Base-temperature, plastochron and chia (*Salvia hispanica* L. - Lamiaceae) yield for different sowing times

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ABSTRACT

Chia is a plant whose seeds are used in cooking and is a natural source of omega-3 fatty acids, fiber and protein, as well as other important nutritional components such as antioxidants. The objective of this work was to estimate the base temperature, plastochron and chia seed yield for different sowing times in Cruz Alta, Rio Grande do Sul, Brazil. The experimental design was completely randomized and the treatments consisted of different sowing times (September, October and November). For the determination of the base temperature for node emission in the main stem of the plants, the method of least mean square error of linear regression between the number of nodes and the accumulated thermal sum was used. Regarding estimation of the plastochron at each sowing time, a simple linear regression was obtained between the number of nodes in the main stem and the accumulated thermal sum. Seed yield was measured at harvest. Sowing in times with air temperature below 19 ºC should be avoided so that the development of plants is not impaired. Plastochron ranges from 28.01 ºC to 32.26 ºC day for successive node emission in the main stem of chia plants and September sowing promotes higher seed yield.

Keywords: lower base temperature; number of nodes; plant development.

INTRODUCTION

Chia (*Salvia hispanica* L. - Lamiaceae) is an annual herbaceous plant native to southern Mexico and northern Guatemala (Álvarez-Chávez *et al.*, 2008). It seeds are considered an important source of fiber, protein and antioxidants. In South America, Argentina is one of the pioneer countries when it comes to the development of research on its cultivation because the plant is considered an alternative for diversification and stability of the northwestern Argentine farms, which reached a yields of 1,602 kg ha^{-1} and 38.6% contents of oil in the seeds have been recorded (Coates & Ayerza, 1996).

The oil is composed of linoleic acid and omega-3 fatty acid (Rosamond, 2002), which are associated with benefits to the human health. In addition, Vázquez-Ovando *et al.* (2009) found high antioxidant activity, which confirms the presence of polyphenols. Furthermore, the observed physicochemical properties indicate that the fraction rich in fiber may be an ingredient for the human diet, in items a such as powders, cereal bars, breads, cookies, beverages, jams, emulsions, among others (Capitani *et al.*, 2012). Another important feature is the absence of gluten, which means that chia flour can replace wheat flour in various foods designed for people intolerant to this compound protein (Bueno *et al.*, 2010).

Commercial crops of chia are commonly reported in Oceania, Central America, and South America (Orona-Tamayo *et al.*, 2017). In northwestern Rio Grande do Sul, some farmers have been cultivating chia in the last years for seed production. However, the scarcity of technical information on cultivation techniques and requirements and the limited market has been hindering the expansion of the crop (Migliavacca *et al.*, 2014).

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In order to increase productivity in agricultural crops, it is necessary to know the temperature ranges that contribute to the plant development, as well as the definition of the appropriate sowing time. The appearance of nodes in the main stem is an excellent measure for understanding the crop development cycle and the rate of appearance of nodes in the main stem is an efficient measure to quantify the time and physiological development of the plant (Streck *et al.*, 2003).

Temperature affects plant growth and one way used to describe this interaction is through degree-days (ºC day), which has a direct relationship with the accumulation of daily heat units or daily thermal sum. Thermal sum has been used to represent the effect of air temperature on plant growth because it is more biologically effective. In this context, the base temperature is that below which plant development is zero or insignificant. For the accurate estimation of plant development, the estimation of the base temperature is crucial, since it is inserted in the equation that determines the daily thermal sum (Lago *et al.,* 2009). The method of the minimum mean square error of linear regression between the number of leaves / nodes and the accumulated thermal sum was used to determine the base temperature in corn (Streck *et al.*, 2009), watermelon (Lucas *et al.,* 2012) and gladiolus (Schwab *et al.*, 2017), proving to be adequate. Through the method, the value of the base temperature is the one that presents the smallest mean square error and, consequently, indicates a high degree of association between the number of nodes emitted and the accumulated thermal sum for the emission of successive nodes in the main stem.

Plastochron represents the time needed for successive nodes to appear on a stem. It is a simple method that contributes to the prediction of the occurrence of developmental stages in cultivated plants, considering as a time measure the number of days after sowing (Gilmore Jr & Rogers, 1958) or the thermal sum. Due to the importance of base temperature estimation and improvement of management techniques for chia cultivation, the objective of this study was to estimate the base temperature, plastochron and chia seed yield in three sowing times.

MATERIAL AND METHODS

The experiment was conducted at the University of Cruz Alta (Unicruz) in 2012/2013, located in Cruz Alta-RS, Brazil, latitude 28°38’19"S, longitude 53°36’23’’W and altitude of 452 m. The area is in the northwest region of Rio Grande do Sul and the climate of the region is subtropical (Kuinchtner & Buriol, 2001). The average air temperature is 18.7°C, with an average minimum temperature of 9.2 °C in July and a maximum average of 30.8 °C in January (Pes *et al.,* 2011). The average annual rainfall is 1721 mm, evenly distributed throughout the year. The soil is classified as Typical Dystrophic Red Latosol, clay texture (Empresa Brasileira de Pesquisa Agropecuária, 2013).

Soil analysis in the 0-20 cm layer showed the following chemical characteristics: pH in water 5.2; O.M. 2.4%; P 1.4 mg dm^3; K 123 mg dm^3; exchangeable Al 0.9 cmolc dm^3; Ca 2.9 cmolc dm^3; Mg 1.3 cmolc dm^3; H + Al 6.9 cmolc dm^3 and base saturation 40%.

The experimental design was completely randomized, with three treatments that consisted of sowing times (28 of September, 31 of October and 28 of November) and seven replications. On each sowing times, tillage was carried out with plowing followed by harrowing and liming of 2.5 t ha^{-1}. The plots were 10 meters long, four rows spaced at 0.80 m and the sowing density was 6 kg ha^{-1}, and manually accomplished. The seeds used were acquired from a local producer from the previous crop.

Fifteen plants per plot were marked in the field with colored wires for weekly counting of the nodes emitted in the main stem after the first node appeared until the beginning of flowering for the estimation of base temperature. The leaves were considered visible when the edges were no longer touching each other.

The method used to determine the daily thermal sum was: $TSd = T_{average} - Tb$ where: $T_{average}$ is the average daily temperature and Tb is the base temperature (Arnold, 1960). The accumulated thermal sum (TSa) was calculated by summing up the values of TSd. Temperature data were collected from the automatic weather station Davis Vantage Pro 2 Plus (Davis Instruments, Hayward, CA, USA) located approximately 200 m from the experimental area.

For the determination of the base temperature for node emission in the main stem of chia plants, the method of the minimum mean square error (MSE) of linear regression between the number of nodes and the accumulated thermal sum was used. Thus, the values of base temperature ranging from zero to 21 ºC with an increment of 1 ºC and the base temperature value was the one with the lowest MSE were used (Sinclair *et al.*, 2004).

Plastochron was estimated at each sowing time by obtaining a simple linear regression between the number of nodes in the main stem and the accumulated thermal sum, using as the base temperature the one estimated in this study. Plastochron was estimated by the inverse of the angular coefficient of linear regression between node number and accumulated thermal sum (Streck *et al.,* 2005).

During the development of the crop, the following was evaluated: the duration of the sowing phases until emergence, emergence until flowering, flowering at the beginning of seed filling and seed filling until harvest, considering that the phase was reached when 50% of the plants showed emergence, flowering, beginning of seed filling and full ripening for harvest, respectively. At harvest, seed yield (kg ha^{-1}) was measured.

Assumptions of mathematical model were verified before analysis of variance by homogeneity of treatment variances and normality of errors by Bartlett's and Shapiro-Wilk's tests ($p<0.05$), respectively. If the assumptions were not met, a Box-Cox procedure was used to verify an appropriate transformation for data using Action software (Equipe Estatcamp, 2014). Productivity data were subjected to analysis of variance and means were cluster by Scott-Knott test at 5% probability of error ($p < 0.05$).

RESULTS AND DISCUSSION

It was observed for the three sowing times that the minimum and maximum average temperatures were 15.4 and 27 ºC, respectively (Figure 1a). In absolute values, the minimum and maximum temperatures were 2.4 ºC and 35.9 ºC and the average temperature was 21.6 ºC. Until the beginning of flowering, the minimum and maximum absolute temperatures were 8.4 and 35.9 ºC, which shows that the crop was subjected to low temperatures over the vegetative development period, which is important for the estimation of the base temperature.

The September sowing time showed the shortest length of the sowing phase until emergence (SOW-EME), with accumulated thermal sum of 5.6 ºC day, while the sowing times of October and November required thermal accumulation of 79.5 and 40.8 ºC day to reach the emergency (Figure 1b). This result demonstrated that the temperature conditions in the early sowing provided a faster emergence compared to the other dates.

The phase from emergence to flowering (EME-FLO) that corresponds to the vegetative period and the elaboration of the reproductive performance of the plant decreased as the sowing time was delayed. Regarding the dates of September, October and November, it was observed that the accumulated thermal sum to complete this phase was 626.7; 497.1 and 424.7 ºC day (Figure 1b). It

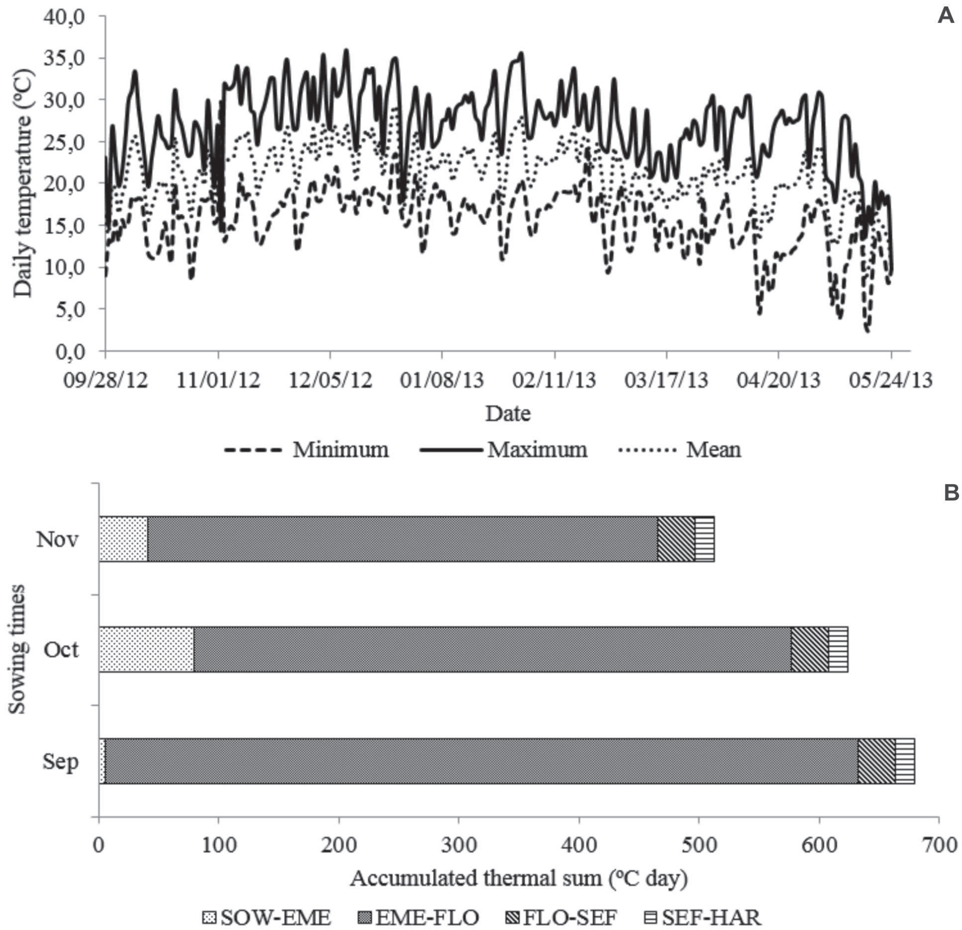

Figure 1: Daily minimum, average and maximum temperatures of chia crop growing for three sowing times (a) and phases of the growth cycle of chia grown for the three sowing times in Cruz Alta – RS (b).

*SOW-EME (sowing to emergence); EME-FLO (emergence to flowering); FLO-SEF (Flowering to seed filling); SEF-HAR (Seed filling to harvest).

could be inferred from this result that the delay of the sowing time had an influence on the vegetative phase, with a consequent reduction of growth period and development of the crop. Goergen *et al.* (2019) found that early sowing times, which started in September in Rio Grande do Sul, Brazil, reflect higher dry mass of the aerial part, height and leaf area index. According to Baginsky *et al.* (2016), the flowering of chia cultivated in Chile occurred with thermal accumulation of 600 to 700 ºC day, which corroborates with the observed in September sowing.

On the other hand, from flowering to the beginning of seed filling (FLO-SEF) and from seed filling to harvest (SEF-HAR), no variation was observed in the accumulated thermal sum in the three sowing times (Figure 1b). This result was due to the fact that the beginning of flowering and seed filling occurred simultaneously in the three sowing times, clearly indicating that the influence of sowing time is mainly on the vegetative phase. On calendar days, the total cycle was 231; 185, and 171 days for the September, October, and November sowing times, respectively. Migliavacca *et al.* (2014) recommends that the most suitable chia sowing time is from October to November.

For all sowing times, the 66 linear equations between the number of nodes and the accumulated thermal sum for the estimation of the base temperature with initial temperature from 0 ºC to the temperature of 21 ºC presented coefficient of determination greater than 0.956 and mean square error less than 0.582 (Figure 2). It can be verified that the base temperature for chia crop ranged from 19 to 20 ºC, where the value of 19 ºC was observed for the sowing time of October where the smallest mean square error was 0.331. For the other dates, the base temperature was 20 ºC, with the smallest mean squares of error of 0.321 and 0.332 for the dates of September and November, respectively. Due to the low variation in values for base temperature between dates, it was assumed that the base temperature for the crop was the lowest temperature observed for the emission of successive nodes in the main stem of the plants, that is, 19 ºC.

For this temperature, the coefficient of determination was higher than 0.975 in the three sowing times, which indicated the high association between the number of nodes and the accumulated thermal sum. Similar to that verified by Martins, Silva & Streck (2007) in study to estimate base temperature for eucalyptus species. For this reason, it can be concluded that eucalyptus development is influenced by large-scale air temperature and the relationship of leaf emission (development) and temperature is linear.

The estimated base temperature of 19 ºC was used to obtain the daily thermal sum and subsequent plastochron estimation. For the three sowing times, the coefficient of determination, wich indicates the relationship between the number of nodes in the main stem and the accumulated thermal sum was greater than 0.9727 demostrating that temperature had a predominant effect on the emission of nodes and on the vegetative development of chia crop. Therefore, temperature is the main environmental effect that determinates the appearance of nodes in the main stem of chia crop. According to Streck *et al.* (2005), the linear regression method is suitable for estimating the emission of leaves or nodes in main stems of agricultural crops.

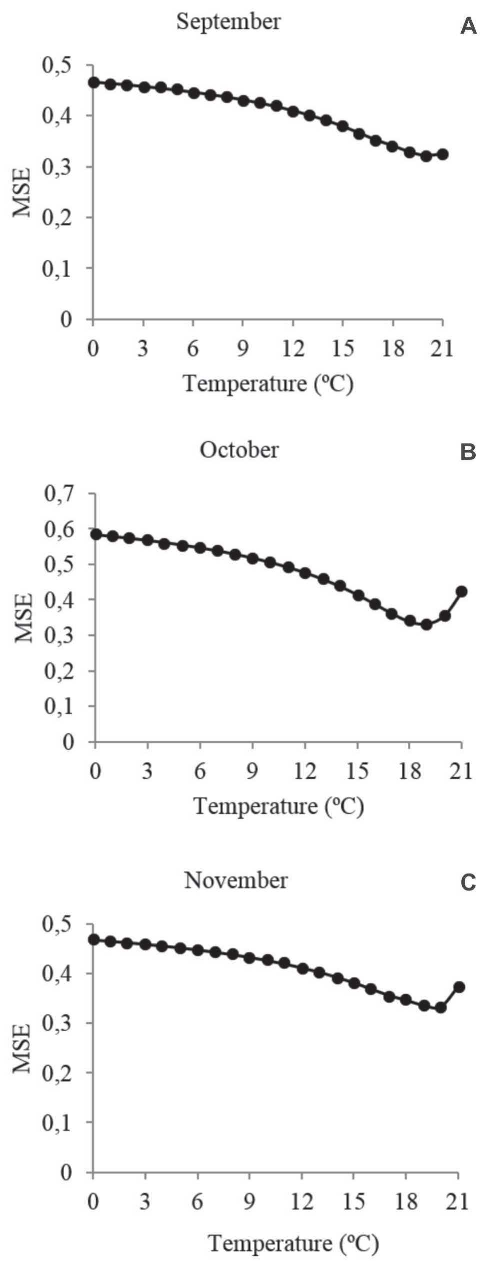

Figure 2: Mean square error (MSE) of the linear regression between the number of nodes on the main stem and the accumulated thermal sum in base-temperature ranging from 0 to 21 ºC for three sowing times (september (a), october (b) and november (c)) of chia in Cruz Alta – RS.

The values for plastochron ranged from 28.01 ºC to 32.26 ºC day and these results indicate that for the emission of a node in the main stem in the three sowing times there was variation of thermal accumulation of 4.25 ºC day. The higher demand for thermal accumulation in the October sowing time was due to the longer period from sowing phase to emergence. The environmental conditions, especially rainfall after sowing, negatively influenced the emergence and initial development of the crop and, consequently, it caused a higher demand for heat units for the emission of new nodes in the main stem. Nevertheless, it can be seen that the highest accumulated thermal sum demand for emission of nodes did not influence important later phases, such as the beginning of flowering and grain filling. Variations in plastochron values were also observed by Toebe *et al.* (2010) on crambe (*Crambe abyssinica*) crop grown at different sowing times.

Seed yield was higher in the September sowing time and differed significantly from October and November (Figure 3). In September, the average yield was 755.35 kg ha^{-1} and in October and November sowing, it was 333.32 and 223.35 kg ha^{-1}, respectively. This result may be related to the greater vegetative period observed in the sowing time of September that culminated in the largest photosynthetic apparatus and, consequently, the highest production of photoassimilates destined for reproductive drains. This result differs from that observed by Win *et al.* (2018) in a study conducted in China. The authors observed that when the chia crop was exposed to sowing conditions in which the cycle was longer (273 days), the yield was 578 kg ha^{-1}, while at the sowing, in which the cycle was 218 days, the yield was 852 kg ha^{-1}. According to the authors, because it is a short-day plant, it is important to avoid sowing times that make the cycle very long and with excessive vegetative growth, which hindered the expression of productivity in the cultivation condition.

It was evidenced that the delay of sowing date drastically reduced the yield of chia seeds, but for the three sowing times, yield was within the limits observed by Grimes *et al.* (2018), who authors obtained productivity ranging from 100 to 1290 kg ha^{-1}, this corroborates the statement that chia cultivation is strongly influenced by environmental and management conditions, such as the choice of location and sowing time. In a project conducted in Argentina during three sowing times from January 11 to February 10, Busilacchi *et al.* (2013) observed a reduction in the average flower spike weight with the delay of the sowing time.

In climatic conditions similar to this research, Goergen *et al.* (2018) in a study conducted in Santa Maria, Rio Grande do Sul, Brazil, found that chia can be sown from September to February with the production of seeds of high physiological quality. According to Baginsky *et al.* (2016), the cultivation site was determinant for the expression of the productive potential, where the location in desert conditions in Valle de Azapa and Canchones, Chile, allowed productivity greater than 2900 kg ha^{-1} in a place at a higher latitude and lower temperature, yield was less than 129 kg ha^{-1}. In Bangladesh, Karim *et al.* (2016) also found variation in yield at different sowing times, when sowing in November enabled the best results, with yield of 1033 kg ha^{-1}.

The edaphic and climatic conditions in Brazil are favorable for chia cultivation, mainly in relation to temperature, altitude and precipitation. Nevertheless, sowing during the adequate period is important for the

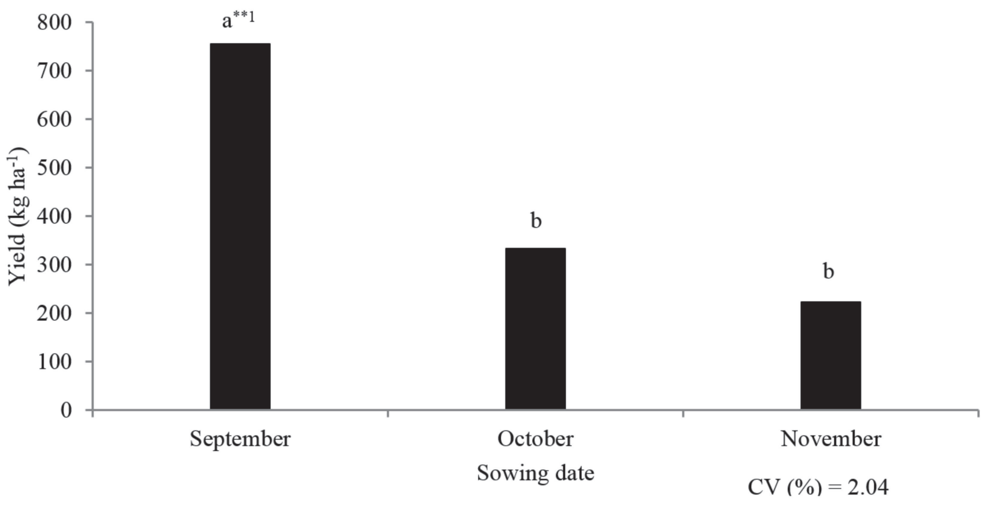

Figure 3: Chia seed yield in sowing times (September, October and November) in Cruz Alta-RS, Brazil.

**Means not followed by the same letter differ from each other by the test of Scott-Knott at 5% probability.

¹Transformed data by Box-Cox method.

success of cultivation. Early or excessively late sowing may be subject to excessive cold or frost, which is a limiting factor for cultivation mainly in the southern region of the country (Migliavacca *et al.* 2014).

CONCLUSIONS

Sowing in times with air temperature below 19 ºC should be avoided so that the development of plants is not impaired. Plastochron ranges from 28.01 ºC to 32.26 ºC day for successive node emission in the main stem of chia plants and September sowing promotes higher seed yield.

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