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Base temperature estimates for lisianthus cultivars grown in different planting seasons

Daniela Höhn[1 ✉],
Roberta Marins Nogueira Peil[2],
Priscila Monalisa Marchi[3],
Paulo Roberto Grolli[2],
Roberto Trentin[2] and
Willian Silveira Shaun[4]

[1] Universidade Federal de Pelotas, Faculdade de Agronomia Eliseu Maciel, Programa de Pós-Graduação em Sistemas de Produção Agrícola Familiar, Avenida Eliseu Maciel, s/nº, Jardim América, CEP 96160-000 Capão do Leão, RS, Brazil. E-mail: dani.hohn.sc@gmail.com

[2] Universidade Federal de Pelotas, Departmento de Fitotecnia, Avenida Eliseu Maciel, s/nº, Jardim América, CEP 96160-000 Capão do Leão, RS, Brazil. E-mail: rmnpeil@gmail.com, prgrolli@gmail.com, trentin@gmail.com

[3] Faculdade Santo Ângelo, Rua do Seminário, nº 188, Vera Cruz, CEP 98807-296 Santo Ângelo, RS, Brazil. E-mail: priscilammarchi@yahoo.com.br

[4] Universidade Federal de Pelotas, Avenida Eliseu Maciel, s/nº, Jardim América, CEP 96160-000 Capão do Leão, RS, Brazil. E-mail: williamsilveira2012@gmail.com

✉ Corresponding author

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Abstract – The objective of this work was to determine the base temperature of six lisianthus cultivars, grown at seven planting seasons in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil. The following cultivars were evaluated: DBL Echo Blue, Robella 2 Pink, Excalibur White, Excalibur 2 Blue Picotee, DBL Echo Champagne, and Arena III Red. Base temperature was determined from the air temperature data collected daily, in each planting season, fusing the lowest variability and development ratio methods. The base temperature for lisianthus cultivars is between 14.0 and 15.0ºC, by the lowest variability method, and between 13.9 and 15.0ºC by the development ratio method. The highest thermal accumulation was obseerved in the second planting season (from 11/23/2017 to 02/22/2018) for all cultivars, and lower air temperatures during the growing season resulted in longer production cycles. In the seven planting seasons, the highest base temperature is 15.0ºC, obtained for cultivar Arena III Red, and the is 14°C, for all lisianthus cultivars.

Index terms: *Eustoma grandiflorum*, degree-day, development ratio, phenology, thermal sum.

Estimativa da temperatura base para cultivares de lisianto em diferentes épocas de plantio

Resumo – O objetivo deste trabalho foi determinar a temperatura base para seis cultivares de lisianto, cultivadas em sete épocas de plantio no município de Capão do Leão, no estado do Rio Grande do Sul, Brasil. As seguintes cultivares de lisianto froam avaliadas: DBL Echo Blue, Robella 2 Pink, Excalibur White, Excalibur 2 Blue Picotee, DBL Echo Champagne e Arena III Red. A temperatura base foi determinada a partir dos dados de temperatura do ar coletados diariamente, em cada época de plantio, por meio dos métodos de menor variabilidade e razão de desenvolvimento. A temperatura base para as cultivares de lisianto é entre 14,0 e 15,0ºC, pelo método de menor variabilidade, e entre 13,9 e 15,0ºC, pelo método de razão de desenvolvimento. O maior acúmulo térmico foi observado na segunda época de cultivo (de 23/11/2017 a 22/02/2018) para todas as cultivares, e as menores temperaturas do ar, durante a estação de crescimento, resultaram em maiores ciclos produtivos. Nas sete épocas de plantio, a maior temperatura base é 15,0ºC, obtida para a cultivar Arena III Red, e a menor é 14,0ºC, para todas as cultivares de lisianto.

Termos para indexação: *Eustoma grandiflorum*, graus-dia, razão de desenvolvimento, fenologia, soma térmica.

Introduction

Lisianthus [*Eustoma grandiflorum* (Raf.) Shinners] belongs to the Gentianaceae family, whose plant is herbaceous, of annual growth, and that is becoming popular for its colorful petals, long post-harvest life, and ease with which it can be transported worldwide (Roni et al., 2017).

The growth and development of lisianthus are affected by different meteorological factors, such as temperature variation, solar radiation, seed vernalization, photoperiod, and light conditions (Oh, 2015). Temperature is one of the main agrometeorological parameters that directly influences the phenology of this species, as it is intrinsically associated with the photosynthetic rate, affecting the plant growth and development (Vaid et al., 2014; Freitas et al., 2017; Anzanello & De Christo, 2019). As temperature increases (up to a point), photosynthesis, transpiration, and respiration increase. When combined with day length, temperature also affects the change from vegetative to reproductive growth. Depending on the situation and the specific plant, the effect of temperature can either speed up or slow down this transition.

In general, the duration of the different developmental phases within a plant species can vary with the plant genotype and its is influenced by environmental conditions, such as that the choice of the variety, cultivar, or hybrid, and of the planting date affect flowering earliness, as well as winter production, which may allow the plant to reach the highest commercial value (Proietti et al., 2022).

The responses of plant development to temperature can be defined by the minimum, average, and maximum temperature (Hatfield & Prueger, 2015). The minimum temperature is also called the lower base temperature (Tb), and it corresponds to the temperature at which, below the respective value, the development of the species is inhibited (Souza & Martins, 2014; Cocco et al., 2016).

The determination of the base temperature is an expensive process, since each species has a base temperature which may very in accordance with the plant genotype and the growing season (Anzanello & Biasi, 2016). In temperate species, leaf growth and expansion start before reaching the temperature of 10°C and, in subtropical species, growth does not occur below 12 to 15°C (Hatfield & Prueger, 2015). The ideal temperature range for lisianthus is from15 to 25ºC, although it can withstand high temperatures (Uddin et al., 2013).

By knowing the lower base temperature for lisianthus, farmers can better plan its cultivation, ensuring that the plant grows in suitable thermal conditions to optimize its growth and production. This can also help to prevent cold damage, which can harm the plant, delaying flowering and reducing crop yield. Therefore, determining the base temperature for lisianthus implies establishing the minimum temperature conditions necessary for its adequate growth and satisfactory production. This is crucial for agricultural planning, especially for choosing the cultivation location, to extend the production window in different regions.

Thus, the base temperature for the development of a crop can be determined by using different methods, from which the most used is the one with the lowest variability and development ratio (Pilau et al., 2011; Luz et al., 2012). For the use of these two methods, phenological observations of a series of different planting times are necessary.

The objective of this work was to determine the base temperature of six lisianthus cultivars, grown at seven planting seasons in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil.

Materials and Methods

The research was conducted during the agricultural years of 2017/2018 and 2018/2019, in a small area of flower production located in the municipality of Capão do Leão (approximate coordinates – 31º46'19"S; 52º20'33" W, at 13 m altitude), a region near Pelotas, RS, Brazil. The climate of this region is characterized by a Cfa type – humid subtropical climate, with well-distributed rainfall and hot summer –, according to the Köppen-Geiger's classification. During the experimental phase, the mean value of temperature was 19.2°C, with 83.1% relative humidity, and 1,528.9 MJ m^{-2} radiation.

The experiments were conducted in a plastic greenhouse in arch-ceiling model, with a wooden structure covered with low-density polyethylene plastic film (100 µm thick) with the following dimensions (width x length x height): 10.0 m x 24.0 m x 3.5 m.

The management of the greenhouse environment was carried out by daily opening the side curtains.

Throughout all experiments, maximum and minimum temperatures were recorded using a digital thermohygrometer, which was installed in a thermometric shelter 1.5 m above the soil surface, inside the plastic greenhouse.

The adopted cultivation system was implemented in beds made directly on the ground, which is widely used by producers of cut flowers. The physical structure of the experiment for each planting season consisted of three beds, with 0.50 m paths between beds, which were arranged parallel to the length of the greenhouse. Each bed had the following dimensions: 6.00 m long, 1.00 m wide and 0.15 m high. Two hundred forty plant seedlings were transplanted per plot, in six rows spaced at 0.10 m between rows and 0.10 m between plants), totaling 720 plants in each experiment. Considering the population of 240 plants per bed, the useful 6 m length and a 1 m width, the planting density in the bed, without considering the paths, was 40 plants m^{-2}. Each plot was divided into six plots of 1 m length, in which 40 plants of each cultivar were transplanted.

Simple soil samples were collected at different points on each experimental unit, before the start of the experiments and after the end of the work, and the soil was a Planossolo type (Santos et al., 2018). The soil samples were collected in accordance with technical recommendations for soil collection and sent to the laboratory for chemical and physical analysis of analyses, at the Universidade Federal de Pelotas. The limestone requirement calculation was adjusted for a pH value between 5.5 and 6.5, using dolomitic limestone, seeking to increase the base saturation (V%) to 75%. Before the installation of the experiments, the base fertilization was carried out in accordance with the soil analysis. Considering the amount of nutrients in the soil, the plants were fertigated using drip irrigation once a week in the spring/summer seasons, and once every 15 days in the autumn/winter seasons. The fertilizer formula used in the fertigation was NPK 13-2-44 (Ouro Fértil, Pelotas, RS, Brazil), used by the producer and also recommended for other species of flowers. Irrigation was performed on average once a day in the spring/summer and once a week during autumn/winter seasons.

The following lisianthus cultivars were evaluated: DBL Echo Blue, Robella 2 Pink, Excalibur White, Excalibur 2 Blue Picotee, DBL Echo Champagne, and Arena III Red, which were obtained from the Isabel Yamaguchi's nursery plants, in the municipality of Atibaia, in the state of São Paulo (SP), Brazil. Seedlings were acclimatized in a shaded environment, after which, their were transplanted to the cultivation beds according to each planting season.

The culture was evaluated by monitoring the experiments in seven planting seasons: 1, (October 13th, 2017); 2, (November 23rd, 2017); 3 (April 6th, 2018); 4 (July 6th, 2018); 5 (August 31st, 2018); 6 (January 19th, 2019); and 7 (February 15th, 2019).

The experimental design was carried out in randomized blocks, in a 6x7 factorial arrangement (six cultivars and seven planting dates) and three replicates.

The base temperature was determined from the air temperature data collected daily, in each planting season, using the methodologies of the lowest variability and development ratio proposed by Arnold (1960). The method of lowest variability is based on the idea that the value assigned to Tb represents the smallest value of the standard deviation obtained in days, defined as the one appropriate for the crop under study (Müller et al., 2009).

Thus, for the cycle under study, the accumulated thermal sum in each growing season was determined above the presupposed base temperature values (Tb) previously chosen, in which the Tb values were from 0.5ºC to 16ºC at 0.5°C intervals. Mean and standard deviation values of the thermal sums, obtained with the series of planting dates, were also estimated for each of the supposed values of Tb. Thus, the standard deviation values, in days, of the different planting times for each of the assumed Tb values were estimated with the aid of below equation. The value that provided the smallest standard deviation in days was defined as the temperature base: Sd (Tb) = Sdd/ (t-Tb), where: Sd (Tb) is the standard deviation in days of the series of planting dates for each assumed value of Tb; Sdd is the standard deviation in degree-days of the series of planting dates for each supposed value of Tb; t is the average air temperature over the entire series of planting dates.

The development ratio method relates the average air temperature of the analyzed period with the relative development of the culture, using the following equation: RD=100/N, where: RD represents the relative development to the average air temperature;

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and N is the number related to the duration of each subperiod to be studied.

The relationship between the relative development of the culture and the air temperature was obtained through simple linear regression, in which the extension of the straight line to the abscissa axis with zero growth rate is indicative of Tb.

In both methods, t lowest variability and development ratio, the required sum of degree-days for the crop to complete the subperiod of the planting date was calculated using the following equation: ATS = Σ(Tmean - Tb), where: ATS corresponds to the accumulated thermal sum necessary for the completion of the lisianthus development cycle; Tmean is the average air temperature determined from the maximum temperature and minimum air temperature; and Tb is the lowest base temperature of the analyzed period.

Results and Discussion

Cultivation in different planting times allowed lisianthus plants to develop in different meteorological conditions throughout each cycle, which was important to estimate the base temperature (Tb) of the cultivars.

The Tb value calculated by the method of the lowest variability was the same for DBL Echo Blue, Robella 2 Pink, Excalibur White, Echo champagne, and Excalibur 2 Blue Picotee cultivars, which was 14.0ºC attained for these materials (Figure 1). For Arena III Red cultivar, the Tb value found was 15.0ºC, which is higher than that of the other cultivars.

In the development ratio method, the Tb value found was 13.9ºC for DBL Echo Blue, Robella 2 Pink, Excalibur White, and Echo champagne cultivars, while for Excalibur 2 Blue Picotee cultivar it was 14.0°C (Figure 2). The Arena III Red cultivr showed a Tb value of 15.0ºC, which is higher than that of the other cultivars evaluated by this method, in the same way as it was observed in the method of the lowest variability.

The Tb values of the cultivars were between 14.0 and 15.0°C for the lowest variability method, and 13.9 and 15.0°C for the development ratio method. A small Tb oscillation of 1.0ºC was observed for the cultivars in the lowest variability method, and in the development ratio method (1.1ºC). However, the highest Tb was found for Arena III Red cultivar, which obtained the same value by the two methods, which shows that this cultivar requires a greater thermal availability to start its development.

The variation between the Tb values found in this work has been also reported for other species. Fagundes et al. (2010) evaluated *Aspilia montevidensis* and also found variation between the Tb values by the two methods; for the lowest variability method, these authors found Tb of 14°C, and for the development rate method 12.9°C, in the same evaluation subperiod.

Therefore, the variations between the methods used in the present work are close to those obtained for other cultures. However, it is evident that the minimum temperature that lisianthus cultivars require for their adequate development is 13.9ºC, to maintain a minimum development. According to Souza et al. (2016), it can be inferred that, below this value, the species has its development inhibited or considered negligible, mainly in times of low temperatures and lower solar radiation, as it occurs in the autumn/winter season in the southern region of Brazil.

Data are presented for the thermal sum, average air temperature, and cycle of cultivars (Table 1). To calculate the ATS, the Tb used was 14ºC, found by the method of the lowest variability referring to DBL Echo Blue, Robella 2 Pink, Excalibur White, DBL Echo Champagne, and Excalibur 2 Blue Picotee cultivars. To calculate the ATS of Arena III Red cultivar, the Tb of 15ºC – found in both methods – was used.

The highest ATS was found Iin the season 2 for Excalibur White and Excalibur 2 Blue Picotee cultivars, in the period from November 23rd, 2017 to February 18th, 2018 (Table 1). At that time, the cultivars also had one of the lowest plant development cycles and the highest air temperature. This may have caused an increase of Tb differences, thus resulting in greater thermal accumulation.

It was reported by Harbaugh (1995) that stem strength, plant vigor, and percentage of flowering plants was influenced by interactive effects of photoperiod x temperature (Samad et al., 2021). In addition, the author found that *Eustoma* cultivars respond differently to photoperiod and temperature.

In this work, the lowest ATS value (808.3ºC) was observed for Arena III Red cultivar in season 7 (period from February 15th, 2019 to June 4th, 2019), in which the cycle was 110 days. This is probably due to the Tb required for Arena III Red cultivar to be higher than the other cultivars by 1ºC (Tb = 15ºC), which reflected in the lower final thermal accumulation. In addition, the Arena III Red also showed a longer development cycle than the other cultivars, in all evaluated planting times, which also influenced the thermal sum.

The average air temperatures during seasons 3, 4, and 7 (autumn/winter) were closer to Tb. When the air temperature is close to Tb, there is a low accumulation of °C day^{-1}, consequently, there will be a small

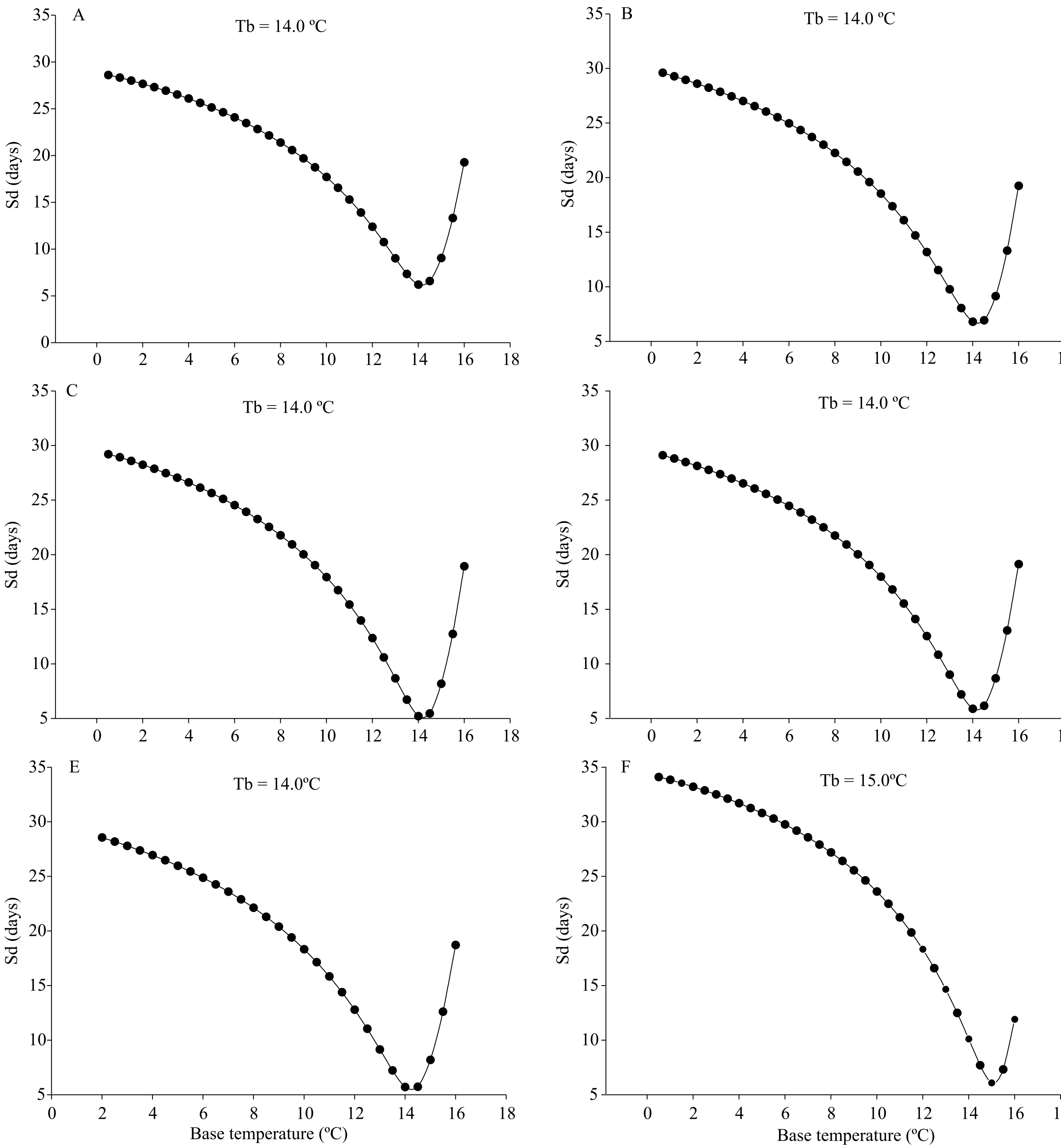

Figure 1. Determination of base temperature (Tb) from transplant to harvest of *Eustoma grandiflorum* cultivars, by the method of the lowest variability, using the standard deviation (Sd), as follows: A, DBL Echo Blue; B, Robella 2 Pink; C, Excalibur White; D, DBL Echo Champagne; E, Excalibur 2 Blue Picotee; and F, Arena III Red, in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil

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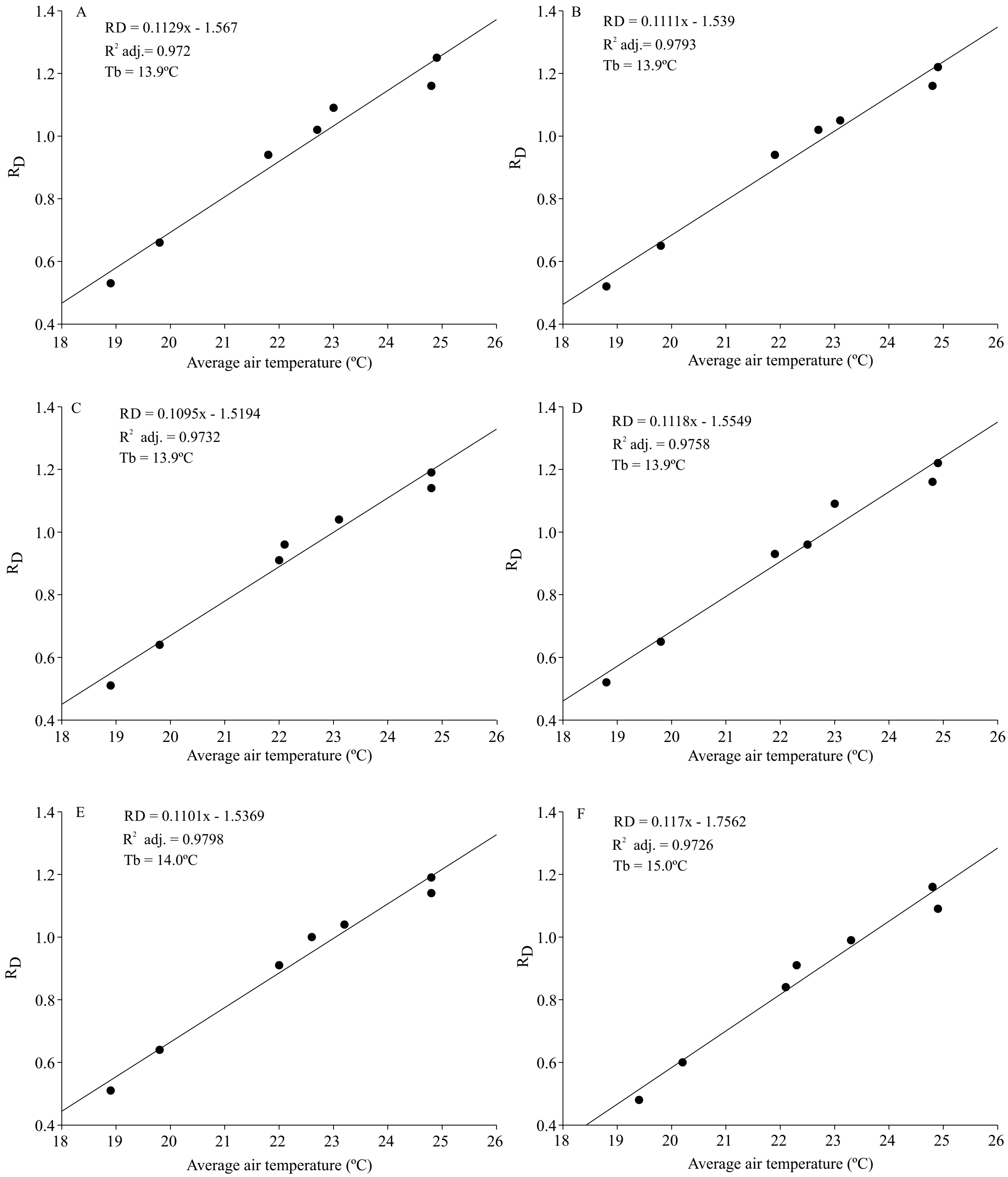

Figure 2. Determination of the base temperature (Tb) of *Eustoma grandiflorum* cultivars from transplant to harvest, by the development ratio (RD) method, as follows: A, DBL Echo Blue; B, Robella 2 Pink; C, Excalibur White; D, DBL Echo Champagne; E, Excalibur 2 Blue Picotee; and F, Arena III Red, in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil.

development of the plants, which ends up lengthening the cultivars cycle in these periods. In lisianthus, temperatures below 16°C reduced the growth rate and increased the production time (Harbaugh et al., 1997). Therefore, the temperature for flowering should be maintained above 18/16°C (day/night), in a protected environment (Harbaugh, 1995; Oh, 2015). Therefore, the lower Tb in the present study indicates a limiting temperature of 13.9°C for lisianthus.

The lowest thermal sum was found for DBL Echo Blue, Excalibur White, Echo Champagne, and Excalibur 2 Blue Picotee cultivars, in season 1 (planting October

Table 1. Accumulated thermal sum (ATS), mean air temperature, and cycle of lisianthus (*Eustoma grandiflorum*) cultivars produced in seven seasons (planting and harvesting dates), in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil.

Cultivar	Period	Season	ATS (ºC)	Air temperature (ºC)	Cycle (days)
DBL Echo Blue	October 13th, 2017 to January 12th, 2018	1	814.5	22.8	92
Robella 2 Pink	October 13th, 2017 to January 15th, 2018		853.3	22.9	95
Excalibur White	October 13th, 2017 to January 16th, 2018		865.9	23.0	96
DBL Echo Champagne	October 13th, 2017 to January 12th, 2018		814.5	22.8	92
Excalibur 2 Blue Picotee	October 13th, 2017 to January 16th, 2018		865.9	23.1	96
Arena III Red	October 13th, 2017 to January 21st, 2018		823.9	23.2	101
DBL Echo Blue	November 23rd, 2017 to February 16th, 2018	2	930.9	24.8	86
Robella 2 Pink	November 23rd, 2017 to February 16th, 2018		930.9	24.8	86
Excalibur White	November 23rd, 2017 to February 18th, 2018		954.6	24.8	88
DBL Echo Champagne	November 23rd, 2017 to February 16th, 2018		930.5	24.8	86
Excalibur 2 Blue Picotee	November 23rd, 2017 to February 18th, 2018		954.6	24.8	88
Arena III Red	November 23rd, 2017 to February 22nd, 2018		911.6	24.9	92
DBL Echo Blue	April 6th, 2018 to October 11th, 2018	3	913.7	18.8	189
Robella 2 Pink	April 6th, 2018 to October 14th, 2018		924.8	18.8	192
Excalibur White	April 6th, 2018 to October 17th, 2018		953.7	18.8	195
DBL Echo Champagne	April 6th, 2018 to October 14th, 2018		924.8	18.8	192
Excalibur 2 Blue Picotee	April 6th, 2018 to October 17th, 2018		953.7	18.8	195
Arena III Red	April 6th, 2018 to November 1st, 2018		867.8	19.1	210
DBL Echo Blue	July 6th, 2018 to December 4th, 2018	4	878.1	19.7	152
Robella 2 Pink	July 6th, 2018 to December 7th, 2018		898.3	19.8	155
Excalibur White	July 6th, 2018 to December 9th, 2018		914.0	19.8	157
DBL Echo Champagne	July 6th, 2018 to December 7th, 2018		898.3	19.8	155
Excalibur 2 Blue Picotee	July 6th, 2018 to December 9th, 2018		914.0	19.8	157
Arena III Red	July 6th, 2018 to December 18th, 2018		860.8	20.2	166
DBL Echo Blue	August 31st, 2018 to December 14th, 2018	5	836.7	21.8	106
Robella 2 Pink	August 31st, 2018 to December 14th, 2018		836.7	21.8	106
Excalibur White	August 31st, 2018 to December 18th, 2018		885.0	22.0	110
DBL Echo Champagne	August 31st, 2018 to December 16th, 2018		860.1	21.9	108
Excalibur 2 Blue Picotee	August 31st, 2018 to December 18th, 2018		885.0	22.0	110
Arena III Red	August 31st, 2018 to December 26th, 2018		857.6	22.1	118
DBL Echo Blue	January 19th, 2019 to April 8th, 2019	6	884.1	24.8	80
Robella 2 Pink	January 19th, 2019 to April 10th, 2019		905.2	24.7	82
Excalibur White	January 19th, 2019 to April 12th, 2019		920.1	24.8	84
DBL Echo Champagne	January 19th, 2019 to April 10th, 2019		905.2	24.8	82
Excalibur 2 Blue Picotee	January 19th, 2019 to April 10th, 2019		905.2	24.4	84
Arena III Red	January 19th, 2019 to April 14th, 2019		850.8	24.8	86
DBL Echo Blue	February 15th, 2019 to May 23rd, 2019	7	864.6	22.8	98
Robella 2 Pink	February 15th, 2019 to May 23rd, 2019		864.6	22.5	98
Excalibur White	February 15th, 2019 to May 29th, 2019		893.1	22.5	104
DBL Echo Champagne	February 15th, 2019 to May 29th, 2019		893.1	22.5	104
Excalibur 2 Blue Picotee	February 15th, 2019 to May 25th, 2019		874.0	22.7	100
Arena III Red	February 15th, 2019 to June 4th, 2019		808.3	22.3	110

13th, 2017), while, for Robella 2 Pink cultivar, the lowest thermal sum occurred in the season 5 (August 31st, 2018 to December 14th, 2018), and for Arena III Red cultivar, in the season 7 (February 15th, 2019 to June 4th, 2019).

These results show that there are differences between cultivars for thermal accumulation and crop cycle occurring in an inverse relationship between the mean air temperature and the length of the period. In the present work, DBL Echo Blue attained the shortest cycle, becoming the earliest cultivar, while Arena III Red had the longest cycle, in all planting seasons, becoming the latest cultivar.

The reduction of the cycle duration in the spring/summer seasons may be associated with some photoperiodic response of the cultivars (Osnato et al., 2022). As day length is longer during spring and summer, plants are stimulated to anticipate flowering, thus reducing the vegetative period, which can be supported by Harbaugh (1995) that *Eustoma* is a day-neutral or quantitative long-day plant.

In addition, the differences may also be due to the subjectivity of the criterion for determining the point of harvest (Cocco et al., 2016; Schmidt et al., 2018), with a variation between about 6 and 9 days, as observed during our experiments. In the present work, when determining the harvest date of the lisianthus cultivars, the periods of low temperatures (autumn/winter) resulted in a delay from 12 to 21 days for the harvest.

From a phenological point of view, it is considered that the biological calendar of plants is affected by the air temperature, and the variables can be used morphogenic eis to describe the development time, which is accounted for by ATS and described in degree days (ºC day^{-1}). Thus, Tb is a variable that is directly related to the thermal requirements of a crop/genotype and, therefore, it provides an important information for crop management.

Thermal availability has a direct effect on plant growth and development. High temperatures accelerate the plant metabolism, while low temperatures reduce the plant growth and prolong the cycle of plants (Anzanello & De Christo, 2019; Proietti et al., 2022), especially in regions with marked annual thermal oscillation, such as in southern Brazil.

It should also be noted that, just like the air temperature, the photoperiod can also be a factor that regulates the period duration for the appearance of the first flowers in crops. According to Yumbla-Orbes et al. (2018), the influence of seed vernalization on the production and development of lisianthus plants resulted in a greater efficiency in the induction of flowering and reduction of the cycle of this crop. The authors also highlight the sensitivity of the culture to photoperiod.

Lisianthus is generally considered a photoperiod-independent flowering crop. Most of the literature refers to the species as a photo-neutral plant and describe that photoperiod has no effect on flowering (Halevy & Kofranek, 1984). However, according to Islam et al. (2005), lisianthus is a quantitative long-day plant, and high light intensities reduce the floral transition time. Also, it is known that flower timing and quality are affected by light intensity ,and that high full day light can accelerate flowering (Rezazadeh et al., 2018). Thus, the hypothesis on the variation of the cycle length and on the growing season is that the photoperiod can also modify the thermal sum, in response to the species or even the cultivar.

In general, environmental conditions significantly influence the physiological processes in plants. However ,it is possible to extend the cultivation period in part of the autumn/winter, as long as the minimum basal temperature required for the cultivar adequate development is taken into account.

Notwithstanding, more studies on all these discussed aspects are important to better understand the requirements of the culture and to manage it properly.

Conclusions

1. The base temperature (Tb) for DBL Echo Blue, Robella 2 Pink, Excalibur White, Excalibur 2 Blue Picotee, DBL Echo Champagne, and Arena III Red lisianthus (*Eustoma grandiflorum*) cultivars is between 14º and 15ºC for the lowest variability method, and between 13.9 and 15.0ºC for the development ratio method, in the municipality of Capão do Leão, in the state of Rio Grande do Sul, Brazil.

2. The lowest Tb indicates a limiting temperature of 14°C for lisianthus found by the method of the lowest variability.

3. Arena III Red cultivar shows 15 ºC as the highest Tb in all seven planting seasons.

4. The highest thermal sum is found in season 2 (November 23rd, 2017 to February 22nd, 2018), for all cultivars, and the lowest is the air temperature, during the growing season, the longest will be the production cycle.

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