ISSN 2175-6813

Revista Engenharia na Agricultura

Viçosa, MG, DEA/UFV - DOI: 10.13083/reveng.v32i1.15549 v.32, p. 1-15, 2024

EMERGENCE AND INITIAL GROWTH OF COWPEA VARIETIES AT DIFFERENT TEMPERATURES

Magno do Nascimento Amorim[1]*, José Aliçandro Bezerra da Silva[1], Diego Ariel Meloni[2], Edson Pereira da Silva[3], Késsia Caroline Dantas da Silva[3] & Marcelo da Silva Martins[1]

1 - Federal University of the São Francisco Valley (UNIVASF), Graduate Program in Agricultural Engineering, Juazeiro, Bahia, Brazil

2 - Universidad Nacional de Santiago del Estero, School of Agronomy and Agroindustry, Santiago del Estero, Argentina

3 - Federal University of Vale do São Francisco, Agricultural and Environmental Engineering Department, Juazeiro, Bahia, Brazil

Keywords:
Optimum temperature
Semiarid
Vigna unguiculata L.

ABSTRACT

Brazil is the largest producer and consumer of beans in the world; however, the prospect of climate change could affect this production. Among these changes, the incidence of rising temperatures can directly affect the crop cycle, influencing biochemical processes that occur during seed germination and seedling emergence. The objective of this work was to determine the optimum temperature level for the emergence and initial growth of three varieties of cowpea. The experiment was conducted in a laboratory linked to the Federal University of the São Francisco Valley, Juazeiro Campus, state of Bahia, with a completely randomized design (DIC), in a 6x3 factorial scheme, with six treatments at different temperature levels: 20, 25, 30, 35, 40 and 45 °C; and three varieties of cowpea: BRS Pajeú, BRS Nova Era and BRS Pujante. The following variables were assessed: speed index, average time, relative frequency and percentage of emergence; stem length and diameter; accumulation of fresh and dry biomass in the stem, leaf and root. The ideal temperature range found for the emergence and initial growth of the cowpea varieties BRS Pajeú ranged from 27 to 32 ºC, for BRS Nova Era between 30 and 41 ºC and for BRS Pujante between 29 and 35 ºC. As the BRS Nova Era variety performs better in high temperature conditions, it could be an alternative for growing beans in the face of climate change.

Palavras-chave:
Temperatura ótima
Semiárido
Vigna unguiculata L.

EMERGÊNCIA E CRESCIMENTO INICIAL DE VARIEDADES DE FEIJÃO-CAUPI SOB DIFERENTES TEMPERATURAS

RESUMO

O Brasil é o maior produtor e consumidor de feijão do mundo, entretanto, as perspectivas de mudanças climáticas podem afetar essa produção. Entre essas alterações, a incidência do aumento da temperatura pode afetar diretamente o ciclo da cultura, influenciando processos bioquímicos que ocorrem durante de germinação de sementes e emergência das plântulas. O trabalho teve como objetivo determinar o nível temperaturas ótimo para a emergência e crescimento inicial de três variedades de feijão-caupi. O experimento foi conduzido em laboratório vinculado a Universidade Federal do Vale do São Francisco, Campus Juazeiro – BA, com delineamento inteiramente casualisado (DIC), em esquema fatorial 6x3, com seis tratamentos em diferentes níveis de temperatura: 20, 25, 30, 35, 40 e 45 °C; e três variedades de feijão-caupi: BRS Pajeú, BRS Nova Era e BRS Pujante. Foram avaliadas as variáveis: índice de velocidade, tempo médio, frequência relativa, e percentual de emergência; comprimento e diâmetro do caule; acúmulo de biomassa fresca e seca no caule, folha e raiz. A faixa de temperatura ideal encontrada para a emergência e crescimento inicial das variedades de feijão-caupi BRS Pajeú foi entre 27 e 32 ºC, para BRS Nova Era entre 30 e 41 ºC e para BRS Pujante entre 29 e 35 ºC. A variedade BRS Nova Era por apresentar melhor desempenho em condições de temperaturas elevadas, pode ser uma alternativa para o cultivo do feijão em evidentes projeções de mudanças climáticas.

Received 16 Mar, 2023 • Accepted 05 Feb, 2024 • Published 01 Mar, 2024

Email (corresponding author)*: magnoamorim@usp.br

SECTION EDITOR IN CHARGE
Gabrielle Ferreira Pires

INTRODUCTION

Brazil is the leading producer and consumer of cowpea (*Vigna unguiculata* L.), a legume of great importance for human consumption due to the presence of different minerals and vitamins in the grain, resulting in a high nutritional value of this food (Araújo *et al*., 2018). This species is mainly grown in hot climates in semi-arid and subtropical regions of the world, with high protein and energy content. Also, itis produced in all Brazilian regions (Dubal *et al*., 2016; Araújo *et al*., 2018).

Cowpea has established itself as one of the most important crops in the country, and is widely consumed in the Northeast of Brazil. In this region, its cultivation has been carried out by family farmers in a partnership system or at the subsistence level (Andrade Júnior *et al*., 2007; Lima *et al*., 2011).

On the other hand, high temperatures in the northeast may have a significant impact on crop yield, as temperature directly affects the rate and speed of emergence, which is directly related to the biochemical processes of the seeds (Carvalho & Nakagawa, 2012), and may affect the phenological cycle of crops and consequently their production.

According to Sita *et al*. (2017), ambient temperatures may increase in the future as a result of global climate change, and this increase may lead to heat stress in plants, threatening agricultural production. In addition, Queiroz *et al*. (2021) projected an increase in air temperature, which, if realized, could affect crop productivity. As temperature is the element that most affects bean crops, it can delay seed germination and seedling emergence (Dubal *et al*., 2016) and crop establishment (Zhou *et al*., 2020).

Temperature variation in seedling metabolism directly affects the enzyme activity and consequently the rate of reactions that are part of the germination, emergence, and initial growth process (Costa *et al*., 2015). According to De Ron *et al*. (2016), vigorous, rapid and uniform germination and emergence under different environmental conditions are desirable traits for seedling growth.

In agricultural systems, the choice of cultivar for planting must be made according to the conditions of the region, so knowledge of the optimal temperature level for maximum emergence is fundamental for greater production efficiency. In addition, it is extremely important to select varieties that are better adapted to heat stress as the producing regions are located in areas with high temperatures. According to Campos, Silva and Silva (2010), it is important to define crops that are resistant to the soil and climatic conditions of the semi-arid region.

Considering the deleterious effects of temperature on plant growth and development and the limited studies that indicate optimum temperatures for growing cowpeas, the aim of this study was to determine optimum temperature values for the emergence and initial growth of seedlings in three cowpea varieties.

MATERIAL AND METHODS

Experimental Procedure

The experiment was carried out at the Cytology and Physiology Laboratory of the Federal University of the São Francisco Valley (UNIVASF), Juazeiro Campus, state of Bahia (BA), located at 09°25'00" S and 40°30'00" W. The seeds corresponding to each variety were selected for uniformity of size, color and appearance. The seeds were planted in plastic containers (cups) with an approximate volume of 50 mL, previously filled with Tropstrato HA® Organic Substrate for Vegetables and perforated at the bottom to allow excess water to drain.

Experimental Design

The experimental design was completely randomized (DIC), in a 6x3 factorial scheme, with six corresponding treatments, each at different temperature levels: 20, 25, 30, 35, 40 and 45 °C; and three cowpea varieties: BRS Pajeú, BRS Nova Era and BRS Pujante. Three replicates were used for each treatment, with each replicate consisting of 10 sample units, for a total of 30 seeds per treatment for each variety.

After sowing, the containers were placed in Biological Oxygen Demand (B.O.D.) germination chambers where light and temperature were controlled. Thus, each treatment received its own temperature level with a variation of ± 1 °C, while the controlled artificial light tried to reproduce the light supply conditions in the field in the region, with a 16-hour photoperiod. Irrigation was performed manually, with two daily applications of approximately 3 mL for each sample unit. During the initial growth period, the amount of water was increased as needed and this new value was applied equally to all seedlings.

Seedling emergence assessment

The emergence speed index (ESI), relative frequency (RF), mean emergence time (MET) and percentage emergence (PE) of seedlings corresponding to each cultivar were evaluated. The ESI was calculated according to the equation proposed by Maguire (1962) (Eq. 01), the MET (Eq. 02) was obtained according to Labouriau and Valadares (1976), the PE according to conventional mathematical methods (Eq. 03) and the RF according to Labouriau and Valadares (1976) (Eq. 04).

$$\mathbf{ESI} = \sum \frac{\mathbf{Ni}}{\mathbf{Di}} \tag{1}$$

$$\mathbf{MET} = \frac{\sum \mathbf{Ni} * \mathbf{Di}}{\sum \mathbf{Ni}} \tag{2}$$

$$\mathbf{PE} = \frac{\mathbf{N_e \; x \; 100}}{\mathbf{N_t}} \tag{3}$$

$$\mathbf{RF} = \frac{\mathbf{Ni}}{\sum \mathbf{Ni}} * \mathbf{100} \tag{4}$$

Where
ESI = Emergence Speed Index, seeds/day;
MET = mean emergence time, days;
PE = percentage emergence, %;
RF = relative frequency of emergence, %;
Ni = number of emergent seedlings per day;
Di = days after emergence;
Ne = total number of seedlings emerged; and
Nt = total number of seeds planted.

Assessment of initial growth and biomass accumulation

On the seventh day after the first emergence, it was possible to determine the initial growth variables, as there was a stability of the unemerged seedlings over the days. The length and diameter of the stem were measured with a ruler and a digital caliper, respectively, with the initial point of measurement at the base and the final point at the apex of the seedlings. To collect data on the roots, the seedlings were removed from the substrate and washed to remove any remnants of the substrate that could interfere with the results.

In addition to the above analyses, biomass accumulation in stems, leaves and roots was evaluated. The fresh mass was determined immediately after collection and the dry mass after drying in an oven at 60ºC, where the weight was checked daily until it stabilized. The fresh and dry masses of leaves, roots and stems were obtained by weighing the material on an analytical balance with an accuracy of 0.001 g.

Statistical Analysis

The data obtained for the variables were subjected to analysis of variance (ANOVA), in which the significant effects were observed. In the presence of significance, the test of Tukey was performed for the qualitative factors and the regression test for the quantitative factors ($p < 0.05$), using SISVAR version 5.6 software (Ferreira, 2011).

RESULTS AND DISCUSSION

Table 1 shows the ANOVA summary for the emergence and initial growth data under the different temperatures and cowpea varieties. Based on the results of the interactions between the factors (temperature x variety), it can be seen that all the variables showed significant differences at 5% probability; the results obtained in this work are presented in the form of graphs for the quantitative factors and tables for the qualitative factors, in order to better visualize the influence between temperature and variety.

According to the equations generated by the regression in Figure 1, the point of maximum emergence in relation to temperature for BRS Pajeú, BRS Nova Era and BRS Pujante occurs at 30.2, 30.8 and 29.5 °C, respectively.

Table 1. Summary of the analysis of variance for emergence data (Percentage of Emergence - PE, Emergence Speed Index - ESI, Mean Emergence Time - MET, Stem Length - SL, Stem Diameter - SD) and initial growth data (Stem Fresh Mass - SFM, Stem Dry Mass - SDM, Leaf Fresh Mass - LFM, Leaf Dry Mass - LDM, Root Fresh Mass - RFM, Root Dry Mass - RDM)

Sources of Variation	DF	Mean square				
		PE	ESI	MET	SL	SD
Temperature (T)	5	11,288.89*	15.79*	5.88*	466.70*	11.69*
Varieties (V)	2	2,755.55*	2.62*	4.52*	0.76^NS^	0.16*
T x V	10	871.11*	1.28*	2.82*	9.23*	0.19*
Residual	36	96.29	0.14	0.13	0.48	0.02
Total	53					
CV (%)		13.59	16.42	10.69	7.29	6.06
Overall Mean		72.22	2.28	3.40	9.50	2.27

Sources of Variation	DF	Mean square					
		SFM	SDM	LFM	LDM	RFM	RDM
Temperature (T)	5	1.01*	0.0069*	0.539*	0.0087*	0.73*	0.0076*
Varieties (V)	2	0.19*	0.0011*	0.126*	0.0004*	0.29*	0.0021*
T x V	10	0.04*	0.0003*	0.019*	0.0003*	0.03*	0.0004*
Residual	36	0.002	0.00002	0.0007	0.00003	0.002	0.00004
Total	53						
CV (%)		9.99	11.54	10.17	16.00	9.08	15.47
Overall Mean		0.45	0.034	0.263	0.034	0.45	0.04

DF: Degree of freedom; CV: Coefficient of variation; (*) significant at 5% probability; (NS) not significant

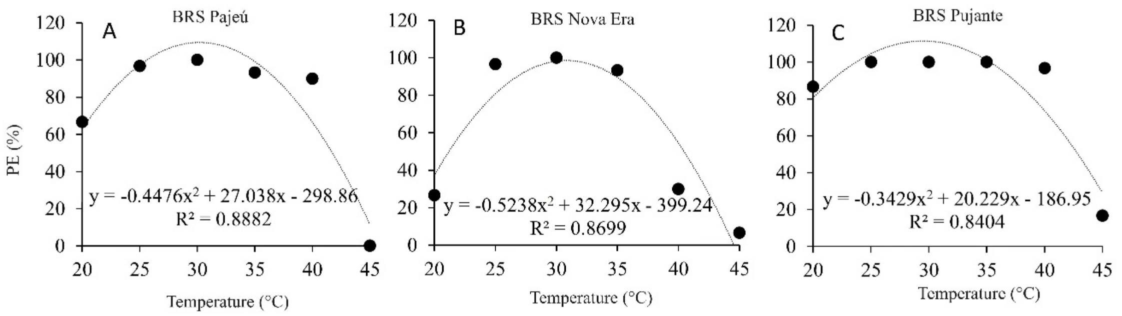

Figure 1. Regression of the percentage of emergence under different temperature levels in the varieties BRS Pajeú (A), BRS Nova Era (B) and BRS Pujante (C)

According to Jeromini *et al*. (2015), low temperatures can alter the metabolism and integrity of the embryo, reduce respiratory activity, and delay the emergence of plant species. In an experiment conducted on beans by De Ron *et al*. (2016), a delay was observed in seedling emergence when seeds were exposed to lower temperatures.

With regard to the temperature factor for BRS Pajeú, BRS Nova Era and BRS Pujante, a rise in the temperature led to an increase in the ability of the seedlings to emerge; however, after 35 °C, a decrease was observed in all three varieties. Table 2 shows the average percentages of emergence of the varieties as a function of temperature, in which 25, 30 and 35 °C showed no statistical differences among the varieties, therefore, presenting the highest average values for percentages of seedling emergence. This phenomenon probably occurred because in this range, there are the ideal temperature ranges for the metabolic events arising from the process to be maximized, thus promoting seed germination.

At 20 °C, emergence rates were low for all varieties, except for BRS Pujante, which may show a decrease in metabolic rates at this temperature compared to the others. According to Marcos Filho (2015), the sharp decrease in emergence with decreasing temperature is explained by the low water imbibition rate, which affects the mobilization of seed reserves for embryo growth.

It is important to observe that the percentage of emergence was similar among the treatments, indicating that the development of seedlings in these varieties occurs over a considerable temperature range, between 25 and 40 °C. In addition, BRS Nova Era was the one with the most limited temperature range, as at 20 and 40 °C, it showed the lowest averages statistically in relation to the other varieties.

For the ESI, according to Figure 2, BRS Pajeú showed the optimum temperature peak at 31.6 °C, which allows a greater number of plants to emerge per day, while BRS Nova Era peaked at 31.1 °C and BRS Pujante at 30.1 °C.

Also, for the variable emergence speed index (ESI), Table 3 shows the distribution of the varieties within the different temperatures, and it can be seen that BRS Pajeú showed the highest means in the temperatures with significant differences, indicating that it is the variety that emerges seedlings faster than the others in the analyzed temperature ranges. According to Figueiredo *et al*. (2019), the highest ESI values indicate that the seeds germinate more quickly and homogeneously, which means that they are more vigorous. In this sense, BRS Pajeú proved to be more vigorous in terms of emergence compared to the other varieties, especially when we look at the results obtained for the 30 °C temperature.

Table 2. Percentage of emergence for the split among varieties and different temperatures

PE (%)			
Temperature (°C)	Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante
20	66.67 b	26.67 c	86.67 a
25	96.67 ^{NS}	96.67	100.00
30	100.00 ^{NS}	100.00	100.00
35	93.33 ^{NS}	93.33	100.00
40	90.00 a	30.00 b	96.67 a
45	0.00 ^{NS}	6.67	16.67

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

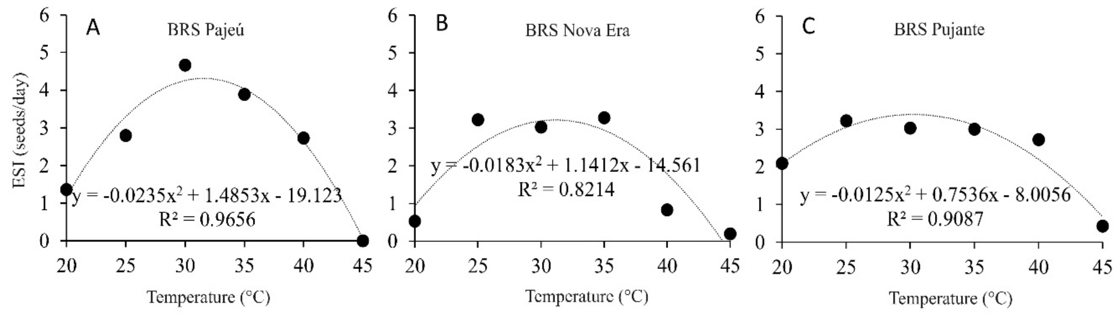

Figure 2. Regression of the Emergence Speed Index (ESI) under different temperature levels in the varieties BRS Pajeú (A), BRS Nova Era (B) and BRS Pujante (C)

Table 3. Emergence speed index for the split between varieties and different temperatures

ESI (seeds/day)			
Temperature (°C)	Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante
20	1.36 a	0.53 b	2.09 a
25	2.80 ^{NS}	3.22	3.22
30	4.66 a	3.03 b	3.03 b
35	3.87 a	3.28 ab	3.00 b
40	2.73 a	2.72 a	0.83 b
45	0.00 ^{NS}	0.19	0.43

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

At the extreme values of the analysis, close to 20° C and 45 °C, there is a decrease in emergence speed. In a work conducted by Dubal *et al*. (2016), when evaluating the physiological quality of bean seeds, it was observed that the germination speed index increases with rising temperature. Based on this perspective, the energy of water increases with increasing temperature, leading to an increase in diffusion pressure, which simultaneously increases metabolic activity in the cells that form the seed structures, resulting in a greater water absorption.

According to Oliveira *et al*. (2019) and Borges *et al*. (2020), the decrease in the ESI value could be related to the difficulty of the seedling to absorb water. In addition, as it is a physical process, water absorption by the seed is facilitated at higher temperatures, causing the tegument to hydrate somewhat faster and promoting root protrusion in less time.

However, there is a maximum temperature limit at which the emergence values become optimal, above which metabolic processes are adversely affected and seed vigor is reduced. For all plant species, there are basal temperatures for seedling emergence that result in greater efficiency of germination and seedling emergence. Therefore, as temperature decreases or increases, there are delays in important growth and developmental events, such as changes in biochemical, physiological, and morphophysiological events.

In Figure 3, the regression equations allow us to identify the optimum temperature for the average emergence time, which for the varieties BRS Pajeú, BRS Nova Era and BRS Pujante are 32.5, 35.0 and 31.8 °C, respectively.

Regarding the MET, which indicates the number of days after sowing that the seedlings begin to emerge, the temperature of 20 °C delayed the emergence in all three cultivars. The temperature with the best results for the mean emergence time, i.e. the lowest values, was between 30 ºC and 35ºC.

In addition, according to Table 4, BRS Pajeú had the statistically lowest MET compared to the other varieties, indicating that it took the fewest days to emerge. This result confirms the one obtained for ESI. BRS Pajeú was more vigorous than the others. According to Figueiredo *et al*. (2019), vigor is associated with performance, germination potential, speed and uniformity of seedling growth.

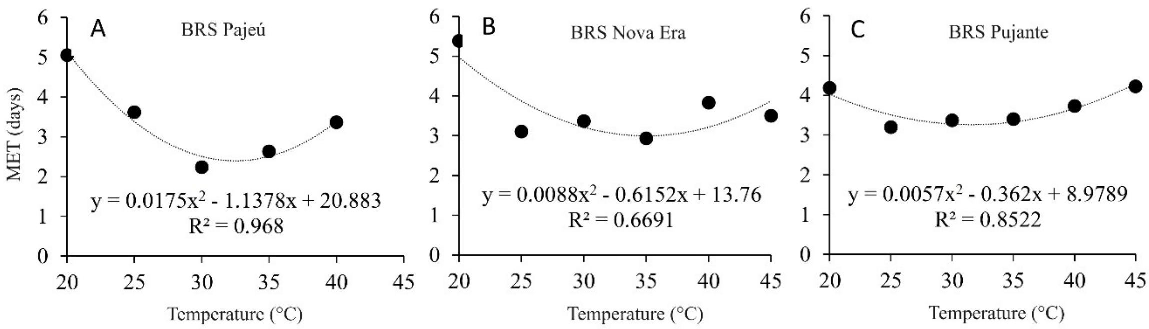

Figure 3. Regression of the mean emergence time (MET) under different temperature levels in the varieties BRS Pajeú (A), BRS Nova Era (B) and BRS Pujante (C)

Table 4. Mean emergence time for the split between varieties and different temperatures

MET (days)			
Temperature (°C)	Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante
20	5.06 a	5.39 a	4.18 b
25	3.62 NS	3.11	3.20
30	2.23 b	3.37 a	3.37 a
35	2.63 b	2.93 ab	3.40 a
40	3.37 NS	3.83	3.73
45	3.30 NS	3.50	4.22

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

In terms of relative frequency (RF), cowpea cultivars showed high variation in emergence frequency as a result of the rise in the temperature. According to Bufalo *et al*. (2012), relative frequency is associated with emergence synchronization index.

In the case of the BRS Pajeú variety (Figure 4), it was observed that at 30 °C, there was a greater emergence in the FR on the second day after planting, with about 80% of the seedlings emerging, pointing to a more suitable temperature level for planting, as it is expected to activate all the phases of the seedling formation process.

As it can be seen in Figure 5, the temperature of 40 °C promoted a greater emergence of the BRS Nova Era variety on the fourth day, with 83% of the seedlings emerging, followed by the temperature of 35 °C, with 80% of the seedlings emerging on the third day. It is likely that these temperature levels promoted an increase in the rate at which biochemical and/or morphological events were activated, facilitating rapid radicle formation. In addition, at this temperature, there was a high seed emergence on the third day after planting.

According to the FR curve for the BRS Pujante variety (Figure 6), emergence was over 60% on the third and fourth days. For the extreme temperatures of 20 °C and 45 °C, the maximum emergence was basically on the fourth day after planting.

Although the BRS Nova Era and BRS Pajeú varieties had seedlings that emerged at 45 °C, they did not show good growth and development, as it will be shown below, because according to Costa *et al*. (2015), at temperatures above the optimum, during photosynthetic activity, the carboxylation of ribulose-1,5-biphosphate (RuBP) is significantly reduced, and due to the increase in temperature, the $O:CO_2$ ratio is altered, interfering with sugar production and making it impossible for plants to grow properly.

On the other hand, temperatures close to 20 °C slowed down the growth and development of seedlings of the three varieties. According to Marini *et al*. (2012), low temperatures promote a lower seedling emergence capacity due to the slower rate of water absorption by the seeds, resulting in a reduction in the hydration level of the tissues and, consequently, the invalidation or malformation of the root protrusion and the aerial part.

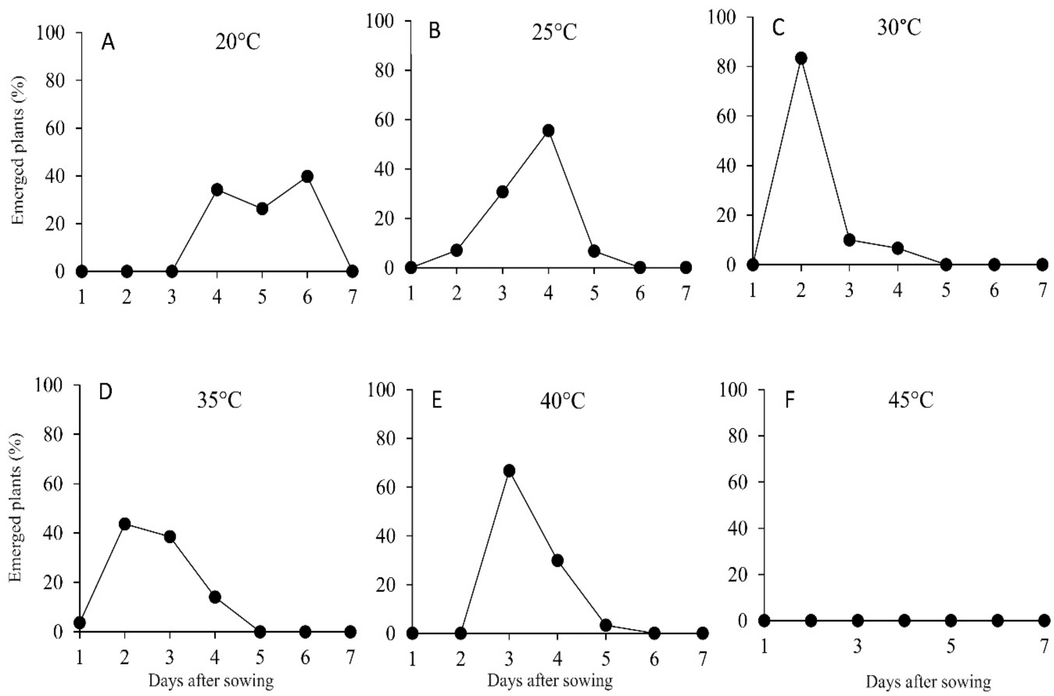

Figure 4. Relative frequency of emergence at temperatures of 20 (A), 25 (B), 30 (C), 35 (D), 40 (E) and 45 ºC (F) for the cowpea variety BRS Pajeú

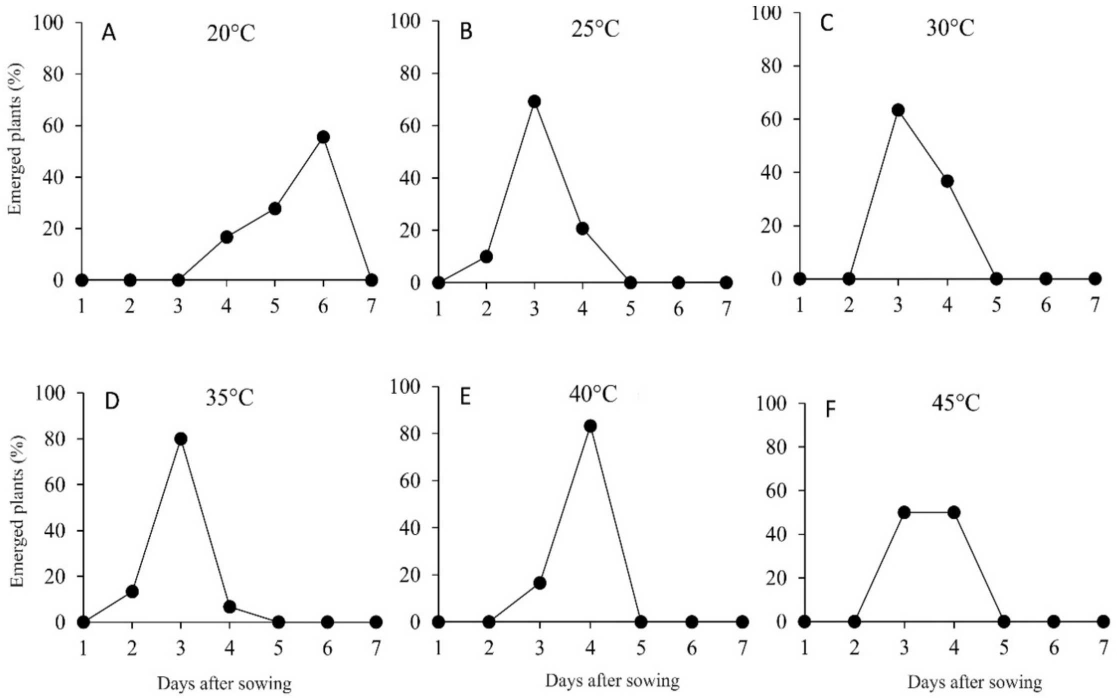

Figure 5. Relative frequency of emergence at 20 (A), 25 (B), 30 (C), 35 (D), 40 (E) and 45 ºC (F) for cowpea variety BRS Nova Era

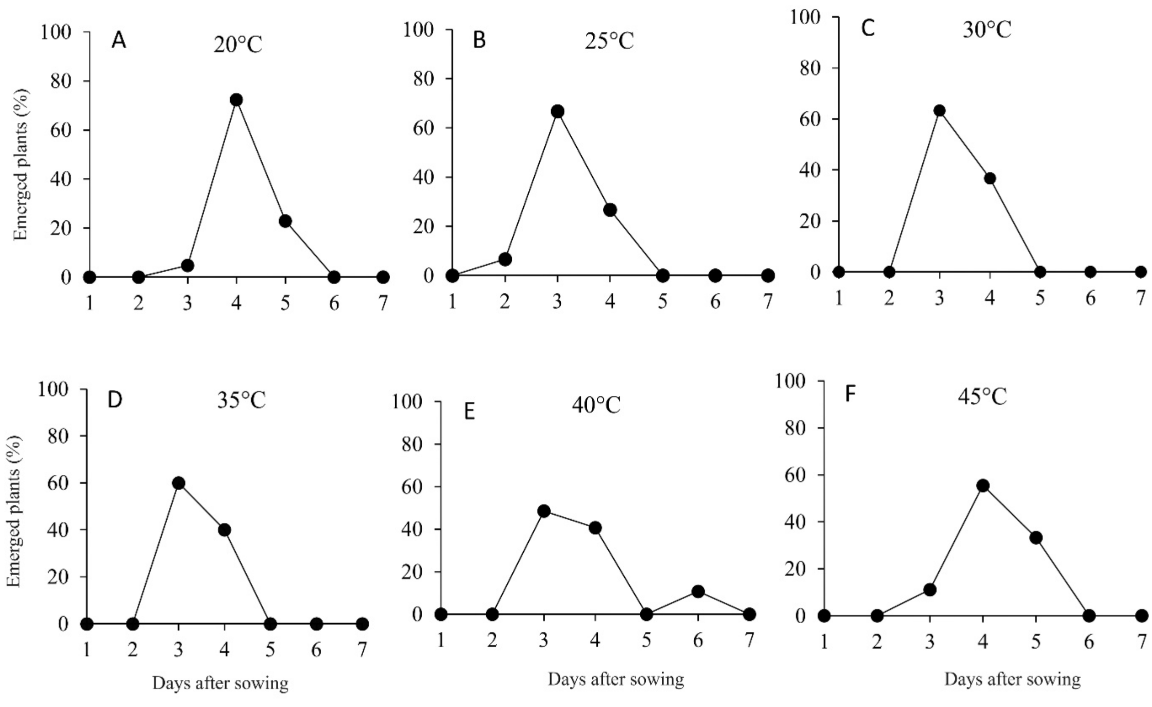

Figure 6. Relative frequency of emergence at 20 (A), 25 (B), 30 (C), 35 (D), 40 (E) and 45 ºC (F) for cowpea variety BRS Pujante

The regression for stem length and diameter (Figure 7) showed that BRS Pajeú had the highest peak of length promotion between temperatures of 30 and 40 °C, in which the 32.68 °C was the level that showed the best result. For BRS Nova Era, the highest values were limited to the temperature range between 30 and 35 °C, with the best result peaking at 32.73 °C. For BRS Pujante, the maximum stem length occurred at 32.86 °C.

In terms of stem diameter, the results were similar to the previous ones in terms of the range of best growth and development, but the maximum points were 27.84, 29.40 and 30.74 °C for the varieties BRS Pajeú, BRS Nova Era and BRS Pujante, respectively.

Table 5 shows that BRS Pajeú has the highest average stem length at 30 and 40 °C. This result shows a correlation with the responses found for ESI and MET, where this variety showed the best seed vigor when subjected to temperature conditions that allowed greater stem growth.

However, the greater length of the stem usually leads to a reduction in its diameter, since the reserves must be distributed in a balanced way among the morphological structures of the plant, which must have led the seedlings of the Pajeú variety to a significant increase in height (Table 5).

From the regression analysis obtained as a function of the dry and fresh mass of the stem (Figure 8), it was possible to find the maximum capacity for accumulation of fresh mass for the Pajeú variety at 32.89 °C (Figure 8a), similar to

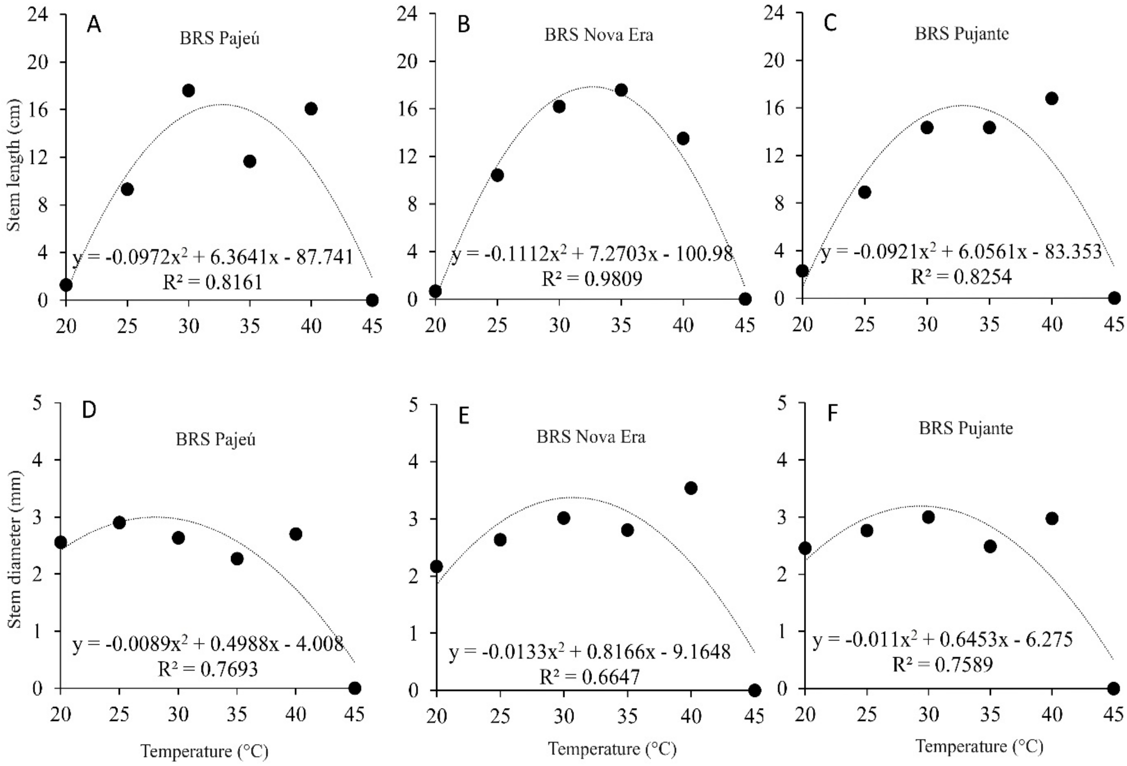

Figure 7. Stem length and diameter for the bean varieties BRS Pajeú (A and D), BRS Nova Era (B and E) and BRS Pujante (C and F) at different temperature levels of 20, 25, 30, 35, 40 and 45 °C

Table 5. Stem length and diameter for the split among varieties and different temperatures

Temperature (°C)	ST (cm)			SD (mm)		
	Varieties			Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante	BRS Pajeú	BRS Nova Era	BRS Pujante
20	1.28 ab	0.67 b	2.32 a	2.55 a	2.17 b	2.46 a
25	9.32 ab	10.42 a	8.92 b	2.90 NS	2.63	2.76
30	17.60 a	16.20 b	14.36 c	2.63 b	3.02 a	3.00 a
35	11.67 c	17.57 a	14.35 b	2.27 b	2.48 b	2.81 a
40	16.08 a	13.51 b	16.78 a	2.70 b	3.54 a	2.97 b
45	0.00 NS	0.00	0.00	0.00 NS	0.00	0.00

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

the maximum dry matter content reached at 32.12 °C. For the Nova Era variety (Figure 8b), the point of maximum accumulation occurred at 33.11 °C for fresh matter and 32 for dry matter. For the variety Nova Era (Figure 8b), the point of maximum accumulation occurred at 33.11 °C for fresh matter and 32 °C for dry matter, while for the variety Pujante (Figure 8c), the point of maximum accumulation occurred at 32.75 °C for fresh matter and 32.13 °C for dry matter.

Table 6 shows the fresh and dry mass of the stem, where BRS Nova Era reached the highest average biomass accumulation in the stem at temperatures close to the above mentioned optimum. On the other hand, BRS Pajeú had the lowest averages. These results are consistent with the values found for stem length, a phenomenon explained by the distribution of structural compounds in the formation of the root, stem and leaf of the seedlings, which is intrinsic to each variety.

According to Pegoraro *et al*. (2014), in the initial period of the cycle, there is a greater accumulation of dry matter in the leaves, following a trend of translocation of organic and inorganic compounds

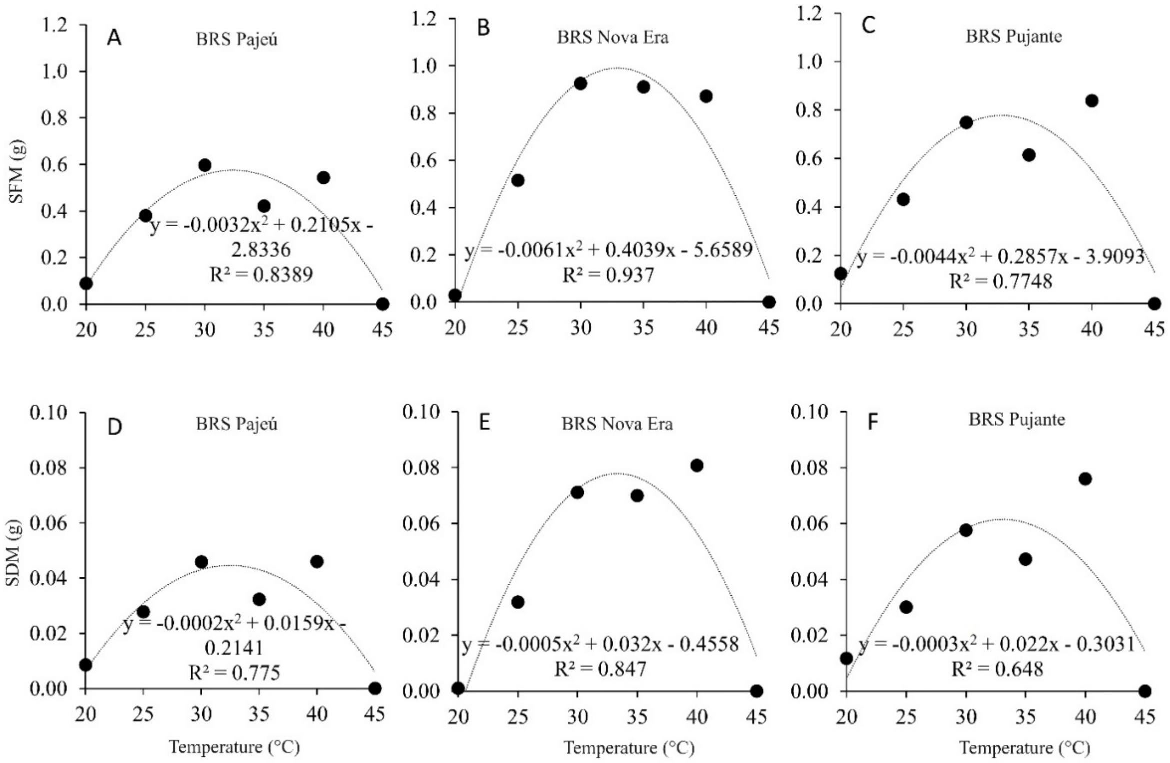

Figure 8. Stem Fresh and Dry Mass for the bean varieties BRS Pajeú (A and D), BRS Nova Era (B and E) and BRS Pujante (C and F) under different temperature levels of 20, 25, 30, 35, 40 and 45 °C

Table 6. Stem fresh and dry masses for varieties and different temperatures

Temperature (°C)	SFM (g)			SDM (g)		
	Varieties			Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante	BRS Pajeú	BRS Nova Era	BRS Pujante
20	0.09 ab	0.03 b	0.12 a	0.009 ab	0.001 b	0.012 a
25	0.38 b	0.52 a	0.43 ab	0.028 NS	0.032	0.030
30	0.60 c	0.93 a	0.75 b	0.046 c	0.071 a	0.058 b
35	0.42 c	0.91 a	0.61 b	0.032 c	0.070 a	0.047 b
40	0.54 b	0.87 a	0.83 a	0.046 b	0.081 a	0.076 a
45	0.00 NS	0.00	0.00	0.00 NS	0.00	0.00

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

that are exported during the cycle, in the growth and development phase, from the leaves to the stem and root, and then this transport occurs during the reproductive phase, mainly from the leaves to the flowers, fruits and, consequently, grains.

The maximum temperature found for the greatest accumulation of biomass in the leaves (Figure 9) was similar to the results obtained for biomass in the stem, in which the varieties Pajeú and Nova Era showed the maximum level of 32.4 °C for fresh mass (LFM) and 30 °C and 36.1 °C for dry mass (LDM), respectively. The Pujante variety had a maximum temperature of 35.1 °C for fresh matter and 29.6 °C for dry matter.

According to the data shown in Table 7, which illustrates the fresh and dry mass of the leaf, it can be seen that BRS Pajeú has the lowest averages close to the optimum temperature, and BRS Nova Era and Pujante have the highest averages, confirming the variables seen above, which indicates a greater accumulation of reserves under the experimental conditions for these two varieties.

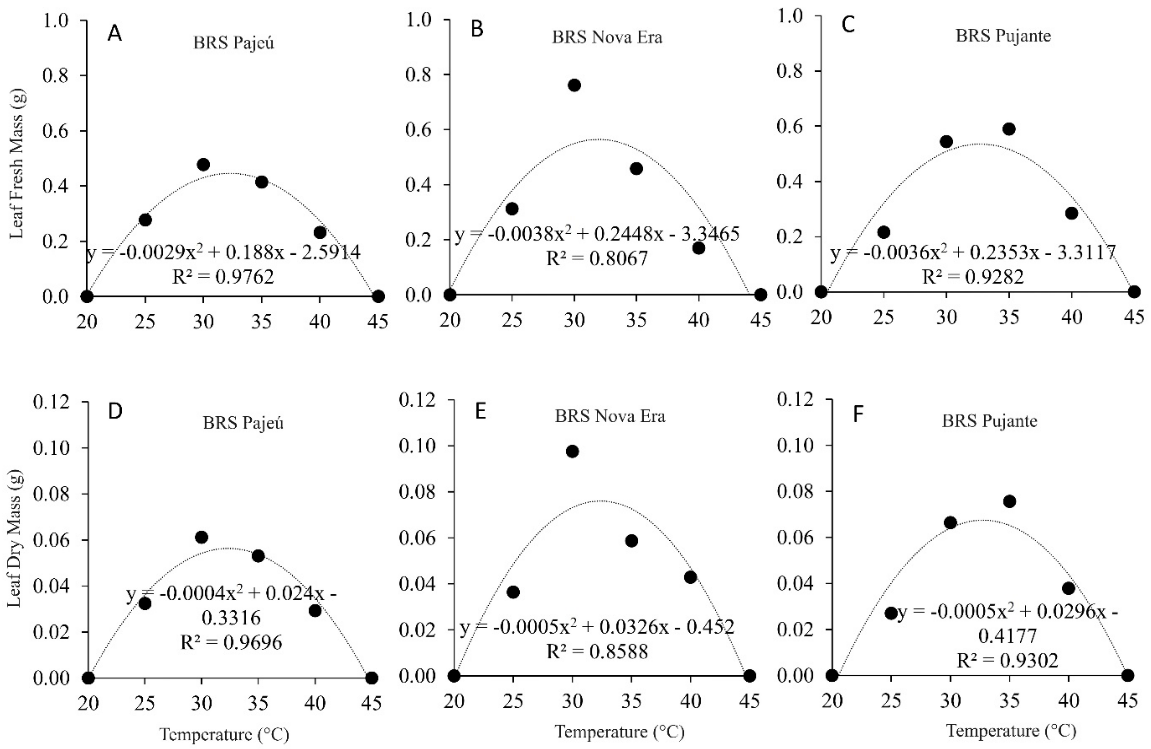

Figure 9. Fresh and dry leaf mass of bean varieties: BRS Pajeú (A and D), BRS Nova Era (B and E) and BRS Pujante (C and F) under different temperature levels of 20, 25, 30, 35, 40 and 45 °C

Table 7. Fresh and dry leaf mass for the split between varieties and different temperatures

Temperature (°C)	LFM (g)			LDM (g)		
	Varieties			Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante	BRS Pajeú	BRS Nova Era	BRS Pujante
20	0.00 NS	0.00	0.00	0.00 NS	0.00	0.00
25	0.28 a	0.31 a	0.22 b	0.033 NS	0.036	0.027
30	0.48 c	0.76 a	0.54 b	0.061 b	0.098 a	0.066 b
35	0.41 b	0.46 b	0.59 a	0.053 b	0.058 b	0.076 a
40	0.23 b	0.17 c	0.28 a	0.029 b	0.043 a	0.038 ab
45	0.00 NS	0.00	0.00	0.00 NS	0.00	0.00

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

In the roots (Figure 10), the accumulation of fresh matter for the varieties BRS Pajeú (a), BRS Nova Era (b) and BRS Pujante (c) was 31.8 °C, 31.32 °C and 31.5 °C, respectively. For dry matter, the maximum peak was 27.16 °C for BRS Pajeú, 33.2 °C for BRS Nova Era and 35.4 °C for BRS Pujante.

As for the accumulation of fresh and dry root mass (Table 8), the variety BRS Nova Era showed the highest averages and BRS Pajeú the lowest averages close to the optimum temperature. In general, the accumulation of biomass in seedlings is related to their vigor, genetic characteristics and interaction with environmental conditions, so for the initial growth it was again found that BRS Nova Era was the variety that performed best under the experimental conditions imposed.

Taking into account the property of heat conduction through the soil, which causes the temperature to decrease from the surface as it increases in depth, it is assumed that the roots require lower temperatures than the ideal ones in the aerial part for their full development, which is in agreement with the results obtained, as the organic

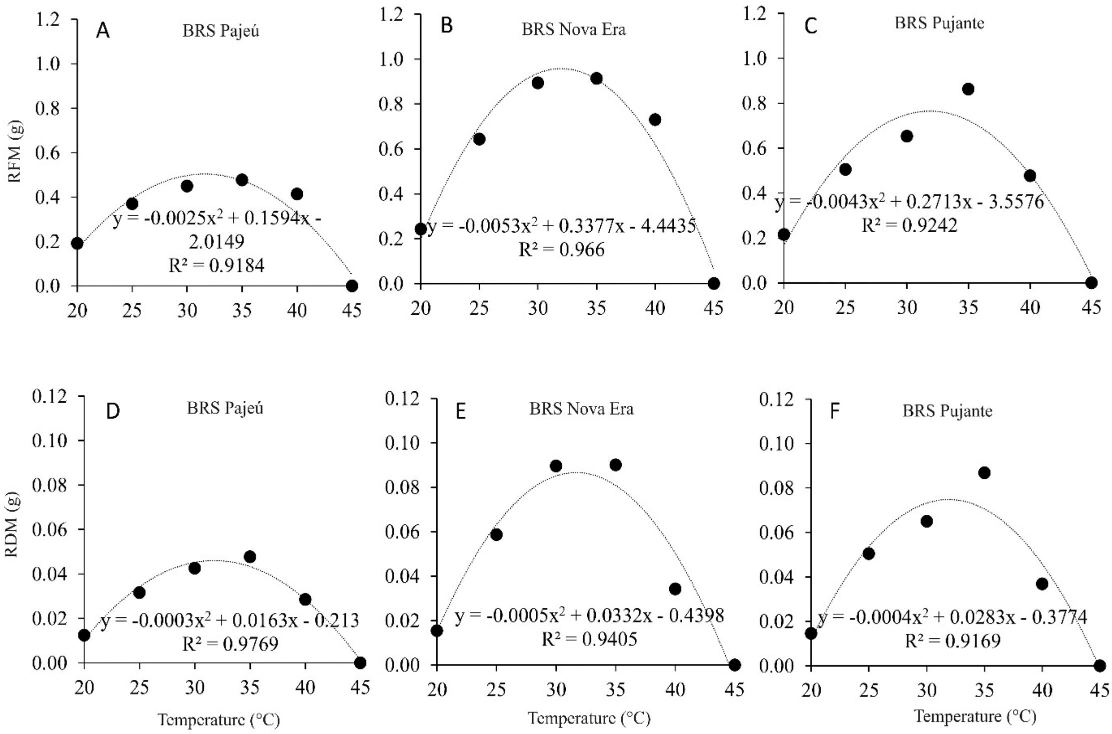

Figure 10. Fresh and dry root mass of the bean varieties BRS Pajeú (A and D), BRS Nova Era (B and E) and BRS Pujante (C and F) at different temperature levels of 20, 25, 30, 35, 40 and 45 °C

Table 8. Fresh and dry root mass for varieties and different temperatures

Temperature (°C)	RFM (g)			RDM (g)		
	Varieties			Varieties		
	BRS Pajeú	BRS Nova Era	BRS Pujante	BRS Pajeú	BRS Nova Era	BRS Pujante
20	0.19 NS	0.22	0.24	0.013 NS	0.016	0.015
25	0.37 c	0.64 a	0.51 b	0.032 b	0.059 a	0.051 a
30	0.45 c	0.89 a	0.65 b	0.043 c	0.089 a	0.065 b
35	0.48 b	0.91 a	0.86 a	0.048 b	0.090 a	0.087 a
40	0.41 b	0.73 a	0.48 b	0.029 NS	0.035	0.037
45	0.00 NS	0.00	0.00	0.00 NS	0.00	0.00

Different letters on the same line are significantly different by Tukey's test ($p < 0.05$); (NS): not significant

substrate, since it does not have these properties, ends up providing the root system with the same temperature conditions as the surface.

Considering the study conducted, it was observed that temperatures between 30 °C and 35 °C provided more favorable conditions for bean seedlings to produce organic components and assimilate inorganic compounds, thus increasing biomass in the aerial part and root system. Facin *et al*. (2014) observed that temperatures around 22 °C provided the best conditions for bean seedlings to increase the dry and fresh matter. Both results are consistent with those of Larcher (2000), who showed that the optimal developmental range for tropical species is between 20 °C and 35 °C.

In addition, the greater developmental capacity obtained by the plants beyond stress conditions allows for a better utilization of metabolites, leading to an optimized incorporation of nutrient reserves and metabolites into the tissues, thus promoting greater biomass accumulation.

CONCLUSIONS

- For the experimental conditions, the ideal temperature range that provides the best conditions for emergence and initial growth of cowpea varieties is between 27.16ºC and 32.89 ºC for BRS Pajeú, between 30.8ºC and 41.0ºC for BRS Nova Era, and between 29.5ºC and 35.4 ºC for BRS Pujante.
- In addition, BRS Nova Era showed a better initial development in higher temperature conditions, especially in the accumulation of biomass in roots, stems and leaves, with a wider temperature range. However, BRS Pajeú showed the best performance in terms of seedling emergence, with a more limited optimum temperature range and lower than the other varieties.
- Therefore, BRS Nova Era may be a more suitable variety for semi-arid regions and for places with prospects of climate change, especially with the increase in temperature, which has a direct influence on the biochemical processes of the seeds and their production cycle. However, further studies are needed, going beyond the analysis of emergence and initial growth, to verify its productivity under these conditions.

AUTHORSHIP CONTRIBUTION STATEMENT

AMORIM, M. N.: Data curation, Formal Analysis, Investigation, Project administration, Software, Writing – original draft; **SILVA, J. A. B.:** Conceptualization, Methodology, Supervision, Writing – review & editing; **MELONI, D. A.:** Conceptualization, Visualization, Writing – review & editing; **SILVA, E. P.:** Investigation, Methodology, Software, Visualization, Writing – review & editing; **SILVA, K. C. D.:** Investigation, Methodology, Visualization, Writing – review & editing; **MARTINS, M. S.:** Visualization, Writing – review & editing.

DECLARATION OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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