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Scientific Article

Occurrence and duration of phenological phases of *Freesia* x *hybrida* grown at different planting dates

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Abstract

Freesia (*Freesia* x *hybrida*) is one of the most cultivated species of cut flowers, ranking sixth in the international market. Phenological processes occurring during the crop cycle are controlled by endogenous mechanisms and the environment, which in turn influence the duration and occurrence of the development phases. This study aimed to analyze the effect of planting dates (Feb 15, March 19, April 16, May 21, and June 21, 2021) on the occurrence and duration of the development phases of two freesia varieties (Blue Bayou and Yvonne). The trial was conducted in a high tunnel. The crop cycle was divided into vegetative, reproductive, and senescence phases. The number of leaves was counted daily. The development phases were significantly shortened with the delay of planting. The vegetative phase ranged between 2269.78 ± 19.22 and 736.50 ± 19.22 GDD for Blue B., and between 1864.48 ± 19.22 and 667.09 ± 19.22 GDD for Yvonne. The reproductive phase lasted 459.50 ± 20.99 and 379.51 ± 20.99 GDD for Blue B., 461.43 ± 20.99 and 487.29 ± 20.99 GDD for Yvonne. The senescence phase was shortened with delayed planting dates only for Yvonne. Plants cultivated at later dates (May 21, and June 21), and consequently exposed to increased photoperiod, had a lower number of leaves at flowering (7.85 ± 0.10) and were less exposed to inductive temperatures than plants cultivated earlier. The transition to the reproductive phase was determined by the interaction between photoperiod, temperature and plant age.
Keywords: floriculture, *Freesia* x *hybrida*, geophytes, phenology, planting dates.

Resumo

Ocorrência e duração das fases fenológicas de *Freesia* x *hybrida* cultivado em diferentes datas de plantio

Freesia (*Freesia* x *hybrida*) é uma das espécies de flores de corte mais cultivadas, ocupando o sexto lugar no mercado internacional. Os processos fenológicos que ocorrem durante o ciclo de desenvolvimento são controlados por mecanismos endógenos e pelo ambiente, que por sua vez influenciam a duração e ocorrência das fases de desenvolvimento. Este estudo teve como objetivo analisar o efeito das datas de plantio (15 de Fevereiro, 19 de Março, 16 de Abril, 21 de Maio, e 21 de Junho, 2021) na ocorrência e duração das fases de desenvolvimento de duas variedades de freesia (Blue Bayou e Yvonne). O ensaio foi conduzido em um túnel alto. O ciclo de cultivo foi dividido em fases vegetativas, reprodutivas, e de senescência. O número de folhas foi contabilizado diariamente. As fases de desenvolvimento foram significativamente encurtadas com o atraso da data de plantio. A fase vegetativa variou entre 2269,78 ± 19,22 e 736,50 ± 19,22 GD para a variedade Blue B., e entre 1864,48 ± 19,22 e 667,09 ± 19,22 GD para a Yvonne. A fase reprodutiva durou entre 459,50 ± 20,99 e 379,51 ± 20,99 GD para a Blue B. e 461,43 ± 20,99 e 487,29 ± 20,99 GD para aYvonne. A fase de senescência foi encurtada com datas de plantio atrasadas apenas para a Yvonne. As plantas cultivadas em datas posteriores (21 de Maio, e 21 de Junho), e consequentemente expostas ao aumento do fotoperíodo, apresentaram um menor número de folhas na floração (7,85 ± 0,10) e estavam menos expostas a temperaturas indutivas do que as plantas cultivadas mais cedo. A transição para a fase reprodutiva foi determinada pela interação entre o fotoperíodo, a temperatura e a idade das plantas.
Palavras-chave: datas de plantio, fenologia, floricultura, *Freesia* x *hybrida*, geófitas.

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Introduction

Floriculture is one of the most profitable agricultural activities in the world. The activity strongly contributes to the economy of the producing countries and is characterized by a combination of intensive land use and high labour demand. Freesia (*Freesia* x *hybrida*) is one of the most cultivated species of cut flowers, ranking sixth in the international market (Faust and Dole, 2021; Khan et al., 2022). It is native to Cape Province, South Africa, and belongs to the Iridaceae family (Wang, 2007; Ma et al., 2021). The species is geophyte, i.e. the flower and corm are the organs of agronomic and economic importance, as saffron (*Crocus sativus* L.), gladiolus (*Gladiolus* x *grandiflorus* Hort.) and watsonia (*Watsonia angusta* Ker Gawl).

In gladiolus, for example, the plant crop cycle consists of the vegetative, reproductive and senescence phases (Streck et al., 2012). The occurrence and duration of those phases are determined by physiological, biochemical and molecular processes controlled by endogenous mechanisms and environmental factors (Bernier and Périlleux, 2005; Erwin, 2007; Thompson et al., 2011; Proietti et al., 2022).

The transition from the juvenile to the adult phase is determined by the meristem's capacity to produce floral organs (Erwin, 2007; Proietti et al., 2022). Freesia can initiate flowers over a wide range of vegetative stages, from 3 to 14 leaves (Gilbertson-Ferriss, 2018), and gladiolus florets differentiation starts at the third true leaf (Schwab et al., 2015).

The temperature and photoperiod conditions that occur during the crop cycle depend on the time of planting (Dhatt and Jhanji, 2021). It has been shown in some species of the Iridaceae family, different planting dates modify the timing and duration of phenological phases, the length of the crop cycle (Streck et al., 2012; Schwab et al., 2015; Uhlmann et al., 2016; Tomiozzo et al., 2018; Adil et al., 2021), and the number of leaves at flowering (Kumar et al., 2017; Fatihullah and Bostan, 2018; Tirkey et al., 2019). In Freesia, the vegetative phase is favoured by days with at least 16 hours with temperatures registered above 21 °C (Heide, 1965; Wang, 2007; Gilbertson-Ferriss, 2018). Likewise, floral induction is triggered by temperatures between 5 °C and 20 °C for 8 hours a day during 6 to 9 weeks. Photoperiod sensitivity can also differ between varieties (Gilbertson-Ferriss, 2018).

Understanding and quantifying the influence of environmental variables on the development of a plant species allows growers and stakeholders to implement crop management practices; thus, the market can be timely provided with flowers, for example, on a commemorative date (Streck et al., 2012; Schwab et al., 2018; Becker et al., 2021; Chandel et al., 2022; Proietti et al., 2022). Therefore, this study aimed to analyze the effect of planting dates on the occurrence and duration of the phenological phases of two varieties of *Freesia* x *hybrida.*

Materials and Methods

Vegetal material

The experiment was carried out in the year 2021, was conducted using corms of *Freesia* x *hybrida* cv. Blue Bayou and Yvonne of 2-2.2 cm in diameter, acquired from local commercial FlorAr (Florencio Varela, Buenos Aires, Argentina). Before planting, they were disinfected by immersion in an antifungal solution of Carbendazim 50% (0.2% in water) for 30 minutes. Corms were planted in beds 0.70 m wide, 0.20 m high and 4 m long. The substrate consisted of a mixture of soil (previously solarized) and agricultural perlite in 3:1 ($v\ v^{-1}$), 1.11 $dS\ m^{-1}$ electrical conductivity, pH 6.4, 2.5%-3.5% of organic matter and 66.8% gravimetric water content of the substrate at field capacity.

Experimental design and crop management

The experiment was set up as a factorial design (2 x 5) with four completely randomized blocks (each bed was considered a block). The factors were the variety of *Freesia* x *hybrida* (V1: Blue B. and V2: Yvonne) and the planting date (expressed as month/days) (D1: 2/15, D2: 3/19, D3: 4/16, D4: 5/21 and D5: 6/21). The planting dates were chosen to expose the crop to different temperatures and photoperiods. The combination of both factors yielded 10 treatments (T), namely T1: V1D1; T2: V2D1; T3: V1D2; T4: V2D2; T5: V1D3; T6: V2D3; T7: V1D4; T8: V2D4; T9: V1D5, and T10: V2D5. The experimental unit consisted of a plot of 18 corms per bed. A total of 72 corms per treatment were evaluated.

The trial was conducted in an experimental field of Faculty of Agronomy, Animal Husbandry and Veterinary Medicine (National University of Tucumán, Tucumán, Argentina) (26º50'6.9''S - 65º16'44.6''W), in a high tunnel. The high tunnel used is 11 m long, 5 m wide and 4 m high. It is oriented in a northwest-southeast direction. Its cover is made of polyethylene (long thermal duration), 100 microns. It has no environmental variables control. Crop management consisted of the application of the chemical pesticide lambda-cyhalothrin (400 $cm^3\ ha^{-1}$), manual weeding and periodical irrigation using a drip system (no water restrictions, the gravimetric value of the substrate at field capacity was used as a reference). Moreover, two 0.125 m x 0.125 m mesh grids were used to support the crop.

Development phases

Crop phenological phases were recorded according to the scale proposed by Santilli et al. (2021). The cycle was divided into three phases: 1- vegetative (from sprouting to the appearance of the flag leaf), 2- reproductive (from the appearance of the flag leaf to harvest), and 3- senescence (from harvest to senescence). The length of the crop cycle was considered as the period between bud break and senescence. The duration of the phases was expressed as number of days and growing degree days (GDD), according to the methodology proposed by Bas-Nahas et al. (2022). The base temperature used was 5 °C (Heide, 1965; Wang, 2007; Gilbertson-Ferriss, 2018). Plants were considered to have reached a certain phenological stage when 50% of them were at that stage. Before harvest, the total number of leaves, including the flag leaf, was counted.

Photoperiod and Temperature

Daily photoperiod was calculated with the Varas 1.0 spreadsheet (Fernández-Long et al., 2015). The air temperature inside the high tunnel was recorded every 30 minutes with a data logger (TPD8016, LogTag, New Zealand).

According to the information available on the number of leaves that marks the beginning of the adult phase (Gilbertson-Ferriss, 2018) and the temperature requirement (Heide, 1965; Wang, 2007; Gilbertson-Ferriss, 2018), the Period with Inductive Temperatures (PIT) for flowering was defined. It started on the first date with 8 hours or more uninterrupted with temperatures between 5 °C and 20 °C, in plants with three or more leaves (Figure 1a).

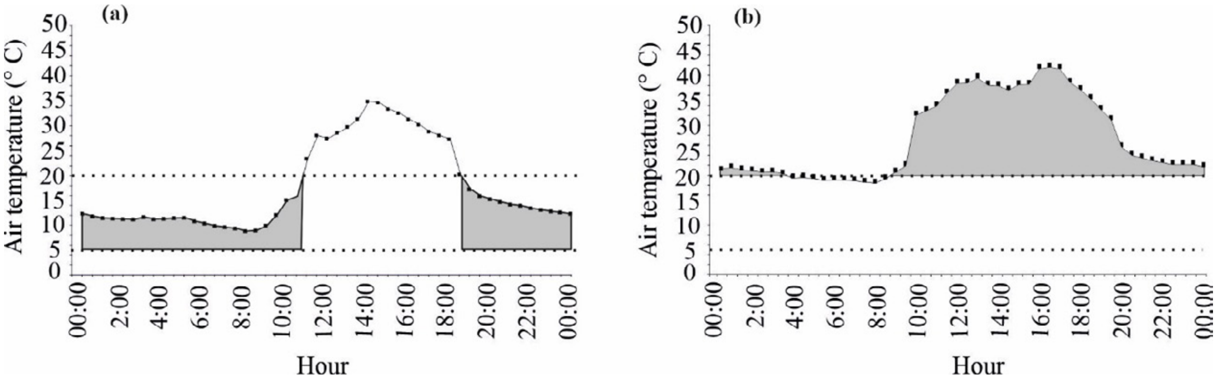

Figure 1. a) Representation of a day in May when the PIT is fulfilled. The shaded area represents the number of hours the crop was under the air temperature range between 5 °C and 20 °C. b) Representation of a day in March when the PnIT is fulfilled. The shaded area represents the number of hours the crop was at air temperatures above 21 °C. Horizontal lines indicate thermal thresholds (5 °C and 21 °C).

Similarly, and consistent with available information on temperatures that favour vegetative development, the number of hours in which the air temperature was above 21 °C for more than 16 hours uninterrupted during the day or night was defined (Heide, 1965; Wang, 2007; Gilbertson-Ferriss, 2018); that period was termed Period with non-Inductive Temperatures (PnIT) (Figure 1b).

The daily temperature data from the data logger were downloaded to a spreadsheet. The number of days (expressed in weeks) during which the crop was in the conditions described in PIT and PnIT was then counted, as shown in Figures 1a and 1b, respectively.

Analysis of data

Data were statistically analyzed using the software Infostat (InfoStat version 2021, Córdoba, Argentina). An ANOVA was performed to test significant differences between mean values. Means were compared using the DGC test (α = 0.05). The interaction between planting dates and varieties was also analyzed.

Results

Environmental conditions

The maximum absolute air temperature of the study period was 52.5 °C (recorded in February) and the minimum absolute was 0.1 °C (recorded in June) (Figure 2). From the beginning of the experiment, the photoperiod shortened until June 21, when 11.3 hours of light were recorded. From that date until the end of the trial, the photoperiod increased; in November, 14.6 hours of light were recorded (Figure 2).

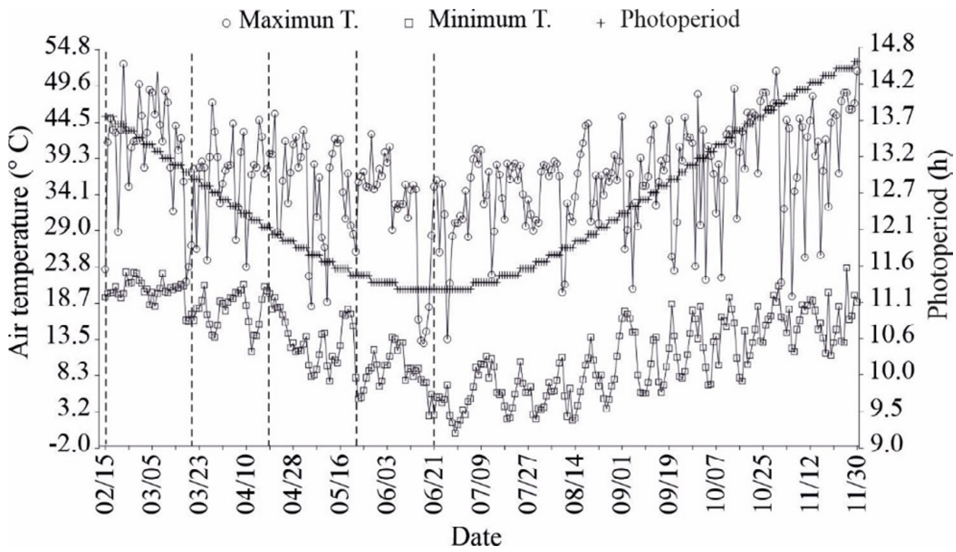

Figure 2. Maximum and minimum temperatures (°C) and photoperiod (h) recorded during the study period. The vertical dotted lines show the five planting dates evaluated.

Influence of planting date on the duration of the phenological phases

For the duration of the vegetative phase, a significant interaction between factors was observed when the phase was expressed both in days and GDD ($p < 0.0001$). As the planting date was delayed, the phase was significantly shortened in the two Freesia varieties analyzed (Table 1).

Table 1. Development phases and number of leaves for five planting dates and two Freesia varieties.

Treatment	Vegetative phase		Reproductive phase		Senescence		Crop cycle duration		N° of leaves (including flag leaf) ± s.e.
	days ± s.e.	GDD ± s.e.	days ± s.e.	GDD ± s.e.	days ± s.e.	GDD ± s.e.	days ± s.e.	GDD ± s.e.	
T1	151.25 ± 1.42 a	2269.78 ± 19.22 a	36.00 ± 1.14 a	459.50 ± 20.99 a	53.25 ± 1.84 c	924.80 ± 29.72 b	230.75 ± 1.29 a	3654.05 ± 32.86 a	16.02 ± 0.11 a
T3	122.25 ± 1.42 b	1664.18 ± 19.22 c	37.25 ± 1.14 a	443.08 ± 20.99 a	54.50 ± 1.84 c	949.65 ± 29.72 b	208.13 ± 1.29 b	3056.93 ± 32.86 c	13.46 ± 0.11 b
T5	97.75 ± 1.42 c	1175.28 ± 19.22 e	39.00 ± 1.14 a	479.82 ± 20.99 a	55.25 ± 1.84 c	984.55 ± 29.72 b	182.75 ± 1.29 c	2639.63 ± 32.86 e	10.91 ± 0.10 c
T7	80.70 ± 1.42 d	878.13 ± 19.22 g	27.75 ± 1.14 b	394.08 ± 20.99 b	49.50 ± 1.84 c	936.33 ± 29.72 b	148.00 ± 1.29 d	2208.58 ± 32.86 g	8.46 ± 0.09 d
T9	56.50 ± 1.42 f	736.50 ± 19.22 h	26.88 ± 1.14 b	379.51 ± 20.99 b	52.00 ± 1.84 c	1031.48 ± 29.72 b	126.00 ± 1.29 e	2147.50 ± 32.86 g	7.85 ± 0.10 f
T2	122.50 ± 1.42 b	1866.48 ± 19.22 b	36.00 ± 1.14 a	416.43 ± 20.99 b	62.50 ± 1.84 b	973.45 ± 29.72 b	230.75 ± 1.29 a	3256.35 ± 32.86 b	13.07 ± 0.10 b
T4	96.25 ± 1.42 c	1324.81 ± 19.22 d	37.25 ± 1.14 a	451.81 ± 20.99 a	68.75 ± 1.84 a	1136.63 ± 29.72 a	208.13 ± 1.29 b	2913.25 ± 32.86 d	10.34 ± 0.11 c
T6	80.00 ± 1.42 d	950.59 ± 19.22 f	39.00 ± 1.14 a	499.55 ± 20.99 a	54.50 ± 1.84 c	990.84 ± 29.72 b	182.75 ± 1.29 c	2451.80 ± 32.86 f	8.13 ± 0.10 e
T8	68.00 ± 1.42 e	702.69 ± 19.22 h	27.75 ± 1.14 b	442.61± 20.99 a	42.25 ± 1.84 d	751.86 ± 29.72 c	148.00 ± 1.29 d	187.15 ± 32.86 h	7.19 ± 0.10 f
T10	52.00 ± 1.42 f	667.09 ± 19.22 h	26.88 ± 1.14 b	487.29 ± 20.99 a	37.75 ± 1.84 d	760.13 ± 29.72 c	126.00 ± 1.29 e	1914.53 ± 32.86 h	7.13 ± 0.10 f

Mean values of days ± standard error (s.e.) and GDD ± standard error (s.e.) are presented. Means with different letters in each column indicate significant differences according to the DGC test (P > 0.05). References: GDD: growing degree days. Treatments: T1: V1D1, T3: V1D2, T5: V1D3, T7: V1D4, T9: V1D5, T2: V2D1, T4: V2D2, T6: V2D3, T8: V2D4 and T10: V2D5.

The first planting date (in February) resulted in the longest vegetative phase for both varieties, T1 (151.25 ± 1.42 days, Blue B.) and T2 (122.50 ± 1.42 days, Yvonne), with significant differences between them. On the contrary, the last planting date (in June) resulted in a shorter vegetative phase for both varieties, T9 (56.50 ± 1.42 days, Blue B.) and T10 (52.00 ± 1.42 days, Yvonne) (Table 1), and with significant differences between them. When the duration was analyzed in GDD, the same trend was observed, although no significant differences were detected between varieties on the last date of planting (Table 1).

For the variable number of leaves, a significant interaction was observed between factors ($p < 0.0001$). The number of leaves decreased with the delay of the planting date (Table 1). Treatments T1 and T2 produced on average 16.02 ± 0.11 and 13.07 ± 0.10 leaves, respectively, whereas the lowest number of leaves was recorded on the last planting date (7.85 ± 0.10 in T9, and 7.13 ± 0.10 in T10); no significant differences were observed in the number of leaves for the variety Yvonne in T8 and T10 (Table 1).

Variety Yvonne required fewer days to reach the flag leaf stage, regardless of the planting date. Therefore, the vegetative phase of this variety was always significantly shorter and with fewer leaves compared with the Blue B. variety (Table 1).

For the duration of the reproductive phase, no significant interaction between factors was observed ($p = 0.5294$). The duration of this phase was significantly shorter for the Blue B. variety (31.40 ± 0.72 days) than for the Yvonne variety (35.35 ± 0.73 days) ($p = 0.0007$). Regarding the analysis of the main effect of the factor planting date ($p < 0.0001$), no significant differences were observed in the planting performed on 2/15, 3/19 and 4/16, with the reproductive phase lasting between 36.00 ± 1.14 and 39.00 ± 1.14 days for both varieties. Moreover, this period was shortened on the last two planting dates (5/21 and 6/21), significantly differing from the previous dates (Table 1).

The analysis of the duration of the reproductive phase expressed in GDD showed a significant interaction between factors ($p = 0.017$). The treatments T2, T7 and T9 required fewer GDD and differed significantly from the other treatments (Table 1).

For the senescence phase, a significant interaction between factors was observed for both the duration in days and GDD ($p < 0.001$). For the Yvonne variety, the duration of the phase (both in days and GDD) was shortened with the delay of the planting date in T4, T6, T8 and T10 (Table 1), whereas for Blue B., no significant differences were detected in the senescence phase duration either in days or GDD.

The crop cycle duration –expressed in days– showed no significant interaction between factors ($p = 0.0571$). The crop cycle was significantly shorter for the Yvonne variety (172.25 ± 0.82 days) than for the Blue B. variety (186.00 ± 0.82 days). Considering the factor planting date, significant differences were observed among the five planting dates evaluated ($p < 0.0001$) (Table 1). For crop cycle duration –expressed in GDD–, a significant interaction was observed between factors ($p = 0.0050$). The GDD requirement decreased with the delay of planting dates. The crop cycle duration was significantly different on the first four planting dates for the two varieties (Table 1). No significant differences were observed between the fourth and fifth planting dates in either variety (Table 1).

Influence of planting date on the transition from the vegetative to the reproductive phase

The transition from the vegetative to the reproductive phase occurred in all plants and was determined by the effect of PIT, photoperiod, plant age, and variety. Plant age, determined by the number of leaves present at the time of transition to the reproductive phase (appearance of the flag leaf), differed among treatments (Table 2).

Table 2. Photoperiod, temperature and plant age in the transition from the vegetative phase to the reproductive phase for five planting dates and two Freesia varieties. References: PnIT: Period with non-Inductive Temperatures (number of weeks the crop was at a temperature above 21 °C); PIT: Period with Inductive Temperatures (number of weeks the crop was exposed to a temperature range between 5 °C and 20 °C). Treatments: T1: V1D1, T3: V1D2, T5: V1D3, T7: V1D4, T9: V1D5, T2: V2D1, T4: V2D2, T6: V2D3, T8: V2D4 and T10: V2D5.

Treatment	Average date when the third leaf appeared (days after planting)	Start of PIT	Average n° of leaves ± s.e. at the beginning of PIT	Average n° of leaves before the appearance of the flag leaf ± s.e.	Average date of flag leaf appearance	Photoperiod recorded at the time of appearance of the flag leaf	PnIT + PIT (weeks)
T1	03/15/2021 (28)	05/5/2022	9.20 ± 0.07	15.02 ± 0.12	07/26/2021	11.6	9.7 + 11.7
T3	04/05/2021 (17)	05/5/2022	6.72 ± 0.07	12.46 ± 0.10	07/27/2021	11.6	6.7 + 11.8
T5	05/01/2021 (15)	05/5/2022	2.97 ± 0.09	9.91 ± 0.10	07/30/2021	11.6	3 + 12.2
T7	06/12/2021 (22)	06/12/2021	2.84 ± 0.06	7.57 ± 0.06	08/20/2021	12.1	0 + 9.8
T9	07/21/2021 (30)	07/21/2021	2.97 ± 0.07	6.85 ± 0.07	09/03/2021	12.4	0 + 6.3
T2	03/26/2021 (39)	05/05/2022	7.82 ± 0.09	12.30 ± 0.13	07/03/2021	11.3	8.1 + 8.4
T4	04/13/2021(25)	05/05/2022	5.77 ± 0.08	9.79 ± 0.13	07/05/2021	11.3	5.5 + 8.7
T6	05/17/2021(31)	05/17/2022	2.65 ± 0.07	7.13 ± 0.09	07/17/2021	11.5	0.7 + 8.7
T8	06/27/2021(37)	06/27/2021	2.86 ± 0.06	6.29 ± 0.07	08/13/2021	11.9	0 + 6.7
T10	07/30/2021 (39)	07/30/2021	2.71 ± 0.06	6.13 ± 0.07	09/06/2021	12.5	0 + 5.2

The PnIT was calculated from February 15 (first planting date) to May 4 under the environmental conditions of the experimental site, whereas the PIT was calculated from May 5 to September 2.

For the Blue B. variety, plants of T1 treatment were 9.7 weeks under PnIT. The PIT began when 50% of the plants had 9.2 ± 0.07 leaves (Table 2). These plants emitted the flag leaf after 11.7 weeks under PIT; at that time, plants had 15.02 ± 0.12 leaves and the photoperiod was of 11.6 hours (Table 2). For T3 and T5 treatments, the PnIT was shorter than for T1, although the plants emitted the flag leaf under the same photoperiod (11.6 hours) and had 12.46 ± 0.1 and 9.91 ± 0.1 leaves, respectively (Table 2), whereas the plants in T7 and T9 treatments did not undergo a PnIT due to the date of planting. Plants in T7 emitted the flag leaf when the PIT reached 9.8 weeks; they had 7.57 ± 0.06 leaves and the photoperiod was 12.1 hours (Table 2). Plants of T9 were only under 6.3 weeks of PIT and emitted the flag leaf when they had 6.85 ± 0.07 leaves under a photoperiod of 12.4 hours (Table 2).

For the Yvonne variety, plants of T2 treatment were 8.1 weeks under PnIT before the beginning of the PIT, which lasted 8.4 weeks. These plants emitted the flag leaf under a photoperiod of 11.3 hours and presented 12.30 ± 0.13 leaves. The plants in the T4 treatment emitted the flag leaf under the same photoperiod as plants in T2, but the latter presented 9.79 ± 0.13 leaves (Table 2). In the T6 treatment, the PnIT lasted 0.7 weeks, whereas in T8 and T10 treatments, it was null due to the dates of planting (Table 2). Plants in T6 were 8.7 weeks under PIT, similarly to plants in T4. However, in T6, the flag leaf appeared 12 days later compared to T4 (Table 2). Plants in T8 treatment were 6.7 weeks under PIT; they had 6.29 ± 0.07 leaves and emitted the flag leaf under a photoperiod of 11.9 hours, whereas plants in T10 treatment were 5.2 weeks under PIT and emitted the flag leaf when they had 6.13 ± 0.07 leaves under a photoperiod of 12.5 hours.

Discussion

The occurrence and duration of the phenological phases were significantly affected by both the date of planting and the variety of Freesia planted. The delay of the planting date produced a shortening of the crop cycle in both varieties, mainly associated with the shortening of the vegetative phase. These results could indicate that the total length of the Freesia crop cycle would be influenced by the length of the vegetative phase.

Unlike the vegetative phase, the duration of the reproductive phase and senescence did not vary with the planting dates. In the reproductive phase, there was only a 10-day difference between planting in February and June, as observed by Schwab et al. (2018) in gladiolus cultivation in the field.

The selected planting dates generated differences in thermal conditions during plant development. Therefore, for both Freesia varieties, early plantations grew for 9 weeks at non-inductive temperatures and produced a greater number of leaves compared to plantations grown at late planting dates. Our results agree with records reported by Berghoef and Zevenbergen (1990), who stated that if Freesia is grown at temperatures higher than 16 °C, the transition to the reproductive phase is delayed, and the shoot apical meristem continues to produce leaves. A similar behaviour was observed in gladiolus and watsonia, in which the delay in the transition to the reproductive phase caused by warmer temperatures resulted in a higher number of leaves (Kumar et al., 2017; Fatihullah and Bostan, 2018; Tirkey et al., 2019).

The results showed that the transition to the reproductive phase was influenced by the interaction between temperature, photoperiod, plant age and variety, as previously reported (Heide, 1965; Gilbertson-Ferriss, 2018). It was observed that the transition to the reproductive phase accelerated as light hours increased, with a lower requirement of weeks at inductive temperatures being recorded. Similar behavior was reported in watsonia by Thompson et al. (2011). However, Wang (2007) and Thakur et al. (2019) considered temperature to be the most important environmental variable, but they conducted the trial at different latitudes, with a different photoperiod regime and used other varieties.

On the earliest planting dates (2/15, 3/19, and 4/16), both varieties switched to the reproductive phase on the same date. The plants of the treatments corresponding to those planting dates met and exceeded the PIT and age requirements proposed by Heide (1965), Wang (2007) and Gilbertson-Ferriss (2018), but did not flower until a determined photoperiod was reached (11.3 hours for Yvonne and 11.6 hours for Blue B). On the subsequent planting dates, as the photoperiod increased, the PIT shortened and the number of leaves before the appearance of the flag leaf was reduced in both varieties.

In Freesia, the different requirements for photoperiod are related to the genetic background of the hybrids (Heide, 1965). Indeed, in the present study, Yvonne and Blue B., whose genetic backgrounds are different, were found to require different photoperiods for flowering. These results disagree with those of Gilbertson-Ferriss (2018), who did not observe differences between hybrids of different colours under long and short photoperiods.

In plants there are strong interactions between different exogenous and endogenous variables that determine the transition to the reproductive phase, where each variable can change its threshold value, thus favoring flowering under favorable environmental conditions (Bernier and Périlleux, 2005; Uhlmann et al., 2020). Likewise, plants capture environmental information and regulate the moment at which the development process is triggered. Overall, in the current study, the different environmental scenarios generated by the planting dates caused variation in the transition to the reproductive phase in the two varieties of Freesia evaluated.

Conclusions

The different scenarios of temperature and photoperiod, generated by the five planting dates evaluated in this study affected the occurrence and duration of the phenological stages and the Freesia crop cycle in Tucumán, Argentina. For both varieties, the first planting dates produced plants with longer vegetative and reproductive phase.

Author Contribution

MVS: design and execution of the experiment, data collection, statistical analysis of the data, writing and drafting the paper. **SSBN:** provision of the plant material used, collaboration in data collection, collaboration in drafting the paper, editing the paper for publication. **NNM:** provision of the plant material used, revision of the paper.

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