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Development of chia plants in field conditions at different sowing-date

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Abstract

The objective of this study was to characterize the development of chia plants sown at different dates, and to determine the relation between the duration of the development cycle and the final number of leaves and the leaf appearance rate on the main stem. A field experiment was conducted in the agricultural year of 2016/2017 in five sowing dates (09/22/16, 10/28/16, 01/03/17, 02/08/17 and 03/24/17) in the edaphoclimatic conditions of the central region of the RS, Brazil. A randomized block design with four replicates was used. For each sowing date, the duration of the vegetative and reproductive phases in days and in °C day (Tb = 11 °C), the final number of leaves and the phyllochron of the main stem were determined. The duration of the vegetative phase of chia plants in days and in °C day varies between the sowing dates, with shorter duration in late sowings in response to the photoperiod reduction. The vegetative phase represents the largest part of the total development cycle in early sowing dates, being overcome by the reproductive phase in late sowing dates (02/08/17 and 03/24/17). The phyllochron for chia varies from 36.23 (very late sowing) to 59.88 °C day (early sowing). Later sowing has a smaller final number of leaves accumulated in the main stem due to the shorter duration of the vegetative phase.

Keywords: phyllochron, *Salvia hispanica* L., sowing date, thermal time

Introduction

Salvia hispanica, Lamiaceae family, popularly known as chia, shows high potential for its nutritional characteristics, being rich in proteins, fibers, minerals and fatty acids (Jin et al., 2012). Its grains have become important for food, and its consumption is more and more frequent by people looking for a healthier diet (Ayerza & Coates, 2012). This scenario encouraged some farmers to invest in chia growth in Brazil. Production of the western region of the Parana state and the northwest region of the Rio Grande do Sul state have been showing good harvest results from since 2013, despite the lack of basic information about the nutritional requirements of the plant, phenology and its edaphoclimatic characteristics (Migliavacca et al., 2014).

The development cycle of most agricultural crops is divided into two major phases: the vegetative phase and the reproductive phase (Streck et al., 2006; Zanon et al., 2015a). The duration of the vegetative phase is associated with the total number of leaves in the plant and with the leaf appearance rate in the main stem, therefore a short vegetative phase results in a lower leaf area index (Zanon et al., 2015b). Thus, the accumulated leaf number (ALN) and the final leaf number (FLN) are important parameters of the vegetative development (Fagundes et al., 2009).

The ALN on a stem or plant is associated with the leaf area expansion, and this is due to the interception of solar radiation, photosynthesis and accumulation of biomass by the crop (Streck et al., 2005). In order to estimate ALN, often is used as a parameter the concept of phyllochron, defined as the time interval between the appearance of two successive leaves on the main stem, expressed in °C day leaf^{-1}, while the plastochron is the time interval between the appearance of two successive nodes in the plant (Streck et al., 2005).

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Environmental factors, such as photoperiod and air temperature vary according to the seasons and have effect on the phyllochron (Curti et al., 2016). It is known that the chia plants are considered short-day plants (Jamboonsrl et al., 2012), that the critical photoperiod for the crop is 12 h (Baginsky et al., 2014), and 500GD to achieve flowering in a photoperiod less than 12 h (Baginsky et al., 2016). Thus, studies on the response of chia development at different sowing dates are fundamental to understand the influence of the photoperiod and air temperature on this crop. These studies are of main importance to determine the best sowing time for the region, a basic knowledge to formulate agricultural crop zoning from the understanding of the crop development, since early sowing results in taller plants due to the longer duration of the vegetative phase, while late sowings, as they result in a shorter duration of the vegetative phase, generate plants with a smaller height (Goergen et al., 2019). Based on knowledge about the crop development, it will be possible to recommend the sowing time of chia for the region, contributing to diversification in rural properties, as the main source of income, or an option in crop rotation.

It is assumed that late sowing results in lower growth and leaf emission, resulting in reduced vegetative phase of chia plants. Thust, the objective of this study was to characterize the development of chia plants sown at different sowing dates, and to determine the relation of the duration of the development cycle with the final leaf number and the leaf appearance rate on main stem.

Material and Methods

The field experiment was conducted in the agricultural year 2016/2017 in the experimental area of the Crop Science Department of the Federal University of Santa Maria, Santa Maria, RS, Brazil (29° 43' S, 53° 43'W and altitude of 95 m). The climate of the region, according to the Köppen classification, is Cfa subtropical wet without dry season and with hot summers (Alvares et al., 2013).

Management practices such as soil pH correction and fertilization were performed according to soil analysis, and because there was no recommendation in the manual of fertilization and liming for *Salvia hispanica*, the fertilization was based on the recommendation for the mint species (*Mentha arvensis* L.) Lamiaceae family. For supplementary irrigation, the crop coefficient (Kc) of mint was used, whereas this information was not available for chia, and weed control was done with manual weeding (Migliavacca et al., 2014).

Seeds were obtained from the local market in Santa Maria, RS. Sowing was done in lines, manually, with a sowing depth of 1 cm, just enough to leave the seed covered by soil (Migliavacca et al., 2014). Experiments were done in five sowing dates (09/22/16, 10/28/16, 01/03/17, 02/08/17 and 03/24/17) which considered to be early (September, October), intermediate (January) and late (February and march) in relation to the more suitable season for the crop that is October/November (Migliavacca et al., 2014).

The experimental design was a randomized complete block design with four replicates. Each plot was composed of five rows measuring 3 m, spaced 0.7 m between them, corresponding to an experimental unit of 10.50 m^2. The plants of the central lines were evaluated, excluding the border lines. After emergence, the plants were thinned to maintain a plant spacing of 5 to 6 cm in the sowing line, and to establish an average of 20 plants per meter (Migliavacca et al., 2014).

The emergence date was considered when 50% of the total seedlings in each row were with the cotyledons fully exposed above the soil surface. Ten plants per plot were evaluated, with 4 replications, totaling 40 plants in each sowing date, randomly marked by colored wires. After the appearance of the first pair of leaves, the number of leaves and phenology were evaluated every week. One leaf was considered developed when it was more than 1 cm in length. The final leaf number (FLN) was recorded when the plants of the plot presented the inflorescence (ear) of the main stem with 1 cm in length. This moment was also considered the beginning of the reproductive phase of the chia plants.

The duration of the vegetative and reproductive phases of chia was determined in days and in °C day. For the purposes of this study, the vegetative phase was considered from the emergence to the beginning of flowering, and the reproductive phase from the beginning of flowering to full maturity, when 80% of the plant leaves were dry or dead (Migliavacca et al., 2014).

The minimum and maximum daily air temperatures were collected at the automatic meteorological station that belongs to the 8th Meteorological District of Nacional Institute of Meteorology (DISME/INMET), located approximately 100 m from the experimental area. These variables were collected during the entire execution of the experiment considering the dates of September 2016 to July 2017. The daily degree days (STd, °C day) was calculated by the method (Arnold, 1960):

$$STd = (Tmed - Tb)\ 1\ day,\ if\ Tmed < Tb\ so\ Tmed = Tb \qquad (1)$$

Being: STd = daily degree days; Tmed = mean daily air temperature, calculated by the arithmetic mean between the minimum temperature and the maximum daily air temperature; Tb = lowest basal temperature for the crop, considered 11°C (Bochicchio et al., 2015).

The STd was accumulated from the emergency, being summed and resulting in the accumulated degree days (STa, °C day):

$$STa = \Sigma\ STd \quad (2)$$

Being: STa = accumulated thermal sum; STd = daily degree days.

Another way to evaluate the development of a crop is through the appearance of leaves or nodes in the main stem. With this information the phyllochron can be estimated, which in chia is the period between the appearance of one pair of leaves and the next pair of leaves on the main stem. The phyllochron was estimated by the inverse of the linear regression coefficient between accumulated leaf number in the main stem (ALN) and STa from the emergency (Streck et al., 2005), considering each sowing date.

Data were submitted to analysis of variance using the F test, and when it was significant, the comparisons between the means of the treatments were performed by the Scott-Knott test at a level of 0.05 of probability. For the analysis, the statistical program SISVAR was used (Ferreira, 2011).

Results and Discussion

During the field experiment, chia plants were exposed to different thermal and photoperiodic conditions (Figure 1). During the experiment, the lowest temperatures were in September, October and early November, reaching maximum values in the summer dates, and decreasing again in May, June and July, when the lowest air temperatures were recorded. The absolute minimum air temperature (T_{min}) was -1.7°C (07/19/17) and the absolute maximum air temperature (T_{max}) was 35.1°C (12/25/16). The photoperiod to which the chia plants were exposed ranged from 11.1 h (06/21/2017) to 14.96 h (12/21/2016).

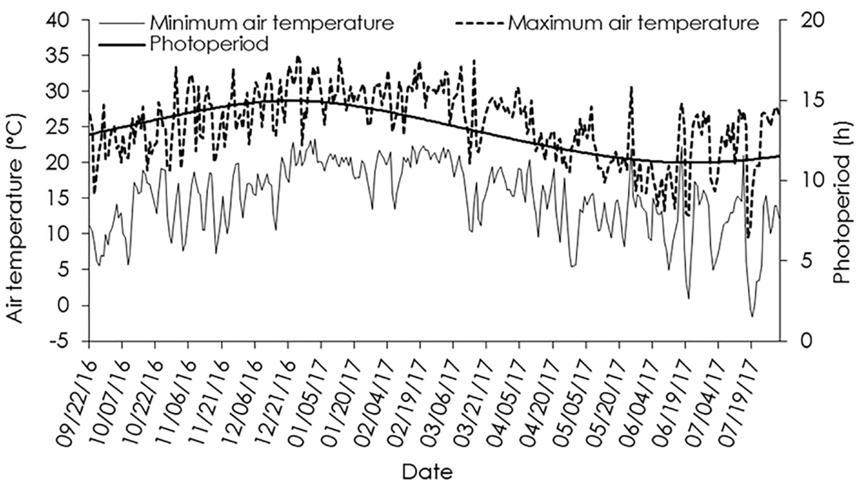

Figure 1. Minimum and maximum daily air temperature (°C) and photoperiod (h) between September 2016 and July 2017.

Figure 2 shows the duration in days (Figure 2A) and in °C days (Figure 2B) of the vegetative and reproductive phases of chia plants sown in the five dates. There is a significant difference in the development cycle of the plants between the five sowing dates and that variation was mainly due to the difference in the duration of the vegetative phase of the plants. While plants sown on September had 178 days of vegetative phase (Figure 2A), plants of the sowing date march presented only 35 days. This difference was also observed when the duration of the phases were calculated in °C day by determining the accumulated degree days (Figure 2B), in which the sowing of 09/22/16 accumulated 2023 °C day during the vegetative phase and the sowing of March accumulated only 299 °C day. With the delay in the sowing dates, there was a reduction in the development cycle due to the shorter vegetative phase of the plants. This reduction can be explained by the effect of the photoperiod to the development of chia, which is considered a short-day plant, i.e. when exposed to more hours of dark, chia development is faster (Jamboonsri et al., 2012; Baginsky et al., 2014). The results reached for chia in the central region of RS, Brazil resemble those found by Brandán et al. (2020) in the province of Salta in Argentina, by Win et al. (2018) in an experiment at 30° N in the Sichuan Basin, China, and by Trentin et al. (2013) and Zanon et al. (2015a) for soybeans, which is also a short-day species.

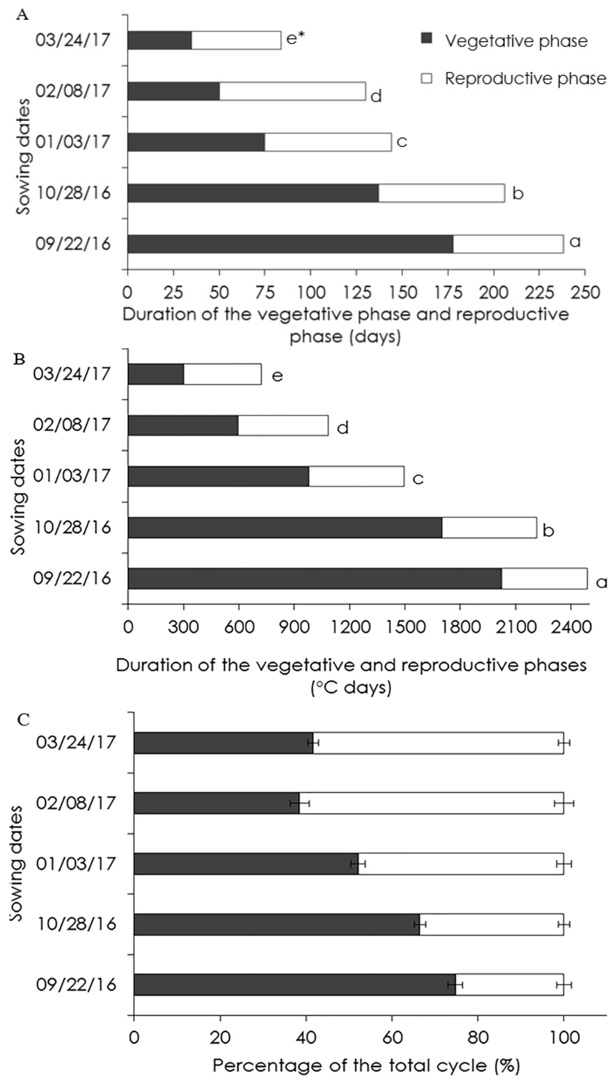

Figure 2 . Duration of the vegetative and reproductive phases of chia in days (A) and in °C day (B), percentage duration of the vegetative and reproductive phases in relation to the total cycle of chia in different sowing dates: 09/22/2016, 10/28/2016, 01/03/2017, 02/08/2017 and 03/24/17, in the agricultural year 2016/2017.

The percentage duration of vegetative and reproductive phases in relation to the total development cycle of chia in the five sowing dates is presented in Figure 2C. In the early sowing, the longest phase is the vegetative, accounting for approximately 75% of the total crop cycle in the sowing of 09/22/16, 67% in the sowing of 10/28/16, and 52% sowing of 01/03/17. Although for the later sowing this process is reversed so the reproductive phase is the longest, with approximately 62 and 58% of the total cycle in the sowing of 02/08/17 and 03/24/17, respectively.

Antecipation of flowering at the later sowing dates, and consequently the shorter duration of the vegetative phase, is due to the short photoperiod (12-13 h) to which the plants were exposed at the beginning of the development cycle, as it was also observed for chia in China (Win *et al*., 2018), in soybean (Zanon et al., 2015a) and in rice (Streck et al. 2006).

The phyllochron of chia was calculated by the relation between the number of leaves in the main stem and the accumulated degree days in the different sowing dates (Figure 3). A high R^2 (> 0.99) is observed at all sowing dates, which is a guarantee that the phyllochron estimation by this method is adequate. There was a difference in the phyllochron of the first four dates (Figure 3: A, B, C, D) compared to the sowing of 03/24/17, which presented the lowest phyllochron, resulting in a lower accumulation of degree days to appear a new leaf (Figure 3E). The larger phyllochron for the other dates indicates a slower development, as it needs a greater accumulation of degree days to emit a leaf. This is due to chia response to air temperature and photoperiod where apparently the air temperature regulates the leaf appearance rate on the main stem and the photoperiod determines the time the plant will remain emitting leaves, thus defining how many leaves a plant will have until it starts the reproductive phase, which corresponds to accumulated leaf number in the main stem (ALN, Figure 4A). On the other hand, the sowing of 03/24/17 presented a statistically lower phyllochron, which may indicate that in very late sowings, due to the highly inductive photoperiod, plus a lower vegetative phase and lower ALN, it will also have a reduction in the leaf appearance rate (phyllochron). Phyllochron differences between sowing dates were also reported in other crops, such as wheat (Toyota & Morokuma, 2020), quinoa (Curti et al., 2016), cassava (Fagundes et al., 2009), and oat (Chaves et al., 2017).

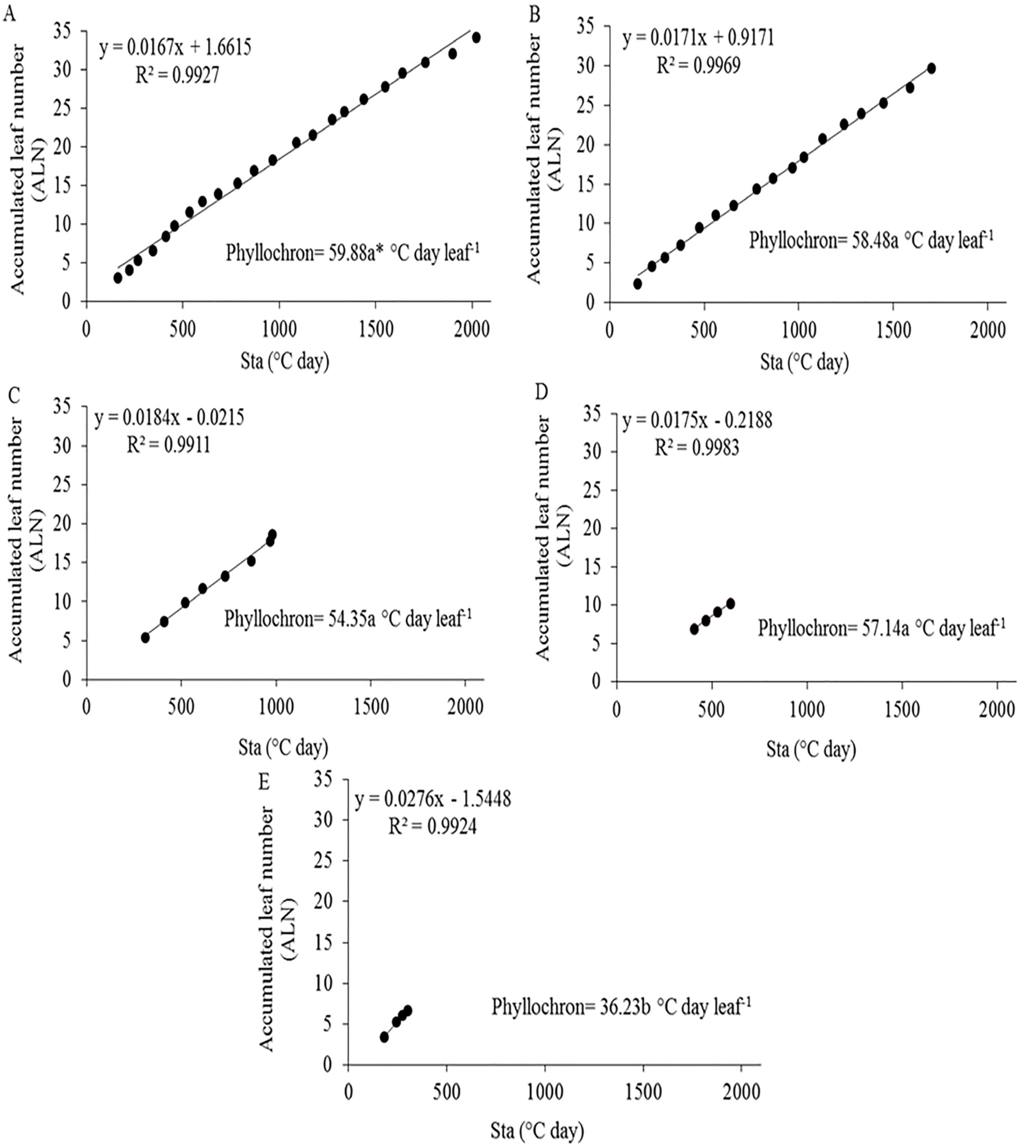

Figure 3. Relation between the accumulated leaf number in the main stem (ALN) and the accumulated degree days from emergence (ST_a, °C day) used to estimate the phyllochron (°C day leaf^{-1}) in chia in the sowing dates 09/22/2016 (A), 10/28/2016 (B), 01/03/2017 (C), 02/08/2017 (D) and 03/24/17 (E), in the agricultural year 2016/2017.

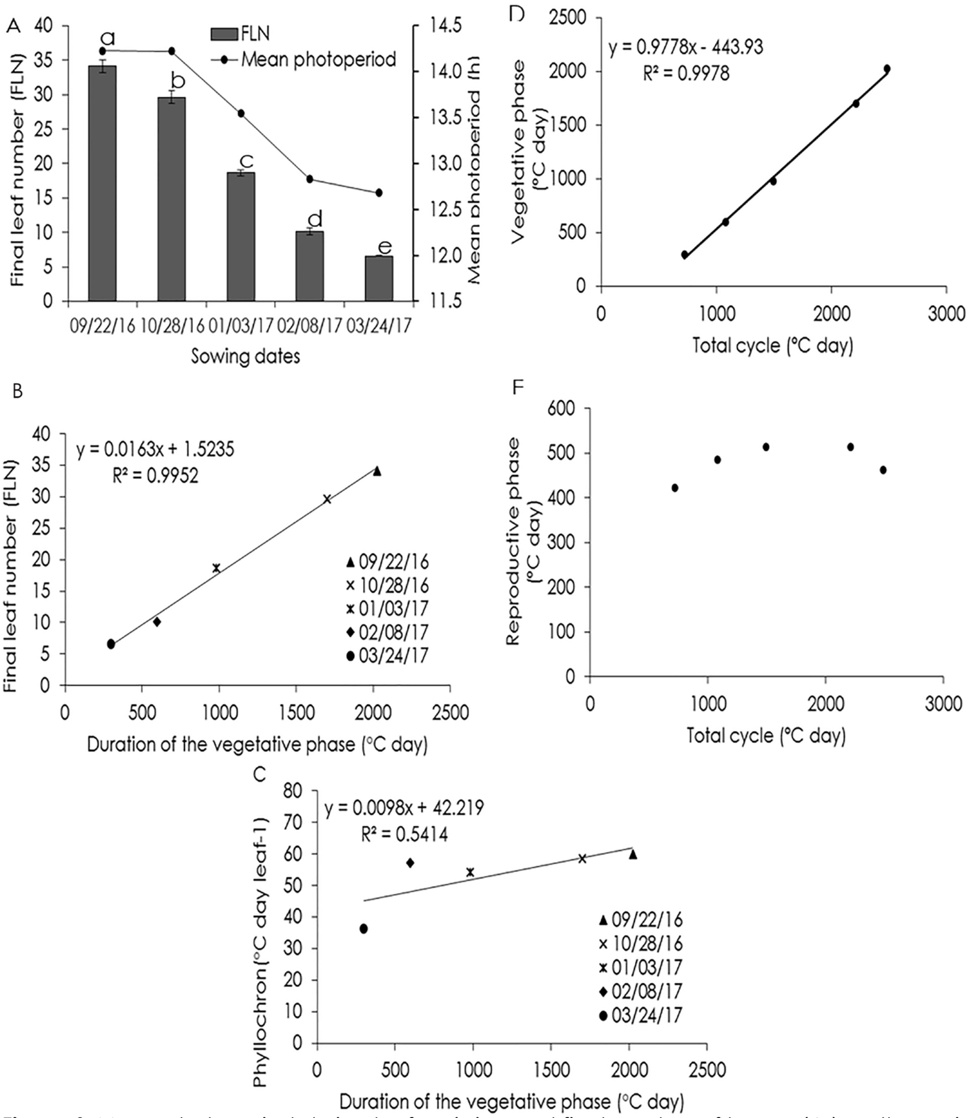

Figure 4. Mean photoperiod during leaf emission and final number of leaves (A.) on the main chia stem at sowing dates: 09/22/16 (1), 10/28/16 (2), 01/03/17 (3), 02/08/17 (4) e 03/24/17 (5). Relation between final number of leaves on the main stem and duration of the vegetative phase (B.), relation between phyllochron and duration of the vegetative phase (C.), relation between duration of the vegetative phase and the total cycle (D.), relation between the duration of the reproductive phase and the total cycle (E.) of chia in the agricultural year 2016/2017.

The duration of the vegetative phase is associated with the change in the final leaf number and to the appearance rate of new leaves on the main stem, so a shorter vegetative phase allows the plant to produce a lower leaf area index (Zanon et al., 2015b). Therefore, the evolution of the accumulated leaf number in the main stem (ALN) and the final leaf number (FLN) are important parameters of the vegetative development (Fagundes et al., 2009). The FLN in chia represents a very important moment, that is when the plants are induced to the flowering and to start the reproductive phase.

FLN varied between sowing dates (Figure 4A). The date 09/22/2016 and 10/28/2016 presented a FLN of 34 and 30, respectively. In later sowings, the plants emitted less leaves (18 leaves at 01/03/2017, 10 leaves at 02/08/2017 and 6 leaves at 03/24/2017). The difference in FLN between sowings confirms the information of Jamboonsri et al. (2012) and Baginsky et al. (2014), who state that chia plants have the development regulated by the photoperiod. Therefore, earlier sowings provided higher FLN as a function of plant exposures to larger (non-inductive) photoperiods, resulting in a longer vegetative phase. The chia response to photoperiod is clear when analyzing that FLN decrease between sowing dates accompanies the reduction of day duration expressed by the line in the graph (Figure 4A).

Similar results are also found for other crops. For example, Streck et al. (2006) observed that there was a difference in the FLN for rice cultivars as a function of sowing dates, being the highest FLN obtained in the earlier sowings due to the elongation of the cycle, with a typical short-day plant response. Fagundes et al. (2009) reported that FLN on the main stem in cassava varied with sowing dates and indicated that air temperature and photoperiod affect leaf appearance rate and FLN, corroborating the data obtained in the present study.

The decrease of the vegetative phase at the later sowing dates occurred due to the decrease in the final leaf number on the main stem, with a R^2 of 0.99 (Figure 4B), and very little by changes in the leaf appearance rate, according to the phyllochron which presented low relation with the vegetative phase (Figure 4C), except for the sowing of March. These results indicate that the difference in the total development cycle of chia plants is a function of the duration of the leaf appearance phase, which in turn is governed by the photoperiod, that is, the earlier the sowing date, the longer the vegetative phase and FLN, and the later, the lower the vegetative phase and the FLN .

The duration of the total chia cycle showed a positive linear relationship with the duration of the vegetative phase with a coefficient of determination (r^2) of 0.99 (Figure 4D). However, the duration of the total cycle in relation to the reproductive phase was not related (Figure 4E). This result is corroborated by Streck et al. (2006) in rice.

Complementary data presented by Goergen et al. (2019) point out that sowing on January 3 for the region resulted in higher grain yield, which showed an intermediate value of 18.64 leaves accumulated on the main stem and an average photoperiod of 13.5 hours (Figure 4A). This date is the most suitable for presenting a better balance between growth and yield, as plants do not remain in the field for a long time, avoiding susceptibility to diseases and weather conditions, as well as they do not remain insufficient time, which would result in a reduced leaf area index and lower grain yield. It is relevant to highlight that in addition to yield, it is important to evaluate the nutritional quality of the grains. In a study carried out in Argentina, Brandán et al. (2022) observed that the delay in sowing causes a decrease in oil concentration and an increase in protein concentration.

Conclusions

The duration of the vegetative phase of the chia plants in days and in °C days varies with the sowing date, with shorter duration in late sowings in response to the photoperiod reduction.

The vegetative phase represents the greatest part of the total development cycle in early sowing dates, being overcome by the reproductive phase in the late sowing dates (08/02/17 and 24/03/17).

The phyllochron for chia varies from 36.23 (very late sowing) to 59.88 °C day (early sowing).

Later sowing has a smaller final number of leaves accumulated in the main stem due to the shorter duration of the vegetative phase.

References

Alvares, C.A., stape, J.L., Sentelhas, P.C., Gonçalves, J.L.M., Sparovek, G. 2013. Köppen's climate classification map for Brazil. *Meteorologische Zeitschrift* 22: 711-728.

Ayerza, R., Coates, W. 2011. Protein content, oil content and fatty acid profiles as potential criteria to determine the origin of commercially grown chia (*Salvia hispanica* L.). *Industrial Crops and Products* 34: 1366-1371.

Arnold, C.Y. 1960. Maximum-minimum temperatures as a basis for computing heat units. *Proceedings of the American Society for Horticultural Sciences* 76: 682-692.

Baginsky, C., Arenas, J., Escobar, H., Garrido, M., Valero, D., Tello, D., Pizarro, L., Morales, L., Silva, H. 2014. http://www.chia.uchile.cl/docs/anexos/Anexo_1.pdf A Access on 10 Dec. 2018.>

Baginsky, C., Arenas, J., Escobar, H., Garrido, M., Valero, N., Tello, D., Pizarro, L., Valenzuela, A., Morales, L., Silva, H. 2016. Growth and yield of chia (*Salvia hispanica* L.) in the Mediterranean and desert climates of Chile. *Chilean Journal of Agricultural Research* 76: 255-264.

Brandán, J.P., Curti, R.N., Acreche, M.M. 2020. Developmental responses of chia (*Salvia hispanica*) to variations in thermo-photoperiod: impact on subcomponents of grain yield. *Crop and Pasture Science* 72: 1-7.

Brandán, J.P., Izquierdo, N., Acreche, M.M. 2022. Oil and protein concentration and fatty acid composition of chia (Salvia hispanica L.) as affected by environmental conditions. Industrial Crops and Products 177: 114496.

Bochicchio, R., Philips, T. D., Lovelli, S., Labella, R., Galgano, F., Di Marisco, A., Perniola, M., Amato, M. 2015. Innovative crop productions for healthy food: the case of chia (*Salvia hispanica* L.). In.: Vastola, A. (ed.). *The Sustainability of Agro-Food and Natural Resource Systems in the Mediterranean Basin*. Springer, Potenza, Italy. p.29-45.

Chaves, G.G., Cargnelutti Filho, A., Alves, B.M., Lavezo, A., Wartha, C.A., Uliana, D.B., Pezzini, R.V., Kleinpaul, J.A., Neu, I.M.M. 2017. Phyllochron and leaf appearance rate in oat. *Bragantia* 76: 73-81.

Curti, R.N., de la Vega, A.J., Andrade, A.J., Bramardi, S.J., Bertero, H.D. 2016. Adaptive responses of quinoa to diverse agro-ecological environments along an altitudinal gradient in North West Argentina. *Field Crops Research* 189: 10-18.

Fagundes, L.K., Streck, N.A., Lopes, S.J., Rosa, H.T., Walter, L., Zanon, A.J. 2009. Desenvolvimento vegetativo em diferentes hastes da planta de mandioca em função da época de plantio. *Ciência Rural* 39: 657-653.

Ferreira, D.F. 2011. SISVAR: A computer statistical analysis system. *Ciência e Agrotecnologia* 35: 1039-1042.

Goergen, P.C.H.; Lago, I., Durigon, A., Roth, G.F.M.; Scheffel, L.G., Slim, T. 2019. Performance of Chia on Different Sowing Dates: Characteristics of Growth Rate, Leaf Area Index, Shoot Dry Matter Partitioning and Grain Yield. *Journal of Agricultural Science Archives* 11: 252-263.

Jamboonsri, W., Phillips, T.D., Geneve, R.L., Cahill, J.P., Hildebrand, D.F. 2012. Extending the range of an ancient crop, Salvia hispanica L.-a new ω3 source. *Genetic Resources and Crop Evolution* 59: 171-178.

Jin, F., Nieman, D.C., Sha, W., Xie, G., Qiu, Y., Jia, W. 2012. Supplementation of milled chia seeds increases plasma ALA and EPA in postmenopausal women. *Plant Foods for Human Nutrition* 67: 105-110.

Migliavacca, R.A., Silva, T.R.B., Vasconcelos, A.L.S., Mourão Filho, W., Baptistella, J.L.C. 2014. O cultivo da chia no Brasil: Futuro e perspectivas. *Journal of Agronomic Sciences* 3: 61-179.

Streck, N. A., Bellé, R.A., Rocha, E.K., Schuh, M. 2005. Estimating leaf appearance rate and phyllochron in safflower (*Carthamus tinctorius* L.). *Ciência Rural* 35: 1448-1450.

Streck, N.A., Bosco, L.C., Michelon, S., Walter, L.C., Marcolin, E. 2006. Duração do ciclo de desenvolvimento de cultivares de arroz em função da emissão de folhas no colmo principal. *Ciência Rural* 36: 1086-1093.

Toyota, M., Morokuma, M. 2020. Morphological and phenological adaptation for convergent development of tillers in Widely spaced wheat sown on different dates. *Plant Production Science* 24: 1-13.

Trentin, R., Heldwein, A.B., Streck, N.A., Trentin, G., Silva, J.C. 2013. Subperíodos fenológicos e ciclo da soja conforme grupos de maturidade e datas de semeadura. *Pesquisa Agropecuaria Brasileira* 48: 703-713.

Win, A.N., Xue, Y., Chen, B., Liao, F., Chen, F., Yin, N., Mei, F., Wang, B., Shi, X., He, Y., Chai, Y. 2018. Chia (*Salvia hispanica*) experiment at a 30° N site in Sichuan Basin, China. Ciência Rural 48: 20180105.

Zanon, A.J., Winck, J.E.M., Streck, N.A., Rocha, T.S.M., Cera, J.C., Richter, G.L., Lago, I., Santos, P.M., Maciel, L.R., Guedes, J.V.C., Marchesan, E. 2015a. Desenvolvimento de cultivares de soja em função do grupo de maturação e tipo de crescimento em terras altas e terras baixas. *Bragantia* 74 :400-411.

Zanon, A.J., Streck, N.A.; Richter, G.L., Becker, C.C.; Rocha, T.S.M., Cera, J.C., Winck, J.E.M., Cardoso, A.P., Tagliapietra, E.L., Weber, P.S. 2015b. Contribuição das ramificações e a evolução do índice de área foliar em cultivares modernas de soja. *Bragantia* 74: 279-290.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.