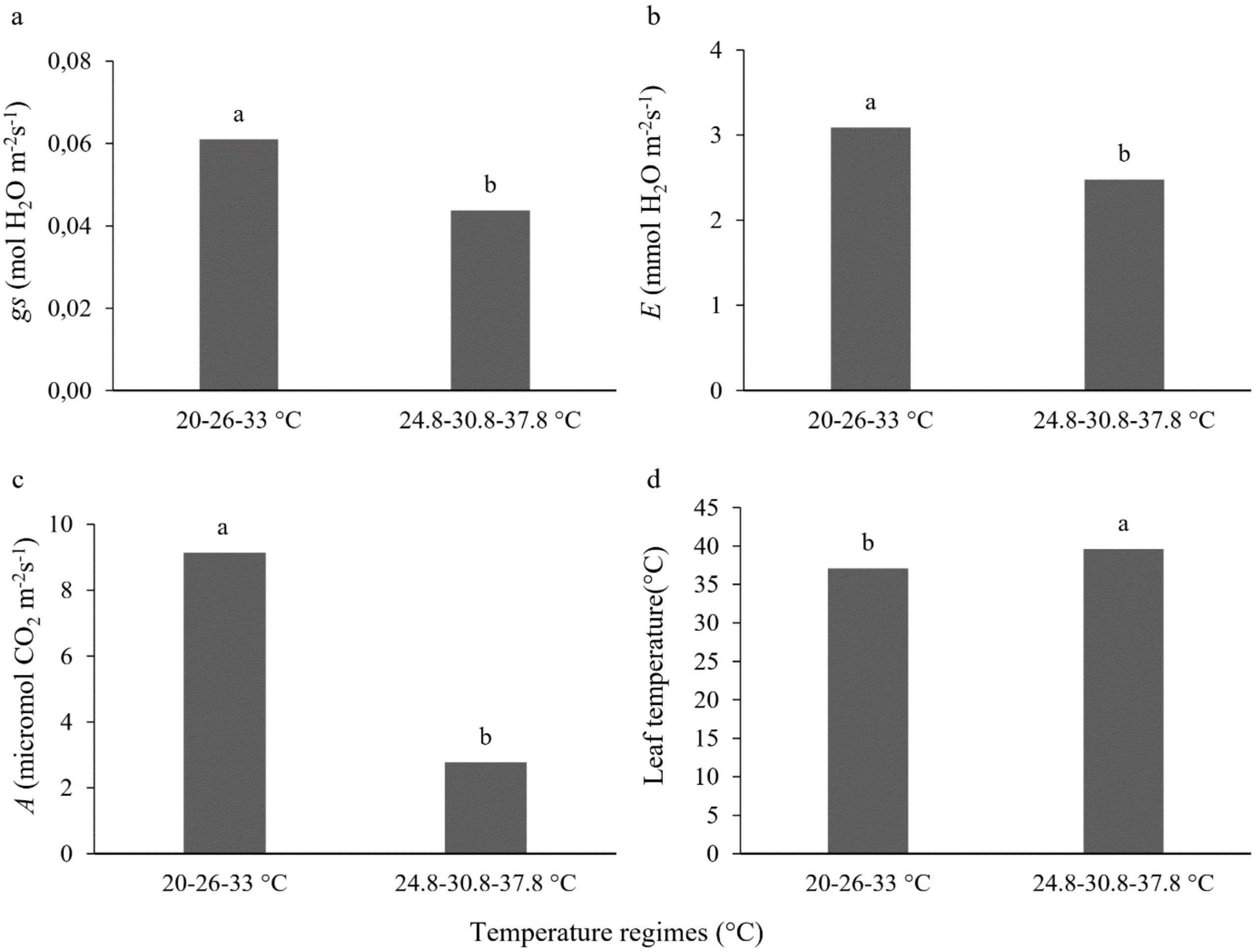

Figure 1. Photosynthetic parameters of cassava cultivars subjected to two temperature regimes. Stomatal conductance (a); Transpiration Rate (b); Photosynthetic (c) and Leaf temperature (d).

Table 2. Summary of the mean square analysis of variance for the variables stem diameter, number of leaves, plant height, shoot fresh mass, shoot dry mass, root fresh mass and root dry mass.

Variation source	MS							
	DF	SD	NL	PH	SFM	SDM	RFM	RDM
Temperature regime (T)	1	0.4889 ns	0.8333 ns	4790.56**	306.56**	19.78**	228.19**	86.49 ns
Cultivar (C)	2	2.0049**	14.4000 ns	987.30**	127.81**	16.49**	2034.64**	1791.71 **
T x C	2	0.1124 ns	0.5333 ns	392.91*	65.99**	9.51**	195.95**	34.26 ns
Residue	24	0.1495	48.333	123.32	7.26	1.42	24.66	25.96
CV%		9.34	27.14	13.34	16.80	13.94	11.55	14.45
Overall average		4.1390	8.1000	83.66	10.04	8.54	43.01	35.26

MS = Mean square; DF = degree of freedom; SD = stem diameter; NL = number of leaves; PH = plant height; SFM = shoot fresh mass; SDM = shoot dry mass; RFM = root fresh mass; RDM = root dry mass; CV = coefficient of variation; ns = not significant, * significant at 5% probability level, ** significant at 1% probability level, by Scott-Knott test.

The increase in plant height contributed to greater biomass production. Cultivars BRS 420 and BRS CS01 showed higher shoot biomass production in the regime 24.8-30.8-37.8 °C, with an increase in fresh mass of 41% and 52% and dry mass of 20% and 37% for BRS 420 and BRS CS01, respectively. Cultivar BRS 417, on the other hand, showed no significant difference in terms of temperature changes (Figures 3a and 3b). When comparing the three analyzed cultivars, it is observed that BRS 420 stood out in terms of biomass production in the high temperature environment (Figures 3a and 3b).

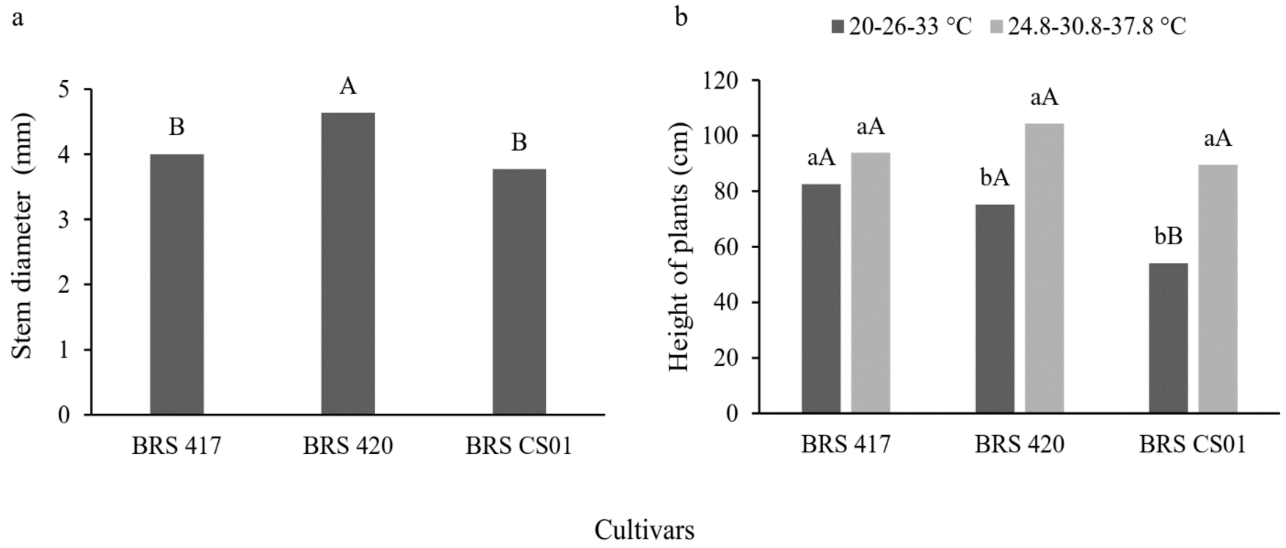

Figure 2. Stem diameter (a) and height of cassava plants (b) maintained under two temperature regimes. * Same lowercase letters for temperature and same uppercase letters for cultivars, do not differ from each other, by the Scott-Knott test, at 5% probability.

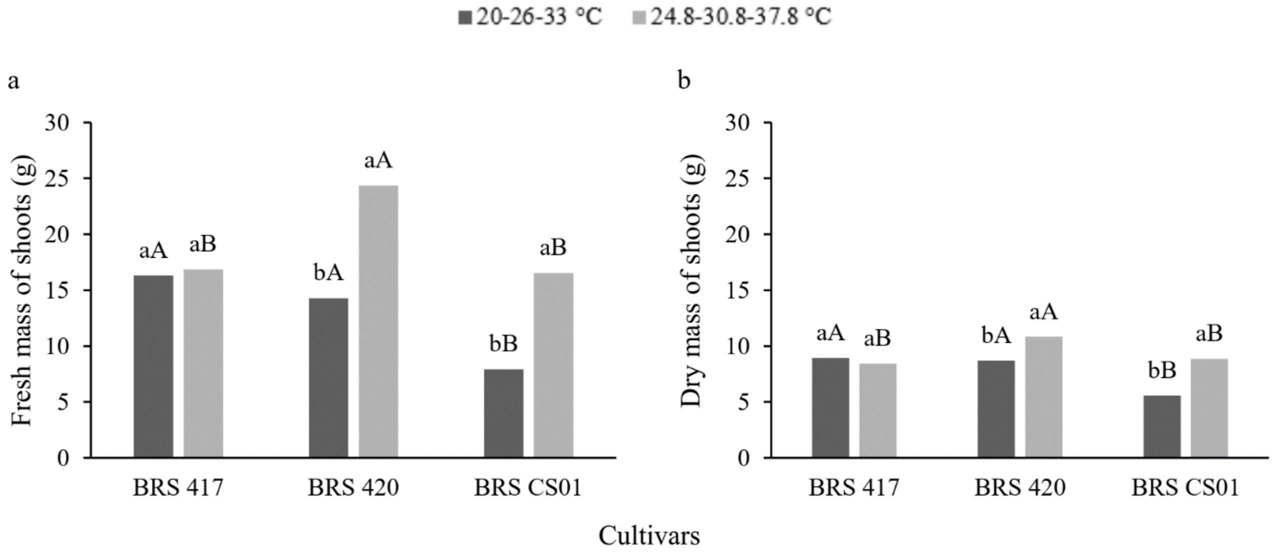

Figure 3. Fresh mass (a) and dry mass (a) of shoots of cassava plants maintained under two temperature regimes. * Same lowercase letters for temperature and same uppercase letters for cultivars, do not differ from each other, by the Scott-Knott test, at 5% probability.

The increase in temperature also contributed to greater fresh mass of the roots of the BRS 417 and BRS CS01 cultivars (Figure 4a). The fresh and dry mass of the root system of the BRS 420 cultivar was higher when compared to the other cultivars, regardless of the temperature regime (Figure 4b).

The impact on physiological responses as a result of increased temperature can decrease yield and quality of crops (BARROS et al. 2021b, ZHANG et al. 2021, KAUSHAL et al. 2016). However, plant response and susceptibility to high temperatures may vary between different crops and during plant development (WAHID et al. 2007). The results obtained in this research show that the increase in temperature, despite reducing the photosynthetic rate (Figure 1), positively affected the biometric and productive variables of young cassava plants (Figures 2, 3 and 4).

Plants that exhibit tolerance to high temperatures, such as cassava, may show increased growth and vegetative development, due to the activity of antioxidant enzymes in the leaves, high phenotypic plasticity and acclimatization, allowing greater adaptation and promoting greater leaf area index and biomass production (GABRIEL et al. 2014, HATFIELD & PRUEGER 2015, BESTER et al. 2022). Studies with cultivated plants show that the antioxidant defense mechanism is part of the adaptation to thermal stress and is correlated with the achievement of thermotolerance in plants. In addition, alterations in the lipid composition of the membrane, transport of ions, osmoprotectors, scavenging free radicals and increase in proteins are some of the main mechanisms of tolerance, involved in cascades of signaling and transcriptional control essential to neutralize the effects of thermal stress on plants (WAHID et al. 2007, WANG et al. 2004, MAESTRI et al. 2002).

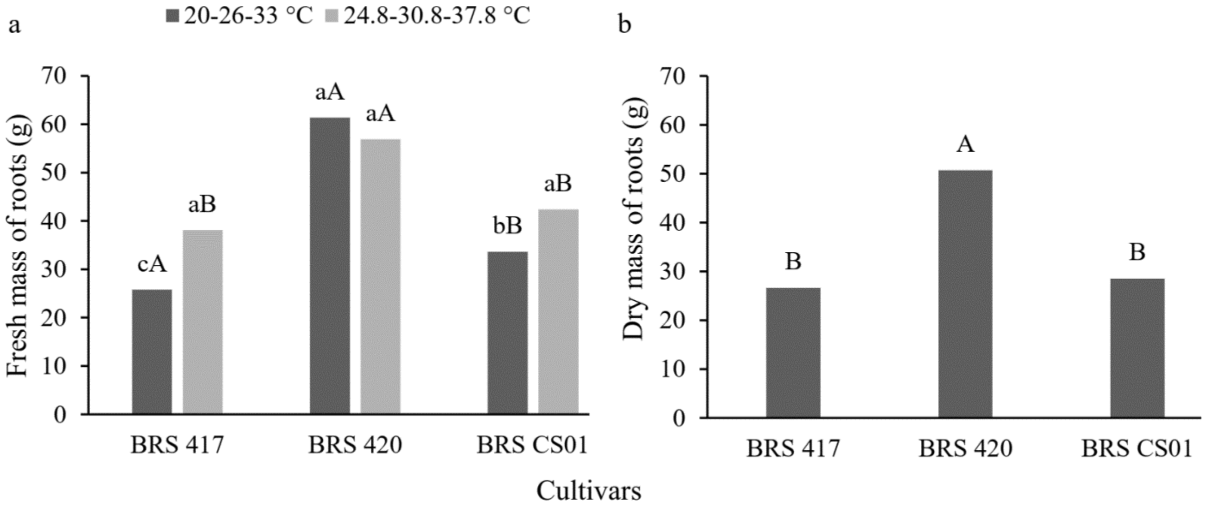

Figure 4. Fresh mass (a) and dry mass (b) of roots of cassava plants maintained in two temperature regimes. * Same lowercase letters for temperature and same uppercase letters for cultivars, do not differ from each other, by the Scott-Knott test, at 5% probability.

OLIVEIRA et al. (2022) evaluating *Manihot* genotypes under high temperatures verified the adaptation of plants to thermal stress, with an increase in vegetative development and consequent increase in biomass. According to HATFIELD & PRUEGER (2015), vegetative development can increase at high temperatures. This is because with the increase in temperature, there is an acceleration of phenology, due to the greater accumulation of degree-days, in addition, thermal stress can stimulate cell division and elongation, which contributes to plant growth and increased biomass (BERGAMASCHI & BERGONCI 2017, PRASAD et al. 2008).

Greater superior part production is an important factor in cassava, both as propagation material and for the production of forage for animal feed (VIDIGAL FILHO et al. 2000). In addition, the morphological structure of the cassava plant can differ according to the cultivar, as observed (Figure 2), with the greater diameter of the stem favoring the accumulation of reserves, which contributes to plant growth (GABRIEL et al. 2014).

Temperature influences the development of the root system during the initial establishment of plants and when subjected to stress by high temperatures, some cultures shape their roots physiologically and morphologically, improving their water efficiency, producing secondary branches and intensifying plant growth (CLARKSON et al. 1986, KOEVOETS et al. 2016). As the temperature favors the increase in the number of roots, there is an increase in the nutrient absorption process, since these roots show high plasticity in response to changes in the soil (CALLEJA-CABRERA et al. 2020). In addition, these changes in the root system will facilitate the absorption of water in dry soils (BARON & BÉLANGER 2020), contributing to the maintenance of plants in the field, ensuring yield stability in an environment of adverse conditions, such as the semiarid.

The results obtained for the initial growth of these cultivars reinforce their potential and provide subsidies for future work. In addition, these cultivars may be recommended for regions with high temperatures, such as the semi-arid region. Given the performance shown in an environment with high temperatures, these cultivars may be indicated for breeding programs, in deepening the tolerance mechanisms of these plants, contributing to the development of other cultivars.

However, to increase the tolerance of cassava plants to future climate scenarios, there is a need for research that shows the interaction between stresses, since they occur simultaneously in the environment, such as high temperatures combined with drought, salinity and high levels of CO_2. Increasing photosynthetic efficiency has been proposed as a strategy to increase the yield of crops such as cassava (SOUZA et al. 2017). In this way, new studies will contribute to a better understanding of the physiological and metabolic mechanisms involved in the responses of cassava plants to these stress combinations, as well as the understanding of the positive and negative interactions between different stresses, which will favor the final yield and the food security.

CONCLUSION

The increase in air temperature, with a daily regime of 24.8-30.8-37.8 °C favored the growth and development of young cassava plants, contributing to their establishment, even with changes in physiological responses.

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REFERENCES

ADU MO et al. 2018. Characterising shoot and root system trait variability and contribution to genotypic variability in juvenile cassava (*Manihot esculenta* Crantz) plants. Heliyon 4: 1-28.

BARON VS & BÉLANGER G. 2020. Climate, Climate-Change and Forage Adaptation. In: MOORE KJ et al. Forages: The Science of Grassland Agriculture. p.151–186.

BARROS JRA et al. 2021a. Initial growth of cowpea cultivars with an increase of 4.8 °C in air temperature. Brazilian Journal of Development 7: 20215-20225.

BARROS JRA et al. 2021b. Selection of cowpea cultivars for high temperature tolerance: physiological, biochemical and yield aspects. Physiology and Molecular Biology of Plants 27: 1-10.

BARROS JRA et al. 2022. Temperature: A major climatic determinant of cowpea production. Acta Scientiarum Agronomy 45: 1-10.

BATISTA LS et al. 2016. Calibração de sonda artesanal de uso com TDR para avaliação de umidade de solos. Revista Brasileira de Agricultura Irrigada 10: 522-532.

BERGAMASHI H & BERGONCI JI. 2017. As plantas e o clima: Princípios e aplicações. Agrolivros, p. 352.

BESTER AU et al. 2022. Three decades of cassava cultivation in Brazil: Potentialities and perspectives. Revista Colombiana de Ciências Hortícolas 15: 1-11.

BRÜSSOW K et al. 2017. Implications of climate-smart strategy adoption by farm households for food security in Tanzania. Food Security 9: 1203–1218.

BYJU G & SUJA G. 2020. Mineral nutrition of cassava. Advances in Agronomy 159: 169-235.

CLARKSON DT et al. 1986. The effect of root temperature on the uptake of nitrogen and the relative size of the root system in Lolium perenne. I. Solutions containing both NH4 + and NO3 -. Plant, Cell and Environment 9: 535-545.

CALLEJA-CABRERA J et al. 2020. Root Growth Adaptation to Climate Change in Crops. Frontiers in Plant Science 11: 1-23.

CAVALCANTI FJ de A. 2008. Recomendações de adubação para o estado de Pernambuco. 3.ed. Recife: IPA. p.212.

CHAUDHRY S & SIDHU GPS. 2021. Climate change regulated abiotic stress mechanisms in plants: a comprehensive review. Plant Cell Reports 41: 1–31.

EL-SHARKAWY MA. 2006. International research on cassava photosynthesis, productivity, eco-physiology, and responses to environmental stresses in the tropics. Photosynthetica 44: 481–512.

EMBRAPA. 2022. Empresa Brasileira de Pesquisa Agropecuária. Disponível em: https://www.embrapa.br/busca-de-noticias/-/noticia/71255757/embrapa-desenvolve-sua-primeira-mandioca-de-mesa-para-o-estado-de-sao-paulo. Acesso em: 20 mar. 2023.

FAO. 2019. Food and Agriculture Organization of the United Nations. Rome: FAO.

GABRIEL LF et al. 2014. Mudança climática e seus efeitos na cultura da mandioca. Revista Brasileira de Engenharia Agrícola e Ambiental 18: 90-98.

HATFIELD JL & PRUEGER JH. 2015. Temperature extremes: effect on plant growth and development. Weather Clim Extrem 10: 4-10.

IPCC. 2021. Intergovernmental Panel on Climate Change. Climate Change: The Physical Science Basis. International Panel on Climate Change.

KAUSHAL N et al. 2016. Food crops face rising temperatures: An overview of responses, adaptive mechanisms, and approaches to improve heat tolerance. Cogent Food & Agriculture 2: 1-42.

KOEVOETS IT et al. 2016. Roots Withstanding their Environment: Exploiting Root System Architecture Responses to Abiotic Stress to Improve Crop Tolerance. Frontiers in Plant Science 7: 1-19.

LATIF S & MÜLLER J. 2014. Cassava—How to explore the "all-sufficient". Rural 21.

MAESTRI E et al. 2002. Molecular genetics of heat tolerance and heat shock proteins in cereals. Plant Molecular Biology 48: 667-681.

MELO JUNIOR JLA et al. 2018. Germination and morphology of seeds and seedlings of *Colubrina glandulosa* Perkins after overcoming dormancy. Australian Journal of Crop Science 12: 639-647.

OLIVEIRA GM et al. 2022. Rise in temperature increases growth and yield of *Manihot* sp. Plants, Research, Society and Development 11: 1-11.

PRASAD PVV et al. 2008. Impacts of Drought and/or Heat Stress on Physiological, Developmental, Growth, and Yield Processes of Crop Plants. In: AHUJA LR et al. (Eds). Response of Crops to Limited Water: Understanding and Modeling Water Stress Effects on Plant Growth Processes. Madison: American Society of Agronomy.

RAI A et al. 2018. Heat stress and its effects on plant growth and metabolism. In: RAI GK (eds) Abiotic stress tolerance mechanisms in plants. Boca Raton: CRC Press p. 203–235.

REINCKE K et al. 2018. Key factors influencing food security of stallholder farmers in Tanzania and the role of cassava as a strategic crop. Food Securet 10: 911-924

REYNOLDS-HENNE CE et al. 2010. Interactions between temperature, drought and stomatal opening in legumes. Environmental and Experimental Botany 68: 37-43.

SOUZA AP et al. 2017. Rooting for cassava: insights into photosynthesis and associated physiology as a route to improve yield potential. New Phytologist 213: 50-65.

TOSCANO S et al. 2016. Physiological and biochemical responses in two ornamental shrubs to drought stress. Frontiers in Plant Science 7: 1–12.

VALLE TL & LORENZI JO. 2014. Variedades melhoradas de mandioca como instrumento de inovação, segurança alimentar, competitividade e sustentabilidade: contribuições do Instituto Agronômico de Campinas (IAC). Cadernos de Ciência & Tecnologia 31: 15-34.

VIDIGAL FILHO PS et al. 2000.Avaliação de cultivares de mandioca na região Noroeste do Paraná. Bragantia 59: 69-75.

WAHID AS et al. 2007: Heat tolerance in plants: an overview. Environmental and Experimental Botany 61: 199-223.

WANG W et al. 2004. Role of plant heat-shock proteins and molecular chaperones in the abiotic stress response. Trends Plant Science 9: 244-252

ZHANG H et al. 2021. Abiotic stress responses in plants. Nature Reviews Genetics 23: 104-119.