Rise in temperature increases growth and yield of *Manihot* sp. plants

O aumento da temperatura incrementa o crescimento e a produção de plantas de *Manihot* sp.

El aumento de la temperatura aumenta el crecimiento y la producción de *Manihot* sp.

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Abstract
The selection of native forage species with yield potential under climate change scenarios can strengthen resilience of the Brazilian semiarid region. This study aimed to evaluate the effect of increasing temperature on growth and morphological and yield responses of plants of the genus *Manihot*. The experimental design was completely randomized in a 2×9 factorial arrangement (two temperature regimes and nine genotypes). The increase in temperature promoted higher plant dry mass (PDM) for genotypes A:24, A:79, A:102, A:EL, and A:GO during establishment. The percentage of leaves was reduced with the highest temperatures in the establishment, except for genotypes A:20, A:21, and A:GO. The increase in temperature during regrowth increased leaf dry mass (LDM) and reduced the leaf to stem ratio, except for A:24, A:79, and A:102, which presented similar values at both temperatures. Species of the genus *Manihot* respond differently to the 4.8 °C increase in air temperature. The increase in temperature shows a positive impact on the biomass production of species of this genus.
Keywords: Native forages; Cassava; Maniçoba; Pornunça; Semiarid.

Resumo
A seleção de plantas forrageiras nativas com potencial produtivo frente aos cenários de mudanças climáticas pode aumentar a resiliência no Semiárido brasileiro. Objetivou-se avaliar o efeito do aumento da temperatura sobre o crescimento, respostas morfológicas e produtivas de plantas do gênero *Manihot*. O delineamento experimental foi inteiramente casualizado, em arranjo fatorial 2x9 (dois regimes de temperatura e nove genótipos). O aumento da temperatura promoveu maior massa seca de planta (MSP) para os genótipos A:24, A:79, A:102, A:E.L e A:G.O durante o estabelecimento. No estabelecimento, a porcentagem de folhas na planta foi reduzida com as maiores temperaturas, com exceção dos genótipos A:20, A:21 e A:G.O. Na rebrota, o aumento na temperatura incrementou a massa seca de folhas (MSF) e reduziu a relação folha:caule para a maioria dos genótipos, exceto A:24, A:79 e A:102 que apresentaram similares valores em ambas as temperaturas. As espécies do gênero *Manihot* respondem de maneira distinta ao aumento de 4,8°C na temperatura do ar. O aumento da temperatura apresenta impacto positivo na produção de biomassa das espécies deste gênero.
Palavras-chave: Forrageiras nativas; Mandioca; Maniçoba; Pornunça; Semiárido.

Resumen
La selección de plantas forrajeras nativas con potencial productivo ante escenarios de cambio climático puede aumentar la resiliencia en el semiárido brasileño. El objetivo fue evaluar el efecto del aumento de la temperatura sobre el crecimiento, respuestas morfológicas y productivas de plantas del género *Manihot*. El diseño experimental fue completamente al azar, en arreglo factorial 2x9 (dos regímenes de temperatura y nueve genotipos). El aumento de temperatura promovió mayor masa seca vegetal (MSP) para los genotipos A:24, A:79, A:102, A:E.L y A:G.O durante el establecimiento. Al establecimiento, el porcentaje de hojas en la planta se redujo con temperaturas más altas, con excepción de los genotipos A:20, A:21 y A:G.O. En rebrote, el aumento de temperatura incrementó la masa seca de hojas (MSF) y redujo la relación hoja:tallo para la mayoría de los genotipos, excepto A:24, A:79 y A:102, que presentaron valores similares en ambas temperaturas. Las especies del género *Manihot* responden de manera diferente al aumento de 4,8°C en la temperatura del aire. El aumento de temperatura tiene un impacto positivo en la producción de biomasa de las especies de este género.
Palabras clave: Forrajes nativos; Mandioca; Manicoba; Pornunça; Semi árido.

1. Introduction

Increases of 1.7 to 4.8 °C in the average air temperature, changes in rainfall patterns, and the occurrence of extreme events are some of the climate changes predicted by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013). These scenarios will directly influence the availability and use of natural resources, including crop cultivation (Magrin et al., 2014; Félix et al., 2020). Long droughts and high temperatures characterize the climate in the Brazilian semiarid region.

Climate change could further aggravate the availability of feed for animals and herd yields. Thus, the use of forage resources with higher yield potential, considering future climate conditions, will play a decisive role in food security and regional socio-economic development. In this sense, a strategy to increase forage supply is the cultivation of native plants, and the Brazilian semiarid region stands out for its rich biodiversity of native plants with forage potential and adaptability to local environmental conditions.

Species of the genus *Manihot*, such as cassava (*Manihot esculenta* Crantz), maniçoba (*Manihot pseudoglaziovii*), and pornunça (*Manihot* sp.) stand out among the native species. Plants of these species are perennial and have adaptability to the regional climate and a high nutritional value (França et al., 2010). Maniçoba and pornunça (a natural hybrid of maniçoba and cassava) have been used in animal feed due to their yield traits and nutritional value (Santos et al., 2017; Matias et al., 2020).

No studies in the literature have reported the effect of temperature rise on the morphological traits and yield responses of native *Manihot* species in the Brazilian semiarid region. However, some studies have shown that cassava can develop at a wide temperature range (18 to 35 °C), with optimal performance in the range from 25 to 27 °C (Jarvis et al., 2012; Nwaiwu et al., 2014). Thus, experiments under controlled conditions can contribute to elucidate this knowledge gap and provide information for breeding programs aimed at selecting native forage genotypes under high-temperature conditions. Thus, this study aimed to evaluate the effect of increasing temperature on growth and morphological and yield responses of plants of the genus *Manihot*.

2. Methodology

Nine *Manihot* sp. genotypes were used, i.e., six maniçoba (*Manihot pseudoglaziovii*) genotypes (A:20, A:21, A:22, A:26, A:79, and A:102), two cassava (*Manihot esculenta* Crantz) genotypes (cultivars Engana-ladrão – EL and Gema-de-ovo – GO), and one pornunça (*Manihot* sp.) genotype (A:24), belonging to the germplasm bank of Embrapa Semiarid. The planting was carried out in black polyethylene bags (20×30 cm) filled with a mixture of 80% soil and 20% manure using stakes obtained from adult plants, with an average pattern of six buds, 15 cm in length, 13 mm in diameter (Table 1), and dried under shade for five days.

Table 1. Average length (L), diameter (D), and weight of stakes of species of the genus *Manihot* before planting, used at both temperature regimes.

	Temperature regimes (°C)					
	20-26-33 °C			24.8-30.8-37.8°C		
Genotype	L (cm)	D (cm)	Weight (g)	L (cm)	D (cm)	Weight (g)
A:20	16.63	15.11	24.12	17.53	13.89	21.15
A:21	15.93	14.48	22.78	15.01	14.52	22.23
A:22	15.19	13.16	20.02	16.30	13.18	21.64
A:24	14.90	13.40	19.51	15.74	13.08	19.35
A:26	15.39	14.14	20.69	15.34	12.98	18.89
A:79	13.94	14.08	17.11	13.70	13.35	15.50
A:102	15.58	14.35	19.81	14.41	14.52	18.79
A:E.L	15.71	13.13	19.32	15.53	12.83	17.85
A:GO	14.41	13.26	21.67	14.23	12.98	20.14

Source: Authors.

The experiment was carried out in Phytotron growth chambers with 12 m^2 and temperature, light, and humidity control. The experimental design was completely randomized in a 2 × 9 factorial arrangement (temperature regimes × *Manihot* sp. genotypes), with four replications. The irrigation of pots was carried out daily to keep the soil close to field capacity.

Temperature regimes consisted of 20–26–33 °C (20 °C from 8:00 pm to 6:00 am, 26 °C from 6:00 am to 10:00 am, 33 °C from 10:00 am to 3:00 pm, and 26 °C from 3:00 pm to 8:00 pm) in chamber 1 and 24.8–30.8–37.8 °C (24.8 °C from 8:00 pm to 6:00 am, 30.8 °C from 6:00 am to 10:00 am, 37.8 °C from 10:00 am to 3:00 pm, and 30.8 °C from 3:00 pm to 8:00 pm) in chamber 2, determined from the average temperature, including the minimum and maximum averages of the Sub-middle of the San Francisco River Valley and applied the temperature increase of 4.8 °C, as foreseen in the IPCC (2013) report.

The study lasted 119 days with two harvests. The first harvest was carried out at 88 days after planting (considered as the establishment), while the second harvest was conducted at 31 days after regrowth.

Cutting was performed at 1 cm from the stake bud and the following variables were analyzed: stem diameter (DC), using a digital caliper and the number of leaves (NL), counting of all leaves. The leaf and stem portions were separated and subjected to pre-drying in a forced-air circulation oven at 55 °C for 72 hours and subsequent weighing to determine leaf (LDM) and stem dry mass (SDM) by the Weende method (AOAC, 2002). The dry mass data allowed determining the leaf to stem ratio (L/S) by dividing the leaf dry mass by the stem dry mass, the leaf (%LDM) and stem dry mass contents (%SDM), considering the amount of water in the plant, and plant dry mass (PDM), determined by the sum of the leaf and stem portions. The percentages of leaves (%PL) and stem (%PS) were also determined considering the plant weight. The forage accumulation rate (FAR) was estimated by dividing the total dry mass by the number of days.

The data were submitted to analysis of variance (ANOVA) and means were compared by Scott-Knott test at a 5% probability using the SISVAR 5.6 program (Ferreira, 2011).

3. Results and Discussion

The interaction temperature x genotype influenced SD, NL, SDM, %SDM, PDM, %PL, %PS, and FAR in the first harvest. Temperature affected L/S and LDM, while genotypes influenced L/S, LDM, and %LDM.

The plant dry mass of genotypes A:24 and A:EL increased 56 and 41%, respectively, at the temperature regime 24.8–30.8–37.8 °C. The highest plant dry mass production was observed in genotypes A:102 and A:GO and A:24, A:79, A:102, A:EL, and A:GO at the temperature regimes 20–26–33 °C and 24.8–30.8–37.8 °C, respectively (Table 2). The forage accumulation rate of genotype A:24 increased by 64% at the temperature regime 24.8–30.8–37.8 °C. Genotypes A:102 and A:GO and A:24, A:102, and A:GO stood out with higher values of forage accumulation rate at the temperature regimes 20–26–

33 °C and 24.8–30.8–37.8 °C, respectively (Table 2).

Only genotype A:24 showed a positive effect of increasing temperature, with a 31% increase in the number of leaves. Genotypes A:102, A:EL, and A:GO and A:24, A:79, A:EL, and A:GO stood out for the number of leaves at the temperature regimes 20–26–33 °C and 24.8–30.8–37.8 °C, respectively (Table 2). The increase in temperature led to a reduction in the percentage of leaves for genotypes A:22, A:24, A:26, A:79, A:102, and A:EL. Genotypes A:20, A:21, A:22, A:24, A:26, and A:79 presented the highest percentage of leaves when subjected to the lower temperature regime (20–26–33 °C), while genotypes A:20, A:21, and A:26 presented the highest percentage of leaves with the higher temperature regime (Table 2).

Table 2. Plant dry mass (PDM), forage accumulation rate (FAR), number of leaves (NL), and percentage of leaves (%PL) in *Manihot* sp. plants maintained under environments with different temperature regimes (20–26–33 °C and 24.8–30.8–37.8 °C) at 88 days after planting.

Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	PDM (g)		FAR (g.dia^{-1})	
A:20	10.15bA	9.15bA	0.11bA	0.10bA
A:21	6.83bA	5.38bA	0.08bA	0.06bA
A:22	8.22bA	9.85bA	0.09bA	0.11bA
A:24	6.57bB	15.23aA	0.06bB	0.17aA
A:26	5.63bA	9.69bA	0.06bA	0.10bA
A:79	9.06bA	11.87aA	0.10bA	0.13bA
A:102	15.59aA	18.57aA	0.17aA	0.21aA
A:E.L	7.25bB	12.43aA	0.08bA	0.14bA
A:G.O	15.88aA	13.93aA	0.17aA	0.15aA
Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	NL		%PL	
A:20	15.20bA	12.80bA	48.56aA	41.96aA
A:21	12.40bA	12.00bA	52.87aA	45.69aA
A:22	14.80bA	12.40bA	49.87aA	31.76bB
A:24	15.00bB	22.20aA	51.19aA	27.60bB
A:26	12.80bA	13.00bA	55.37aA	37.86aB
A:79	15.20bA	19.60aA	44.45aA	30.30bB
A:102	17.80aA	16.40bA	34.99cA	24.32bB
A:E.L	20.20aA	19.60aA	41.51bA	29.71bB
A:G.O	20.80aA	25.20aA	29.48cA	32.40bA

*Means followed by the same lowercase letter in the column and upper case in the row do not differ at 5% probability by the Scott-Knott test. Source: Authors.

The SD of genotypes A:24, A:26, and A:EL and %SDM of genotypes A:24 and A:EL were higher with increasing temperature. Moreover, genotypes A:24, A:26, A:79, A:EL, and A:21 showed lower SD at the temperature regimes 20–26–33 °C and 24.8–30.8–37.8 °C, respectively (Table 3).

Genotypes A:24, A:102, and A:EL showed higher SDM with an increase of 4.8 °C in air temperature. The comparison between genotypes showed that A:102 stood out for stem dry mass production with an increase in temperature (Table 3).

Genotypes A:24 and A:EL had a 31% increase in %SDM with increasing air temperature (Table 3). Genotypes A:102

and A:GO showed higher %SDM at the temperature regime 20–26–33 °C, with no difference compared to plants subjected to 24.8–30.8–37.8 °C (Table 3).

Genotypes A:22, A:24, A:26, A:79, A:102, and A:EL presented an increase in %PS with increasing temperature (Table 2). On the other hand, genotypes A:102, A:GO, and A:22 and A:24, A:79, A:102, A:EL, and A:GO showed higher %PS at at the temperature regimes 20–26–33 °C and 24.8–30.8–37.8 °C, respectively (Table 3).

Table 3. Stem diameter (SD), stem dry mass (SDM), stem dry mass content (%SDM), and percentage of the stem (%PS) in *Manihot* sp. plants maintained under environments with different temperature regimes (20–26–33 °C and 24.8–30.8–37.8 °C) at 88 days after planting.

Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	SD (cm)		SDM (g)	
A:20	8.48aA	7.91aA	5.29bA	5.97cA
A:21	7.44aA	6.58bA	3.56bA	3.05cA
A:22	7.79aA	9.09aA	4.21bA	6.79cA
A:24	6.73bB	8.82aA	3.31bB	11.04bA
A:26	6.62bB	8.11aA	2.84bA	6.13cA
A:79	7.20bA	8.24aA	5.59bA	8.55bA
A:102	9.26aA	9.57aA	10.09aB	14.16aA
A:E.L	5.56bB	8.73aA	4.23bB	8.85bA
A:G.O	7.84aA	8.30aA	11.35aA	9.59bA
Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24,8-30,8-37,8	20-26-33	24,8-30,8-37,8
	%SDM		%PS	
A:20	20.62bA	21.37aA	51.44cA	58.03bA
A:21	20.82bA	18.30aA	47.12cA	54.30bA
A:22	20.94bA	21.49aA	50.12cB	68.23aA
A:24	16.35bB	23.76aA	48.80cB	72.40aA
A:26	18.33bA	21.64aA	44.63cB	62.13bA
A:79	19.34bA	22.80aA	55.55cB	69.69aA
A:102	25.72aA	25.90aA	65.00aB	75.67aA
A:E.L	15.52bB	22.51aA	58.48bB	70.28aA
A:G.O	24.77aA	20.37aA	70.52aA	67.59aA

*Means followed by the same lowercase letter in the column and upper case in the row do not differ at 5% probability by the Scott-Knott test. Source: Authors.

A reduction of 52% in the leaf to stem ratio was observed with an increase of 4.8 °C in air temperature (Table 4).

Table 4. Leaf to stem ratio (L/S) of plants of the genus *Manihot* sp. maintained at different temperature regimes (20–26–33 °C and 24.8–30.8–37.8 °C) at 88 days after planting.

Variable	Temperatura (°C)	
	20-26-33	24.8-30.8-37.8
L/S	1.38a	0.73b

Means followed by the same lower case letter on the line do not differ at 5% probability by the Scott-Knott test. Source: Authors.

The comparison of performance between genotypes showed that the highest values of leaf dry mass were observed in A:20, A:102, and A:GO. On the other hand, the genotypes A:20, A:21, A:26, and A:20, A:21, A:26, and A:102 presented the highest leaf to stem ratio and dry mass content, respectively (Table 5).

Table 5. Leaf dry mass (LDM), leaf to stem ratio (L/S), and leaf dry mass content (%LDM) of different *Manihot* sp. genotypes at 88 days after planting.

Variable	Genotype								
	A:20	A:21	A:22	A:24	A:26	A:79	A:102	A:E.L	A:G.O
LDM	4.02a	2.79b	3.53b	3.72b	3.17b	3.39b	4.94a	3.29b	4.43a
L/S	1.36a	1.84a	1.01b	1.01b	1.59a	0.90b	0.70b	0.57b	0.53b
%LDM	27.23a	26.53a	24.93b	24.80b	26.11a	24.27b	26.13a	23.86b	24.33b

Means followed by the same lower case letter on the line do not differ at 5% probability by the Scott-Knott test. Source: Authors.

Forage production, the main source of animal feed in the semiarid region, will depend on the response and acclimatization of plants in future climate scenarios. As observed in the present study, temperature affects stake sprouting, leaf formation, stem size, and plant growth (Tables 2, 3, 4, and 5). However, *Manihot* sp. genotypes respond differently to an increase in temperature, with differences in morphological and yield traits. It occurs because each species has defined temperature ranges (maximum and minimum) in which cell division, elongation, and differentiation are higher, resulting in plant development differences (Taiz et al., 2017).

Vegetative growth can be stopped above the maximum limit temperature, as this climate element determines the speed of biochemical reactions responsible for plant tissue formation (leaves, stems, flowers, and roots). A temperature around 30 °C has been identified in the literature as ideal for CO_2 assimilation (Sage & Kubien, 2007) and higher temperatures can lead to a reduction in gas exchange and a decrease in photosynthesis (Doughty & Goulden, 2008). The effect of increasing temperature depends on the species acclimatization and its photosynthetic apparatus. In the case of cassava, plants have a high photosynthetic rate at temperatures of 25–40 °C, with peaks in the range of 30–35 °C (El-Sharkawy, 2006), which contributes to biomass production, a feature of plants adapted to tropical environments (Gabriel et al., 2014). However, no specific studies have been performed on maniçoba (*M. pseudoglaziovii*) and pornunça (*Manihot* sp.), with only the adaptive capacity to long periods of drought being reported (Morgante et al., 2020).

In the second cut, the interaction between temperature and genotype was significant for SD, LDM, SDM, L/S, PDM, %PL, %PS, and FAR. The isolated effect of temperature and genotype was significant for NL. Plant dry mass after regrowth was higher at the temperature regime 24.8–30.8–37.8 °C for all genotypes, except for A:79, which maintained mass even with increasing temperature (Table 6).

Genotypes A:20, A:21, A22, A:26, A:EL, and A:GO showed higher leaf dry mass at the temperature regime 24.8–30.8–37.8 °C. Genotypes A:24, A:79, and A:102 showed the highest LDM value at the temperature regime 20–26–33 °C. The temperature regime 24.8–30.8–37.8 °C showed the highest LDM in genotypes A:20, A;21, A:24, A:26, A:79, A:102, and A:GO (Table 6).

Genotypes A:24, A:79, A:EL, and A:GO maintained the percentage of leaves on the plant with increasing temperature, with a reduction between 23 and 40% in the other genotypes. Genotypes A:20, A:21, A22, A:26, and A:102 showed the highest %PL at the temperature regime 20–26–33 °C. On the other hand, only genotypes A:EL and A:GO had higher %PL values at the temperature regime 24.8–30.8–37.8 °C (Table 6).

The leaf to stem ratio was maintained for genotypes A:79, A:EL, and A:GO with increasing temperature, while the other genotypes presented a reduction from 40 to 66%. Genotypes A:22 and A:26 had higher L/S values at the temperature regime 20–26–33 °C (Table 6).

Table 6. Plant dry mass (PDM), leaf dry mass (LDM), percentage of leaves (%PL), and leaf to stem ratio (L/S) in *Manihot* sp. plants maintained under environments with different temperature regimes (20–26–33 °C and 24.8–30.8–37.8 °C) at 31 days after regrowth.

Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	PDM (g)		LDM (g)	
A:20	1.05cB	3.75bA	0.59bB	1.48aA
A:21	0.75cB	3.90bA	0.43bB	1.55aA
A:22	0.63cB	3.11cA	0.39bB	1.20bA
A:24	3.81bB	4.94aA	1.73aA	1.81aA
A:26	0.95cB	4.04bA	0.60bB	1.52aA
A:79	5.31aA	4.91aA	2.05aA	1.72aA
A:102	3.15bB	5.01aA	1.83aA	1.88aA
A:E.L	0.11cB	1.30dA	0.05cB	0.64cA
A:G.O	1.10cB	3.17cA	0.60bB	1.55aA
Genótype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	%PL		L/S	
A:20	52.59aA	39.85bB	1.20bA	0.66aB
A:21	56.10aA	39.79bB	1.28bA	0.66aB
A:22	63.66aA	39.29bB	1.96aA	0.65aB
A:24	38.99bA	36.79bA	0.98bA	0.58aB
A:26	63.95aA	37.81bB	1.80aA	0.61aB
A:79	39.29bA	35.53bA	0.66cA	0.56aA
A:102	58.19aA	37.64bB	1.39bA	0.60aB
A:E.L	39.75bA	49.62aA	0.72cA	1.01aA
A:G.O	48.84bA	48.83aA	1.06bA	0.95aA

*Means followed by the same lowercase letter in the column and upper case in the row do not differ at 5% probability by the Scott-Knott test. Source: Authors.

The temperature rise maintained the FAR values of genotypes A:79 and A:EL. The other genotypes increased the FAR values from 37 to 83% with increasing temperature. Genotypes A:79 and A:24 and A:79 were superior at the temperature regimes 20–26–33 °C and 24.8–30.8–37.8 °C, respectively (Table 7).

Genotypes A:20, A:21, A:22, A:24, A:26, and A:102 showed higher stem diameter, stem dry mass, and percentage of the stem in the plant with increasing temperature. However, for these variables, genotype A:79 was not influenced by an increase in temperature (Table 7). The stem diameter of genotypes A:EL and A:GO were higher with increasing temperature. Genotype A:79 had the highest stem diameter at the temperature regime 20–26–33 °C (Table 7).

The variable SDM of genotype A:GO was negatively influenced by the temperature increase. The SDM of genotype A:79 stood out compared to the others at the temperature regime 20–26–33 °C, with the highest value. Genotypes A:24, A:79, and A:102 had the highest SDM values at the temperature regime 24.8–30.8–37.8 °C (Table 7).

Genotypes A:24, A:79, and A:102 and A:20, A:21, A:22, A:24, A:26, A:79, and A:102 had the highest %PS values at the temperature regimes 20–26–33 °C and 24.8–30.8–37.8 °C, respectively (Table 7).

Table 7. Forage accumulation rate (FAR), stem diameter (SD), stem dry mass (SDM), and percentage of the stem (%PS) in *Manihot* sp. plants maintained under environments with different temperature regimes (20–26–33 °C and 24.8–30.8–37.8 °C) at 31 days after regrowth.

Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	FAR (g.dia-[1])		SD (cm)	
A:20	0.01cB	0.05bA	4.97cB	6.06aA
A:21	0.01cB	0.06bA	4.52cB	6.40aA
A:22	0.01cB	0.05bA	4.59cB	6.72aA
A:24	0.05bB	0.08aA	5.59bB	6.92aA
A:26	0.01cB	0.06bA	4.38cB	6.77aA
A:79	0.07aA	0.08aA	6.61aA	6.56aA
A:102	0.05bB	0.08aA	5.65bB	7.07aA
A:E.L	0.01cA	0.02cA	2.05dB	4.19bA
A:G.O	0.01cB	0.03bA	3.70cB	4.94bA
Genotype	Temperature (°C)		Temperature (°C)	
	20-26-33	24.8-30.8-37.8	20-26-33	24.8-30.8-37.8
	SDM (g)		%PS	
A:20	0.45dB	2.26bA	47.40cB	60.14aA
A:21	0.31dB	2.35bA	43.89cB	60.21aA
A:22	0.24dB	1.90cA	36.34cB	60.71aA
A:24	2.09bB	3.13aA	51.96bB	63.20aA
A:26	0.35dB	2.52bA	36.05cB	62.18aA
A:79	3.25aA	3.19aA	60.70aA	64.46aA
A:102	1.32cB	3.13aA	41.81cB	62.36aA
A:E.L	0.06dA	0.65dA	60.24aA	50.37bB
A:G.O	0.49dB	1.62cA	51.15bA	51.16bA

*Means followed by the same lowercase letter in the column and upper case in the row do not differ at 5% probability by the Scott-Knott test. Source: Authors.

The number of leaves in *Manihot* sp. plants was higher at the temperature of 24.8–30.8–37.8 °C (Table 8). Genotypes A:24, A:79, A:102, and A:GO presented the highest number of leaves (Table 9).

Table 8. Number of leaves (NL) in *Manihot* sp. plants under environments with different temperature regimes (20–26–33 °C and 24.8–30.8–37.8 °C) at 31 days after regrowth.

Variable	Temperature (°C)	
	20-26-33	24.8-30.8-37.8
NL	8.19b	13.76a

Means followed by the same lower case letter on the line do not differ at 5% probability by the Scott-Knott test. Source: Authors.

The adaptation of species of the genus *Manihot* is reflected in the results obtained in this study, in which the morphological and yield variables stem diameter, stem dry mass content, stem dry mass, percentage of the stem, number of leaves, plant dry mass, leaf to stem ratio, and percentage of leaves did not decrease with increasing temperature, both at the establishment (Table 3) and regrowth stages (Table 8).

Table 9. Number of leaves (NL) of different accessions of *Manihot* sp. at 31 days after regrowth.

	Genotype								
	A:20	A:21	A:22	A:24	A:26	A:79	A:102	A:E.L	A:G.O
NL	7.90b	8.30b	7.80b	14.27a	7.50b	15.10a	13.60a	9.90b	14.45a

Means followed by the same lower case letter on the line do not differ at 5% probability by the Scott-Knott test. Source: Authors.

The positive responses of plants of the genus *Manihot* relative to the increase in temperature regarding the number and percentage of leaves directly reflect on biomass accumulation. Plants adapted to high temperatures can promote an increase in vegetative development (Hatfield & Prueger, 2015) by increasing the activity of antioxidant enzymes in the leaves, promoting a higher leaf area index and biomass production. Thus, increases in temperature for some species, especially tropical species, contribute to the PSII functioning of leaves, allowing for greater adaptation (Martinez et al., 2014).

Furthermore, plants of the genus *Manihot* can be propagated by stems. Thus, the stem diameter is related to stake quality, which may vary between genotypes, growth stages, and the part of the stem from which the stake was cut (Mattos et al., 2006). The increase in temperature showed no negative effect on the variables related to the stem, which indirectly reflects the maintenance of the stake supply for planting in the field.

Genotypes A:102 and A:GO stood out for PDM compared to the others relative to the temperature regime 20–26–33 °C, considered the average temperature of the Sub-middle of the São Francisco River Valley, located in the Brazilian semiarid region. However, pornunça (A:24), maniçoba (A:79 and A:102), and cassava (A:EL and A:GO) showed higher values with an increase in temperature when compared to the others (Table 3); therefore, adaptive capacity is related not only to the species but also to the genotype. Cassava genotypes (A:GO) and mainly A:EL had lower PDM compared to pornunça (A:24) and maniçoba (A:26, A:79, and A:102) at regrowth, indicating their higher capacity for the management with successive harvests.

The increase in PDM in the regime with higher temperatures was due to an increase in LDM (A:20, A:21, A:22, A:26, A:EL, and A:GO) (Table 8), the number of leaves (A:24) (Table 3), and mainly SDM (Tables 3 and 8), promoting a reduction in the leaf participation in the plant and L/S, except for genotype A:EL at regrowth due to the lower PDM. Leaf participation in the plant establishment at the temperature regime 20–26–33 °C reached, on average, 45.37%, while an increase in temperature led to average participation of 33.07%. The increase in temperature can promote a higher plant development rate, but it can reduce the leaf to stem ratio due to an increase in lignification, impairing the nutritional forage quality (Habermann et al., 2019; Perotti et al., 2021). Thus, studies involving forage quality under increasing air temperature will be necessary given the importance of using native species in animal feed in the Brazilian semiarid region. Furthermore, the prediction of the increase in air temperature is associated with changes in the rainfall pattern. Thus, knowing the impacts of temperature increase on different soil water availabilities for native tropical forages would be strategic for the adoption of adaptation measures and maintenance of food security. Also, this study allowed a pre-selection of genotypes as a function of growth and morphological and yield responses to temperature increase, contributing to the breeding program as a measure to increase resilience in the cultivation of native forages in the semiarid region.

4. Conclusions

Species of the genus *Manihot* respond differently to the 4.8 °C increase in air temperature. Temperature rise has a positive impact on the growth and biomass production of species of this genus. Heating promotes changes in the morphological composition through the increase in the number of leaves and especially stem diameter and its percentage.

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