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Base temperature, phyllochron, and radiation use efficiency of okra cultivars

Temperatura base, filocrono y eficiencia de uso de radiación de cultivares de okra

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ABSTRACT

This study aimed to determine the base temperature, phyllochron, solar radiation use efficiency, and productivity of okra cultivars in five sowing seasons at a latitude near 30º S. The experiment was carried out in the experimental area of the Department of Plant Production of the Federal University of Santa Maria during the agricultural season of 2016/2017. Treatments were composed by ten combinations of two okra cultivars (Santa Cruz 47 and Valença) and five sowing seasons (season 1 = 11/4/2016, season 2 = 11/19/2016, season 3 = 12/4/2016, season 4 = 12/19/2016, and season 5 = 1/3/2017). The experimental design was a randomized block design in a 5 × 2 factorial scheme, with a split-plot arrangement and four replications. The five sowing seasons were randomized in the main plot and the two cultivars in the subplot. Spacing was 0.8 m between rows and 0.40 m between plants in the row. Base temperature, which was estimated using the lower mean-square error (MSE), presented values of 11.5 and 11.0 ºC for the cultivars Santa Cruz 47 and Valença, respectively. Phyllochron ranged between sowing seasons from 14.4 to 18.9 ºC day leaf^{-1} for the cultivar Santa Cruz 47 and 18.4 to 25.7 ºC day leaf^{-1} for the cultivar Valença. The cultivar Valença presented a higher radiation use efficiency, resulting in a higher fruit productivity.

Keywords: *Abelmoschus esculentus* L. Moench. Santa Cruz 47, Valença, Phenology.

RESUMEN

Este estudio determinó la temperatura base, el filocrono, la eficiencia del uso de la radiación solar y el rendimiento de cultivares de okra en cinco temporadas de siembra a una latitud cercana a los 30º S. El experimento se llevó a cabo en el área experimental del Departamento de Producción Vegetal de la Universidad Federal de Santa María durante la temporada agrícola 2016/2017. Los tratamientos fueron compuestos por diez combinaciones de dos cultivares de okra ('Santa Cruz 47' y 'Valença') y cinco temporadas de siembra (temporada 1 = 04/11/2016, temporada 2 = 19/11/2016, temporada 3 = 04/12/2016, temporada 4 = 19/12/2016, y temporada 5 = 03/01/2017). El diseño experimental fue un diseño de bloques al azar en un esquema factorial 5 × 2, con parcelas divididas y cuatro repeticiones. Las cinco temporadas de siembra se asignaron al azar en la parcela principal y los dos cultivares en la subparcela. El espaciamiento fue de 0,8 m entre líneas y 0,40 m entre plantas en la línea. La temperatura base, que se estimó utilizando el menor error cuadrático medio (ECM), presentó valores de 11,5 y 11,0 ºC para los cultivares 'Santa Cruz 47' y 'Valença', respectivamente. El filocrono varió entre las temporadas de siembra de 14,4 a 18,9 ºC día hoja^{-1} para el cultivar 'Santa Cruz 47' y de 18,4 a 25,7 ºC día hoja^{-1} para el cultivar 'Valença'. El cultivar 'Valença' presentó una mayor eficiencia en el uso de la radiación, lo que resultó en un mayor rendimiento de la fruta.

Palabras clave: Abelmoschus esculentus *L. Moench, Santa Cruz 47, Valença, Fenología.*

Introduction

Okra is an annual vegetable of the family Malvaceae. The largest okra's producing countries are India and Nigeria. However, the average fruit productivity obtained for these countries is 11.4 and 1.4 t ha^{-1}, respectively, which is below the potential crop production. In Brazil, the largest okra production can be found in the states of the Southeast and Northeast regions, which present a latitude below 20º S and productivity between 15 and 20 t ha^{-1} (Filgueira, 2008; Oliveira *et al*., 2013).

In Brazil, okra has been stood out in small and medium rural properties of family farming, being widely used in the Brazilian cuisine, and considered as a plant of high nutritional value

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(Oliveira *et al*., 2013; Kumar *et al*., 2015). In 2006, the Southeast and Northeast regions accounted for 87.6% of the total Brazilian okra production. In the same year, the South region produced 2,639 tons, but the Rio Grande do Sul State produced 25 tons, accounting for only 0.02% of the total Brazilian production (IBGE, 2006).

The lack of information about this vegetable by the southern population, predominantly of European descendants, could explain its low consumption and scarcity in the market at affordable prices. However, there is a consumption potential driven by stimulating plant products with nutraceutical properties. One of the main obstacles to okra cultivation in southern Brazil is the scarcity of information on climatic requirements for its growth and development throughout the year.

Okra originates in Africa, possibly in Ethiopia, in regions characterized by high temperatures, average radiation of 19.5 MJ m^{-2} day^{-1}, average annual precipitation of 817 mm, and relative air humidity between 40 and 60% (Fazzini *et al*., 2015). In the Southeast and Northeast production regions of Brazil, the environmental conditions are close to those found in the regions of origin. However, in the Northeast region, water scarcity has been a limiting factor to okra cultivation. In the South region of Brazil, air temperature can exceed 35 ºC and the global solar radiation can exceed 24 MJ m^{-2} during the summer months (Alvares *et al*., 2014), with a higher thermal amplitude and precipitation when compared to the Northeast region. In the other seasons, air temperature can reach values close to zero and solar radiation can reach levels below the trophic limit.

The most favorable climatic availability to the cultivation of summer vegetables, i.e. those demanding of high temperatures, is between the thermal limits of 12 and 32 ºC and a minimum amount of radiation of 8.5 MJ m^{-2} day^{-1}. Temperatures above 32 ºC together with radiation levels above 25 MJ m^{-2} day^{-1} are detrimental to growth, productivity, and quality of vegetables (Castilla and Baeza, 2013).

The main indicators that have been used to determine thermal requirements of cultivated plants are base temperature and phyllochron (Maldaner *et al*., 2009; Lucas *et al*., 2012). In this sense, phenological results can be found in the literature relating air temperature with melon (Bouzo and Küchen, 2012), and strawberry development (Tazzo *et al*., 2015). However, no similar information indicating thermal and radiative limits and potential production in regions other than the traditional ones was found for okra.

Thus, the aim of this study was to determine the base temperature, phyllochron, solar radiation use efficiency, and productivity of okra cultivars in five sowing seasons at a latitude near 30º S.

Material and Methods

The experiment was composed of five sowing seasons and two okra cultivars, being carried out in the experimental area of the Department of Plant Production of the Federal University of Santa Maria (UFSM), Santa Maria, RS, Brazil, located at the geographical coordinates 29º42′ S and 53º49″ W, with an altitude of 95 m, in the agricultural season of 2016/2017. According to Köppen's classification, local climate is type Cfa, i.e. a humid subtropical climate with an annual precipitation above 1000 mm (Alvares *et al*., 2014). During the experimental period, global solar radiation, minimum and maximum air temperatures, and precipitation were recorded daily at the UFSM Meteorological Station, located 70 m from the experimental area.

The soil of the experimental area is classified as a sandy dystrophic red Argisol. Prior to the experiment installation, soil samples were collected at a depth of 0–20 cm and sent to the UFSM Laboratory for Soil Analysis. The following results were obtained from the analysis: pH in water (1.0: 2.5) = 6.1, P = 39.4 mg dm^{-3}, K = 0.5 $cmol_c$ dm^{-3}, Ca = 6.3 $cmol_c$ dm^{-3}, Mg = 2.6 $cmol_c$ dm^{-3}, S = 11.3 mg dm^{-3}, H^{+}+Al^{3+} = 2.4 $cmol_c$ dm^{-3}, and organic matter = 1.6%.

The ten treatments were composed by the combination of two okra cultivars (Santa Cruz 47 and Valença) and five sowing seasons (season 1 = 11/4/2016, season 2 = 11/19/2016, season 3 = 12/4/2016, season 4 = 12/19/2016, and season 5 = 1/3/2017). The experimental design was a randomized block design in a 5 × 2 factorial scheme, with a split-plot arrangement and four replications. The five sowing seasons were randomized in the main plot and the two cultivars in the subplot. The experimental unit, with an area of 6.72 m^2, consisted of three rows of 2.8 m in length with a spacing of 0.8 m between rows and 0.40 m between plants in the row, totaling 21 plants. Assessments were performed in the useful area, which was composed of the five central plants in the central row (2.5 m^2). The other 16 plants were considered as borders.

Soil tillage was carried out by means of plowing and harrowing in order to provide favorable conditions for sowing and plant development. Sowing was performed by placing three seeds per pit. After seedling emergence, thinning was performed and only one plant remained per pit, which corresponds to a population density of 31,250 plants ha^{-1}.

Topdressing fertilization was carried out based on soil analysis and divided into four equal applications, being provided 100 kg ha^{-1} of N and 90 kg ha^{-1} of K_2O, as recommended by Filgueira (2008). The first application was conducted on thinning day and the others every 20 days. Fertilizer sources used were urea (45% N) and potassium nitrate (44% K_2O and 13% N). Management practices consisted of thinning the seedlings, irrigation, weed control and phytosanitary control.

Water supply was performed by a localized drip irrigation method with a flow rate of 7.5 L h^{-1} m^{-1}. The applied water volume was based on the crop evapotranspiration (ETc), obtained by multiplying the potential evapotranspiration (ETo) and the crop coefficient (Kc) at the different crop phases (ETc = ETo × Kc). Potential evapotranspiration was estimated by multiplying the class A tank evaporation (ETa), installed near the experiment, and a correction factor of 0.75 (ETo = ETa × 0.75).

The days from sowing to the beginning of flowering, from flowering to the end of harvest, and from sowing to the end of harvest were counted. Weekly, from seedling emergence to the beginning of flowering, the number of leaves (NF) was counted in the central plant of each experimental unit, totalizing 40 plants in the experiment. We considered as definitive the leaves with a length greater than 4 cm.

To determine the base temperature (Tb) of okra cultivars, we adopted the methodology of the lower mean-square error (MSE) from the linear regression between NF and the accumulated thermal sum (TSa) from seedling emergence to the beginning of flowering (Sinclair *et al.*, 2004; Lucas *et al.*, 2012). As proposed by these authors, for TSa calculation, base temperature values of 0, 0.5, 1.0, 1.5… 20 °C were simulated in an Excel spreadsheet. The lowest MSE was considered as the Tb value of each of the 40 plants (Sinclair *et al.*, 2004). Base temperature for each cultivar was obtained by the average base temperatures of seasons (average of 20 plants), as Paula and Streck (2008) and Streck *et al.* (2009). In addition, phyllochron was estimated by Tb values of each cultivar.

Daily thermal sum (TSd, °C day) was calculated by the difference between the arithmetic mean of the maximum (Tmax, °C) and minimum (Tmin, °C) daily air temperatures and the crop base temperature (Tb), as proposed by Arnold (1960):

$$\mathrm{TSd} = \frac{\mathrm{Tmax} + \mathrm{Tmix}}{2} - \mathrm{Tb} \times 1 \text{ day} \quad (1)$$

The sum of TSd values from seedling emergence to the flowering of okra plants was used to determine TSa (°C day):

$$\mathrm{TSa} = \sum \mathrm{TSd} \quad (2)$$

The parameters of simple linear regression of NF as a function of TSa were estimated from the number of leaves of each season and cultivar and for each of the 40 plants. Phyllochron was estimated in each plant by the inverse of the angular coefficient of regression equations (Streck *et al.*, 2009; Tazzo *et al.*, 2015).

Commercial green okra fruits were harvested from the five central plants of the central row at each experimental unit every two days from December 2016 to April 2017. These fruits, with a length between 12 and 18 cm (Filgueira, 2008), were collected by using a sharp penknife. Data on the production components of each plant were accumulated. After each harvest, fruits were transported to the Biometrics Building of the Department of Plant Production to assess the number of fruits per plant (average of five plants, fruits $plant^{-1}$) and fruit mass per plant (average of five plants, g $plant^{-1}$). Fruits productivity (t ha^{-1}) was obtained by multiplying the fruit mass per plant (g $plant^{-1}$) by the number of plants per hectare (31,250 plants ha^{-1}), divided by 1,000,000.

Radiation use efficiency by plants (g MJ^{-1}) during crop cycle was calculated by the ratio between fruit mass per m^2 (g m^{-2}) and accumulated solar radiation (MJ m^{-2}), according to and Muchow (1999).

The results were submitted to analysis of variance by the F test and the means compared by the Tukey test at 5% probability level. The data related to solar radiation use efficiency were assessed by polynomial regression. All statistical analyses were performed using the statistical software Sisvar 5.6 (Ferreira, 2014).

Results and Discussion

During the experimental period, daily global solar radiation (Figure 1A), daily air temperature (Figure 1B), and precipitation (Figure 1C) were recorded at the experimental site. The accumulated global solar radiation was 3,143.84 MJ m^{-2}, the accumulated precipitation was 955.2 mm, and the average air temperature was 23.3 ºC. The lowest daily global solar radiation recorded was 4.43 MJ m^{-2} (Figure 1A), while the lowest and highest temperatures were 7.2 ºC and 35.1 ºC, respectively (Figure 1B). The accumulated precipitation from November 2016 to April 2017 was 110.6; 148.4; 229.2; 234.6; 232.4 and 0.00 mm, respectively (Figure 1C).

In the cultivar Valença, no significant difference was observed for the number of days from sowing to the beginning of flowering (SW–BF) considering the sowing seasons, with an average value of 45.2 days (Table 1). However, the delay in sowing the cultivar Santa Cruz 47 increased the number of days needed for the plants to begin flowering. In the first sowing season, plants started flowering 51 days after sowing, while in the fifth season, it took 85 days. This situation results in a delay in harvesting and a reduction in the number of harvests (Table 1), which may reduce crop productivity.

Considering all sowing seasons, the cultivar Valença was earlier to start flowering and hence presented a longer harvest period (Table 1). In the fifth sowing season, the cultivar Valença produced during 51 days, while the cultivar Santa Cruz 47 produced fruits only during 10 days. Climatic variation registered during the experimental period indicates that the plants were submitted to different air temperature conditions (Figure 1B), which is desirable for determining the base temperature and phyllochron. In the first half of April 2017, the experiment was concluded due to a severe attack of powdery mildew (*Erysiphe cichoracearum*), which preclude to continue the harvests (Table 1) even with the appropriate phytosanitary control. In addition to the phytosanitary problem, the average air temperature reduced with the beginning of autumn (20/3/2017) (Figure 1B).

MSE variation as a function of temperatures simulated in the thermal sum calculation for a plant of the second season is shown in Figure 2. Coincidentally, both Tb values corresponded to the average of the five seasons for each cultivar. We observed a predominance of base temperature with a value higher than 10 ºC for all plants from all cultivars and seasons. Base temperature considered in our study for each cultivar was resulting from the average of Tb of sowing seasons (Martins *et al.*, 2007; Streck *et al.*, 2009), with a value of 11.5 ºC for the cultivar Santa Cruz 47 (Figure 2A) and 11.0 ºC for the cultivar Valença (Figure 2B). These values were

Table 1. Number of days from sowing to the beginning of flowering (SW-BF), from the beginning of flowering to the end of harvest (BF–EH), and from sowing to the end of harvest (SW-EH) of two okra cultivars at different sowing seasons.

SS	DS	SE	DFCNF	SW-BF		BF-EH		SW-EH	
				Cultivar					
				Santa Cruz 47	Valença	Santa Cruz 47	Valença	Santa Cruz 47	Valença
1	11/4/2016	11/12/2016	11/17/2016	51dA	47aB	94aB	98aA	145aA	145aA
2	11/19/2016	11/27/2016	12/7/2016	65cA	46aB	65bB	85bA	130bA	130bA
3	12/4/2016	12/12/2016	12/20/2016	76bA	46aB	46cB	77cA	122cA	122cA
4	12/19/2016	12/27/2016	1/4/2017	80abA	45aB	30dB	64dA	109dA	109dA
5	1/3/2017	1/11/2017	1/18/2017	85aA	43aB	10eB	51eA	94eA	94eA
	Mean			71.2	45.2	48.8	74.8	120	120

SS = sowing season; DS = date of sowing; SE = seedling emergence; DFCNF = date of the first count in the number of leaves. Means followed by the same lowercase letters in the columns and uppercase letters in the rows do not differ from each other by the Tukey's test (p ≤ 0.05).

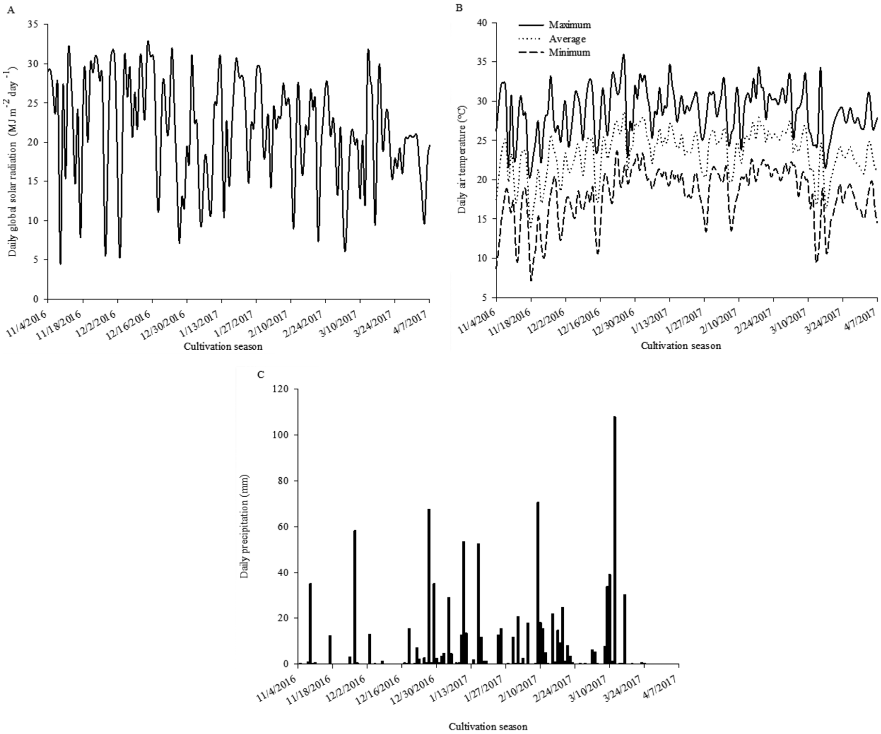

Figure 1. Daily global solar radiation (A), daily air temperature (B), and precipitation (C) at the experimental site.

used to estimate phyllochron. Although no scientific information on base temperature of okra was found in the literature, values here estimated (Figure 2) it is similar to those registered for other crops of the same family such as cotton (*Gossypium hirsutum* L.), which varies from 12.0 to 15.5 ºC (Silva *et al.*, 2011).

The increase in the accumulated thermal sum increased leaf emission of the cultivars Santa Cruz 47 (Figure 3A) and Valença (Figure 3B). For each assessed plant, the data of the number of leaves and accumulated thermal sum were plotted to obtain the regression equations. High values of

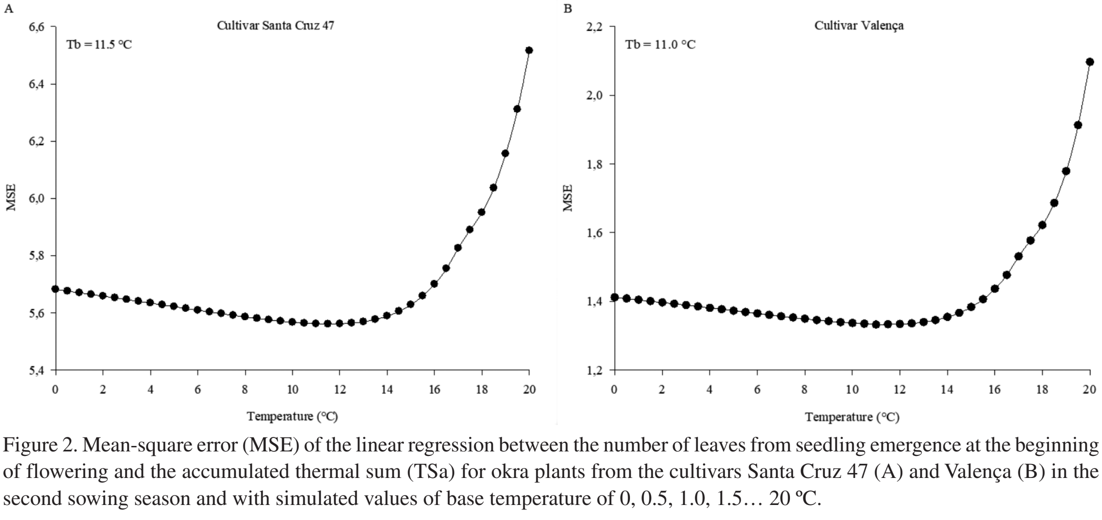

Figure 2. Mean-square error (MSE) of the linear regression between the number of leaves from seedling emergence at the beginning of flowering and the accumulated thermal sum (TSa) for okra plants from the cultivars Santa Cruz 47 (A) and Valença (B) in the second sowing season and with simulated values of base temperature of 0, 0.5, 1.0, 1.5… 20 ºC.

coefficient of determination were observed in all plants, reinforcing the initial hypothesis that leaf emission of okra is influenced by air temperature.

Moreover, when assessing the coefficients of determination (R^2) of linear regression equations between the number of leaves and the accumulated thermal sum for the cultivars Santa Cruz 47 and Valença, a high relation between both variables was observed, with values above 0.90 and 0.93, respectively. According to Martins *et al.* (2007), Paula and Streck (2008), and Lucas *et al.* (2012), high coefficients of determination (R^2) of linear regression equations between the number of leaves and the accumulated thermal sum indicate that leaf emission by okra plants has a linear relation with air temperature. The same methodology used to determine the base temperature and phyllochron (Figures 2 and 3) was successfully tested in other crops of commercial interest such as rice (*Oryza sativa* L.) (Paula and Streck, 2008), corn (*Zea mays*) (Streck *et al.*, 2009), eucalyptus (*Eucalyptus grandis* and *E. saligna*) (Martins *et al.*, 2007), and strawberry (*Fragaria* × *ananassa* Duch.) (Tazzo *et al.*, 2015).

Phyllochron was influenced by the interaction sowing season × cultivar (Table 2). For the cultivar Santa Cruz 47, the third sowing season (12/4/2016) provided a higher phyllochron value (18.5 ºC day leaf^{-1}). The values of the other sowing seasons did not differ from each other, showing a numerical variation of 14.4 to 15.5 ºC day leaf^{-1} (Table 2). In the first and third sowing seasons, phyllochron values of the cultivar Valença did not differ from each other, being higher when compared to the values of the second (18.8 ºC day leaf^{-1}), fourth (21.9 ºC day leaf^{-1}), and fifth (18.6 ºC day leaf^{-1}) sowing seasons. The highest phyllochron value was registered in the cultivar Valença in all sowing seasons. The cultivar Valença presented a phyllochron value 41.6% higher (22.1 ºC day leaf^{-1}) than the cultivar Santa Cruz 47 (15.6 ºC day leaf^{-1}).

The highest phyllochron value in the cultivar Valença (Table 2) indicates that for the same sowing season, it requires a higher thermal energy (ºC day) to emit a leaf and hence it presents less number of leaves when compared to the cultivar Santa Cruz 47 (Figure 3). According to Streck *et al.* (2009), phyllochron variation as a function of sowing season and cultivars (Tazzo *et al.*, 2015) is common because this variable is dependent on air temperature. Similar results were observed in other vegetables such as eggplant (*Solanum melongena*) (Maldaner *et al.*, 2009) and tomato (*Solanum lycopersicum*) (Schmidt *et al.*, 2017).

The cultivar Valença presented the highest thermal energy accumulation favorable to its development since its base temperature (11.0 ºC) is lower than that of the cultivar Santa Cruz 47 (11.5 ºC) at the same air temperature. Therefore, theoretically, this cultivar would present a greater development. However, the cultivar Santa Cruz 47 presented the highest number of leaves and size, confirming that plant development also depends on factors other than air temperature, such as the interaction between cultivar and environment (Martins *et al.*, 2007; Teixeira *et al.*, 2015).

The results of number of fruits per plant and fruit productivity showed no significant interaction between the assessed sources of variation for okra yield components. However, these variables were influenced by the isolated effect of sowing seasons and cultivars (Table 3).

The maximum number of fruits per plant in the cultivar Santa Cruz 47 was registered in the first sowing season and presented a value of 45.6

Table 2. Phyllochron (ºC day leaf^{-1}) of two okra cultivars at different sowing seasons.

Sowing season	Date of sowing	Cultivar Santa Cruz 47	Cultivar Valença
		Phyllochron (ºC day leaf^{-1})	
1	11/4/2016	14.4bB	25.7aA
2	11/19/2016	14.4bB	18.8cA
3	12/4/2016	18.5aB	25.4aA
4	12/19/2016	15.5bB	21.9bA
5	1/3/2017	15.1bB	18.6cA
	Mean	15.6 B	22.1 A

Means followed by the same lowercase letters in the columns and uppercase letters in the rows do not differ from each other by the Tukey's test ($p \leq 0.05$).

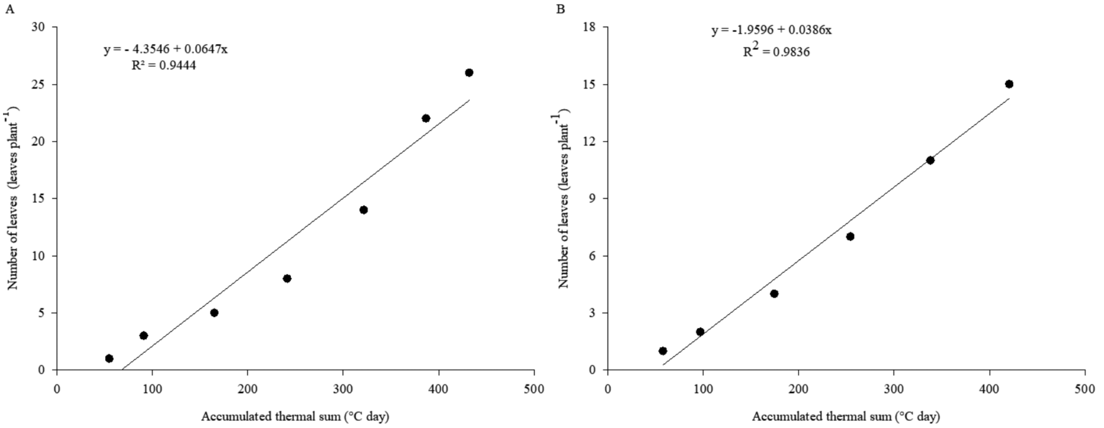

Figure 3. Phyllochron in okra cultivars. Values correspond to one of the replications of the cultivars Santa Cruz 47 (A) and Valença (B) in the first sowing season. The estimated phyllochron was 15.5 (A) and 25.6 ºC day leaf^{-1} (B).

fruits plant^{-1}. Sowing at the beginning of January 2017 resulted in fewer fruits (1.40 fruits plant^{-1}). Similar behavior was observed for the cultivar Valença, but the number of fruits registered in the fifth sowing season was 15.55 fruits plant^{-1}, which is 1,010.7% higher in relation to the number of fruits obtained in the cultivar Santa Cruz 47 (Table 3). Almost all treatments, except for the in the fourth and fifth sowing season, presented values that exceeded the mean of 28.3 fruits plant^{-1} registered by Nunes *et al.* (2018) when studying the density of okra plants of the xingó hybrid, in the state of Paraíba, Brazil. For both cultivars, the reduction in the number of fruits per plant as the sowing season delayed is a result of the shorter harvest period (Table 1) and lower energy accumulation by plants (Table 3) in the last sowing seasons. In spite of this reduction, the number of fruits obtained in the first sowing season in the cultivar Santa Cruz 47 and in the first, second, and third sowing seasons in the cultivar Valença was similar to those obtained by Oliveira *et al.* (2014).

The higher the phyllochron is, the lesser the number of leaves emitted at the same time interval and, consequently, the lower the absorption of solar energy, photosynthesis, and growth. Leaf emission is a developmental variable while the emission of drain structures, such as fruits, also depends on

Table 3. Values of number of fruits per plant (NFP) and fruit productivity (PD) of two okra cultivars during five sowing seasons.

SS	1	2	3	4	5	
DS	11/4/2016	11/19/2016	12/4/2016	12/19/2016	1/3/2017	
Ra (MJ m^{-2})	3143.84	2809.46	2585.33	2219.05	1913.26	
TSa Santa Cruz 47 (ºC day)	1834.7	1695.7	1556.6	1390.0	1176.8	
TSa Valença (ºC day)	1912.2	1765.7	1619.3	1445.0	1224.3	
			Cultivar Santa Cruz 47			Mean
NFP (fruits plant^{-1})	45.60 a	25.35 b	25.90 b	11.35 c	1.40 d	14.02 B
PD (t ha^{-1})	25.38 a	13.80 b	14.12 b	6.78 c	0.83 d	12.18 B
			Cultivar Valença			Mean
NFP (fruits plant^{-1})	61.41 a	46.90 b	41.20 b	22.75 c	15.55 c	37.56 A
PD (t ha^{-1})	35.90 a	27.77 b	24.01 b	14.02 c	10.77 c	22.49 A

SS = sowing season; DS = date of sowing; Ra = accumulated global solar radiation; TSa = thermal sum accumulated during crop cycle. Means followed by the same lowercase letters in the rows and uppercase letters in the columns do not differ from each other by the Tukey's test ($p \leq 0.05$).

growth. A reduction in the photosynthesis rate decreases the production of assimilates, which results, for vegetables, in flower abortion and/or fruit drop in the early stages of development after pollination. However, the results of our study showed a different behavior for okra plants since the number of fruits was higher in the cultivar with a less number of leaves (Table 3). This indicates that in okra plants, a competition between leaves and fruits for assimilates may exist, as both grow simultaneously. It also means that in this species, no fixed relationship exists between leaf and fruit emission, as it occurs in tomato (Chamarro, 1995). These results show that phyllochron must be considered together with the intensity of incident solar radiation because photosynthesis depends on the leaf area that intercepts this radiation.

In addition, although the cultivar Santa Cruz 47 has emitted the highest number of leaves (Figure 2), the advantage of the production components of the cultivar Valença is also related to the lower value of the ratio between the total number of leaves and the total number of fruits (2.3 leaves for each fruit). In the cultivar Santa Cruz 47, on the other hand, this ratio was 4.5 leaves for each fruit (not considering the values of the last sowing season, in which the production was very low and raised too much the average value of this ratio). The average number of leaves of the cultivars Santa Cruz 47 and Valença at the beginning of flowering was 45 and 19 leaves, reaching flowering at 702.0 and 419.9 ºC days after seedling emergence, respectively. The difference of 282.1 ºC days between them indicates a higher precocity of the cultivar Valença in relation to Santa Cruz 47. These results are in accordance with the seed manufacturer's (Feltrin®) information, in which the beginning of production for the cultivar Santa Cruz 47 occurs between 60 and 70 days and for the cultivar Valença this period is about 10 days shorter.

The highest productivity of okra fruits in the cultivar Valença was obtained when sowing was performed at the beginning of November 2016, with an average value of 35.90 t ha^{-1} (Table 3). The values of fruit productivity registered in the second and third sowing seasons did not differ from each other. However, the sowing performed in the first half of December under the local climatic conditions led to productivity values of 27.77 and 24.01 t ha^{-1} in the second and third sowing seasons, respectively, which is higher than the average found in the Southeast and Northeast regions, the largest okra producers in Brasil (Filgueira, 2008; Oliveira *et al.*, 2013; Oliveira *et al.*, 2014).

The lower fruit productivity in the last two sowing seasons (Table 3) is related to the lower accumulation of energy (1,390.0 and 1,176.8 ºC days, respectively) and global solar radiation. Considering that crop cycle is 150 days, the plant needs an accumulation of solar radiation of approximately 2,900 MJ m^{-2} to express its productive potential.

The difference between fruit productivity of the cultivars Santa Cruz 47 and Valença may be a consequence of plant architecture, which affects solar radiation absorption. Both cultivars have lobed leaves, but the cultivar Santa Cruz 47 presents lobes with a deep incision, while in the cultivar Valença, the lobule incision is medium. Radiation use efficiency was higher in the cultivar Valença (Figure 4) possibly due to its greater leaf area. In addition, energy accumulation in this cultivar was higher in all sowing seasons due to its lower base temperature. These results are in accordance with Kumar *et al.* (2015), who found that even in regions of tropical and semi-arid climate the anticipation of okra sowing results in a higher fruit productivity due to a greater availability of solar energy for the plants.

The accumulated solar radiation values were 3,143.84; 2,809.46; 2,585.33; 2,219.05 and 1,913.26 MJ m^{-2} from the first to the fifth sowing seasons, respectively (Table 3). The cultivar Valença presented a fruit productivity 60.4% higher (22.49 t ha^{-1}) when compared to the cultivar Santa Cruz 47 (14.02 t ha^{-1}) (Table 3).

Despite the absence of a significant effect of the interaction of sowing season × cultivar, solar radiation use efficiency by okra plants was influenced by the isolated effect of the studied sources of variation. Radiation use efficiency increased linearly as the accumulated global solar radiation increased during the growing season and considering all sowing seasons and cultivars (Figure 4A). This variable reached daily values close to 30 MJ m^{-2} day^{-1} in the summer and air temperatures higher than 30 ºC (Figure 1). The highest efficiency was obtained in the cultivar Valença (0.85 g MJ^{-1}) when compared to the cultivar Santa Cruz 47 (0.43 g MJ^{-1}), probably indicating a greater capacity to destine its photoassimilates for fruit growth (Figure 4B).

When considering the solar radiation use efficiency (Figure 4) and the climatic amplitude

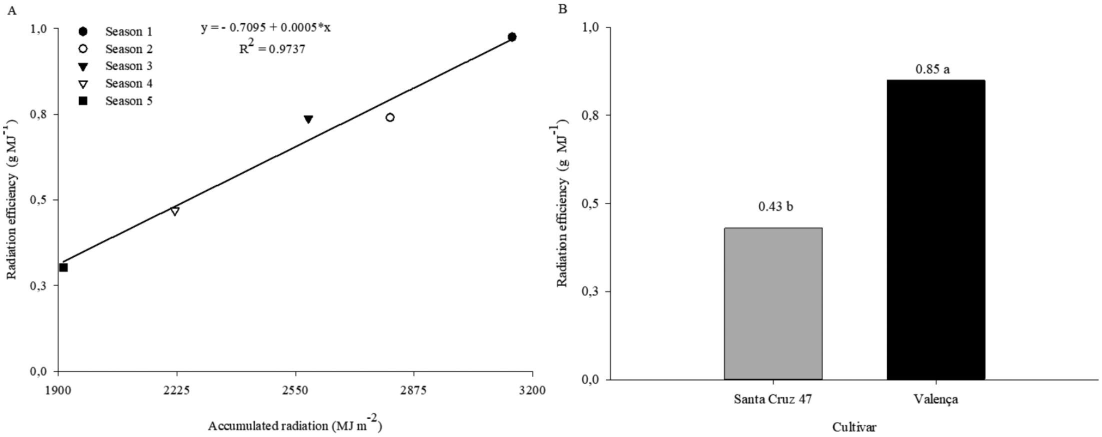

Figure 4. Solar radiation use efficiency by okra plants as a function of the accumulated global solar radiation (A) in the cultivars Santa Cruz 47 and Valença (B). Means followed by the same letter do not differ statistically from each other by the Tukey's test ($p<0.05$).

registered in the experimental period (Figure 1), we observed that other vegetables such as tomatoes would have a reduced growth under these conditions (Chamarro, 1995). This result is unprecedented and shows the high phenotypic plasticity of the cultivar Valença, which can be grown in a range of latitudes between 5° and 30°, approximately.

Oliveira *et al.* (2014) registered a maximum fruit productivity of 21 t ha^{-1} for the cultivar Santa Cruz 47 during a 170-day period in the Paraíba State. Once the average daily radiation was 19 MJ m^{-2}, solar radiation use efficiency was 0.65 g MJ^{-1}. This value is higher than that registered for the same cultivar in the Rio Grande do Sul State, but 30.8% lower than that registered for the cultivar Valença (Figure 4). These results indicate that the Rio Grande do Sul State has potential to be a producer of okra fruits of the cultivar Valença during spring-summer.

Conclusions

Base temperatures for the cultivars Santa Cruz 47 and Valença were 11.5 and 11.0 °C, respectively.

Phyllochron varied between sowing seasons from 14.4 to 18.9 °C day leaf^{-1} for the cultivar Santa Cruz 47 and 18.4 to 25.7 °C day leaf^{-1} for the cultivar Valença.

The cultivar Valença showed a higher solar radiation use efficiency, resulting in a higher fruit productivity.

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