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ARTICLE

Artificial vernalization and GA_3 on the phenology and productivity components of statice 'Pastel Shade' in a semi-arid tropical climate

Vernalização artificial e GA_3 sobre a fenologia e componentes de produtividade da statice 'Pastel Shade' em clima tropical semiárido

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Abstract
Statice (*Limonium sinuatum* (L.) Mill.) has potential to diversify floriculture production in the Sub-middle São Francisco Valley, Brazil. However, prolonged low temperature requirements for floral induction may limit cultivation under tropical semi-arid conditions. This study aimed to evaluate the effects of artificial vernalization and gibberellic acid (GA_3) concentrations applied at different times on floral induction, phenology, and productivity components of statice 'Pastel Shade' cultivated under tropical semi-arid conditions. The experiment followed a randomized block design, with artificial vernalization (10 °C for three weeks) and single or sequential foliar applications of GA_3 (250, 500, and 1000 mg L^{-1}) at 2 or 2 and 30 days after transplanting (DAT), respectively. Flowering occurred only in treated plants, whereas no floral stem emission was observed in the control treatment. Sequential applications of 250 mg L^{-1} GA_3 at 2 and 30 DAT resulted in the highest observed flowering percentage (31.3%, 5 of 16 surviving plants). Artificial vernalization resulted in floral stem emergence at 20 DAT; but only one of 14 surviving plants flowered (7.1%). Productivity was low across treatments, reaching a maximum of 2.5 floral stems m^{-2} with a single application of 250 mg L^{-1} GA_3. High temperatures may have contributed to the limited reproductive response. Although floral stem production occurred under tropical semi-arid conditions, the low flowering percentages and productivity indicate that further studies are needed before recommending these strategies for commercial cultivation.
Keywords: *Limonium sinuatum*, floral induction, multiple floral stems, cut flower, Sub-Middle São Francisco Valley.

Resumo
A statice (*Limonium sinuatum* (L.) Mill.) apresenta potencial para diversificar a produção de flores no Vale do Submédio São Francisco, Brasil. Entretanto, a exigência de baixas temperaturas prolongadas para a indução floral pode limitar seu cultivo em condições tropicais semiáridas. Este estudo teve como objetivo avaliar os efeitos da vernalização artificial e de diferentes concentrações de ácido giberélico (GA_3), aplicadas em diferentes momentos, sobre a indução floral, a fenologia e os componentes de produtividade da statice 'Pastel Shade', cultivada em condições tropicais semiáridas. O experimento foi conduzido em delineamento em blocos casualizados, com vernalização artificial (10 °C durante três semanas) e aplicações foliares únicas ou sequenciais de GA_3 (250, 500 e 1.000 mg L^{-1}), realizadas aos 2 ou aos 2 e 30 dias após o transplantio (DAT), respectivamente. O florescimento ocorreu apenas nas plantas submetidas aos tratamentos, enquanto nenhuma emissão de haste floral foi observada no tratamento controle. As aplicações sequenciais de 250 mg L^{-1} de GA_3 aos 2 e 30 DAT resultaram no maior percentual observado de plantas com florescimento (31,3%; 5 de 16 plantas sobreviventes). A vernalização artificial resultou na emissão de haste floral aos 20 DAT; entretanto, apenas uma das 14 plantas sobreviventes floresceu (7,1%). A produtividade foi baixa em todos os tratamentos, atingindo o máximo de 2,5 hastes florais m^{-2} com uma única aplicação de 250 mg L^{-1} de GA_3. As altas temperaturas podem ter contribuído para a limitada resposta reprodutiva. Embora tenha ocorrido produção de hastes florais em condições tropicais semiáridas, os baixos percentuais de florescimento e a reduzida produtividade indicam a necessidade de estudos adicionais antes de recomendar essas estratégias para o cultivo comercial.
Palavras-chave: *Limonium sinuatum*, Indução floral, Hastes florais múltiplas, Flor de corte, Vale do Submédio São Francisco.

Introduction

Floriculture is considered one of the most profitable segments of Brazilian agribusiness and has attracted many investors. It is a sector with a strong presence of family farming and has been expanding in the country (Reis et al., 2020). In 2024, the flower and ornamental plant sector generated R$ 21.23 billion, representing a 9.9% increase compared to 2023, with floriculture accounting for a significant share of the national ornamental market (Ibraflor and Cepea, 2025).

In the Sub-middle São Francisco Valley (SFV), characterized by a hot semi-arid climate (Alvares et al., 2013), cut flower production presents great potential, evidenced by the presence of a commercial *Protea* spp. grower and by studies developed by the Plantas Ornamentais no Vale do São Francisco (POVASF) research group, which also corresponds to the PhenoGlad VSF team, involving ornamental species such as torch ginger (Furtado et al., 2023), gladiolus (Nascimento et al., 2024), heliconias (Souza et al., 2024), and cut sunflower (Tomiozzo et al., 2025).

In this scenario, the "Flowers for All Project" stands out as the largest floriculture extension project in Brazil, coordinated by PhenoGlad teams across different Brazilian states (Uhlmann et al., 2019; Streck and Uhlmann, 2021). Through research and extension activities, the PhenoGlad teams seek to develop solutions for the sustainable intensification of cut flower production, focusing on the demands of small rural properties and promoting sustainable floriculture for future generations, contributing to keeping families in rural areas (Alves et al., 2025).

Among the crops promoted by the PhenoGlad team is statice (*Limonium sinuatum* (L.) Mill.), a species widely cultivated in southern Brazil due to its rusticity, ease of management, low establishment cost, and high postharvest durability (Whipker and Hammer, 1994; Ciotta and

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Nunes, 2011; Buffon et al., 2022; Tomiozzo et al., 2022). However, its cultivation has not yet been explored under the edaphoclimatic conditions of the SFV, requiring studies to enable its adaptation and commercial viability in the region.

Floral induction in this species is accelerated under long-day conditions (≥14 h), although flowering may also occur under short days following prior vernalization. Therefore, the crop is classified as a facultative long-day plant (FLDP), presenting photoperiodic plasticity (Semeniuk and Krizek, 1972; Shillo, 1976; Shillo and Zamski, 1985). In the SFV, the annual photoperiod ranges from 12.3 to 13.4 h, remaining close to the critical limit for floral induction in statice plants (Tomiozzo et al., 2022). However, floral induction also depends on prolonged exposure to low temperatures, ideally between 11 and 13 °C (Semeniuk and Krizek, 1973; Shillo, 1976), which occur rarely and for short periods in the region (Alvares et al., 2013). This thermal characteristic may limit commercial production because it compromises the transition from the vegetative to the reproductive meristem and consequently reduces floral stem production. This interaction suggests that floral signaling integrates thermosensitive and photoreceptor pathways, although the mechanisms involved are still not fully understood (Semeniuk and Krizek, 1972; Shillo, 1976; Shillo and Zamski, 1985).

Exogenous application of gibberellic acid (GA_3) can partially or completely substitute for the vernalization requirement (0-10 °C) in some species, such as *Oenothera biennis* L., promoting earlier flowering and floral development (Zhang et al., 2026). In *Limonium sinuatum*, exogenous application of GA_3 at concentrations ranging from 400 to 500 ppm was able to partially or completely replace the vernalization requirement, while also promoting earlier flowering and increasing productivity (Wilfret and Green, 1975; Wilfret and Raulston, 1975).

In this context, to better understand crop development and establish commercial production in the region, artificial vernalization (Buffon et al., 2021) and the use of plant growth regulators such as gibberellic acid (GA_3) (Wilfret and Green, 1975; Wilfret and Raulston, 1975) emerge as promising management strategies to induce flowering and enable statice cultivation under tropical semi-arid conditions.

Therefore, this study aimed to evaluate the effects of different gibberellic acid (GA_3) doses applied at different times after transplanting, as well as artificial vernalization, on floral induction, development, and yield components of *Limonium sinuatum* 'Pastel Shade' cultivated under tropical semi-arid conditions.

Material and Methods

The experiment was conducted under field conditions in the municipality of Petrolina, Pernambuco State, Brazil (09°21′ S, 40°34′ W), from January 23 to August 31, 2025. According to the Köppen climate classification, the region is classified as BSh, characterized as hot semi-arid (Alvares et al., 2013). Throughout the experimental period, the data on temperature, average air humidity and global solar radiation were obtained from the Davis Automatic Weather Station, model Vantage PRO 2, with temperature (± 0.5%) and air humidity (± 35%) sensors, located 1.6 km from the growing area (Fig. 1).

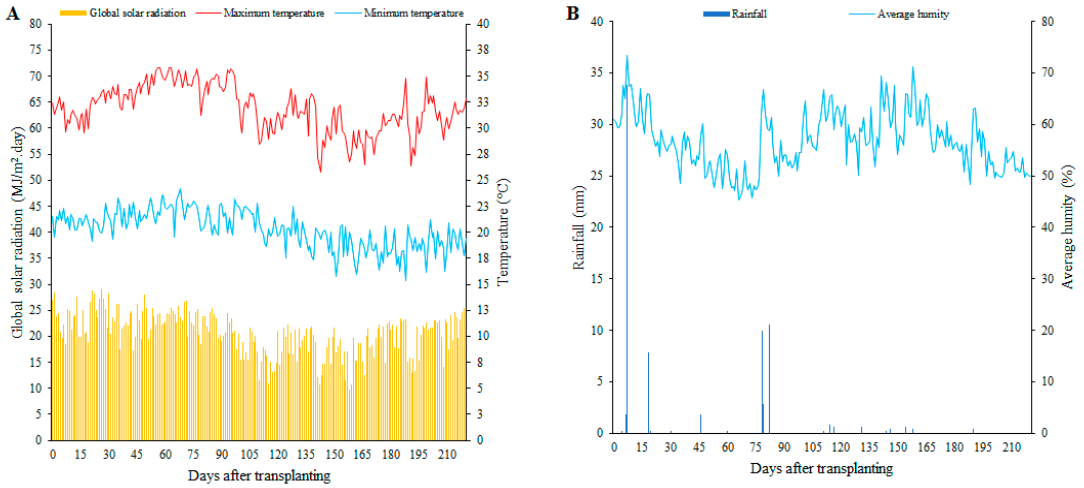

Fig. 1. Climate data, between January 23 and August 31, 2025, corresponding to 0 to 220 days after transplantation. A) Daily global solar radiation (maximum) and daily maximum and minimum temperature. B) Daily rainfall and average humidity.

Days before transplanting, soil samples were collected for fertility analysis, followed by plowing and bed preparation using a tractor. Fertilization recommendations were based on Tomiozzo et al. (2022). Organic fertilization and mulching were applied before transplanting, whereas inorganic fertilization was supplied via fertigation after transplanting. Irrigation was performed using a localized drip system, with one dripper per plant positioned along the planting row. Weed control was performed weekly.

The experiment was conducted according to the recommendations proposed by Tomiozzo et al. (2022). A randomized block design was adopted, consisting of eight floral induction treatments and four replications, totaling 32 experimental units. Each experimental unit consisted of four evaluated plants and four border plants. The treatments consisted of different floral induction strategies (Table 1).

Table 1. Detailed description of the treatments applied.

Treatments	Description
T1-Control	Single foliar application of distilled water containing 0.1% Tween, performed at 2 days after transplanting (DAT), without artificial vernalization or GA_3 application.
T2-AV	Artificial vernalization performed in a B.O.D. chamber at 10 °C (± 2 °C), under a 10-hour photoperiod, for three weeks, according to Buffon et al. (2021).
T3-GA250$_{2DAT}$	Single foliar applications of GA_3 at 250 mg L^{-1}, prepared in distilled water containing 0.1% Tween, performed at 2 DAT.
T4-GA250$_{2\text{-}30DAT}$	Two foliar applications of GA_3 at 250 mg L^{-1}, prepared in distilled water containing 0.1% Tween, performed at 2 and 30 DAT, using the same concentration in both applications.
T5-GA500$_{2DAT}$	Single foliar applications of GA_3 at 500 mg L^{-1}, prepared in distilled water containing 0.1% Tween, performed at 2 DAT.
T6-GA500$_{2\text{-}30DAT}$	Two foliar applications of GA_3 at 500 mg L^{-1}, prepared in distilled water containing 0.1% Tween, performed at 2 and 30 DAT, using the same concentration in both applications.
T7-GA1000$_{2DAT}$	Single foliar applications of GA_3 at 1000 mg L^{-1}, prepared in distilled water containing 0.1% Tween, performed at 2 DAT.
T8-GA1000$_{2\text{-}30DAT}$	Two foliar applications of GA_3 at 1000 mg L^{-1}, prepared in distilled water containing 0.1% Tween, performed at 2 and 30 DAT, using the same concentration in both applications.

DAT = days after transplanting.

For the exogenous application of GA_3, solutions of the plant growth regulator were prepared at concentrations of 250, 500, and 1,000 mg L^{-1} (Table 1). Analytical-grade gibberellic acid (GA_3; CAS No. 77-06-5; Êxodo Científica) was used as the active ingredient. Initially, the GA_3 was dissolved in 3 mL of 96% ethyl alcohol, and the volume was then made up to 250 mL with distilled water previously prepared with 0.1% Tween surfactant.

Statice 'Pastel Shade' seedlings (Takii Seed®) were produced in 128-cell plastic trays (19 cm^3 per cell) filled with Tropstrato HA Hortaliças substrate. One seed was sown per cell at a depth of 1 cm. After sowing, the trays were irrigated, covered with aluminum foil, and maintained in a ventilated shed protected from direct sunlight until seedling emergence. Sowing was performed on November 18, 2024, and seedling emergence occurred three days later (November 21, 2024), with a mean emergence percentage of 81.0% and an emergence speed index (ESI) of 214.2.

After emergence, seedlings were transferred to a shaded environment with 50% light reduction and maintained until plants reached the stage of five true leaves (V5). At this stage, part of the seedlings was transferred to the laboratory for application of treatment T2-AV (Table 1), where they remained for 21 days. Seedlings assigned to the other treatments remained under shaded conditions. After completion of the T2-AV treatment, seedlings were acclimatized in a shed for 24 h under indirect sunlight exposure. Subsequently, they were returned to the shaded environment, where all seedlings remained until reaching the V12 stage (12 true leaves), when transplanting was performed on January 23, 2025. This stage falls within the recommended range proposed by Tomiozzo et al. (2022), who recommend transplanting statice plants between 8 and 12 true leaves.

At this stage, seedlings were transplanted into four raised beds at a spacing of 0.30 m between plants and 0.50 m between rows. Early in the morning, except for treatment T2-AV, all remaining treatments received foliar spraying applications according to Table 1. During the first GA_3 application at 2 DAT, approximately 1.35 (±0.1) mL $plant^{-1}$ was sprayed, whereas during the second application at 30 DAT, approximately 2.70 (±0.4) mL $plant^{-1}$ was applied.

The evaluated variables after transplanting included the percentage of plants with the first visible floral stem (FVFS) and the periods between transplanting (TP) and the phenological stages R1.1 (first visible floral stem), R5.1 (90% of the flowers open on the first flower stem), and R9 (complete plant senescence), according to the phenological scale proposed by Buffon et al. (2022). From these evaluations, the intervals TP-R1.1, R1.1-R5.1, and TP-R9 were determined. In addition, the number of green leaves per plant (NL) was evaluated weekly.

It is important to note that each experimental unit initially consisted of four plants, totaling 16 plants per treatment. However, plant losses occurred in some replicates due to mortality after transplanting (Table 2). Therefore, the percentage of plants with the first visible floral stem (FVFS) was calculated using the following formula:

$$FVFS = \frac{number\ of\ plants\ with\ the\ first\ visible\ floral\ stem}{number\ of\ surviving\ plants} \times 100$$

The following variables were also evaluated: number of floral stems produced per plant, estimated productivity per area (stems m^{-2}), floral stem length (SL, cm), measured from the stem base to the inflorescence apex, and floral stem diameter (SD, mm), measured at 1 cm above the cutting point. Additionally, the number of branches (NB) was determined and classified as primary branches, emitted from the main stem, and secondary branches, emitted from primary branches, as well as the number of corymbs per floral stem (NC).

The data for the percentage of plants with the first visible floral stem (FVFS) and the number of leaves (NL) were subjected to tests for residual normality using the Shapiro–Wilk test and for homogeneity of variances using Bartlett's test, both at the 5% probability level. The FVFS data did not meet the assumption of normality and were therefore analyzed using descriptive statistics. Analysis of variance (ANOVA) was performed only for NL data using the F-test to evaluate treatment effects at a 5% significance level.

For the remaining variables, the number of observations was insufficient to ensure adequate statistical robustness due to plant mortality after transplanting. Therefore, these variables were analyzed using descriptive statistics. Means and standard deviations were calculated based on the total number of floral stems produced by the surviving plants in each treatment throughout the production cycle (Tables 2 and 4). Thus, the results for these variables were presented using descriptive statistics, including means and standard deviations, when applicable. Statistical analyses for NL and FVFS were performed using R software, version 4.5.0 (R Core Team, 2025), and figures were prepared using Microsoft Excel 2016 (Microsoft Corporation, 2016).

Results and Discussion

The results demonstrated that floral induction strategies (artificial vernalization and GA_3 application) enabled the emergence of the first visible floral stem (FVFS) in plants transplanted during the cultivation period (Table 2; Fig. 2), characterized by temperatures ranging from 15.3 °C (night) to 35.8 °C (day) (Fig. 1A). However, FVFS percentages were limited in all treatments, except for the control treatment (T1-Control), which did not show flowering. The highest proportion was observed in T4-GA250$_{2\text{-}30DAT}$, in which 5 of 16 surviving plants (31.3%) exhibited FVFS, suggesting that the combination of successive GA_3 applications (250 mg L^{-1} at 2 and 30 DAT) partially mimicked the effect of vernalization (Table 2; Fig. 2).

Table 2. Number of surviving plants and plants with the first visible flower stem from each floral induction treatment.

Number of surviving plants and plants with the first visible flower stem										
Treatment	R1		R2		R3		R4		Total per treatment	
	SP	PF	SP	PF	SP	PF	SP	PF	SP	PF
T1-Control	4	0	4	0	2	0	4	0	14	0
T2-AV	3	0	4	0	4	1	3	0	14	1
$T3\text{-}GA250_{2DAT}$	4	0	4	1	4	2	4	0	16	3
$T4\text{-}GA250_{2\text{-}30DAT}$	4	0	4	1	4	1	4	4	16	5
$T5\text{-}GA500_{2DAT}$	3	0	4	0	4	2	4	0	15	2
$T6\text{-}GA500_{2\text{-}30DAT}$	4	1	4	1	3	1	3	1	14	4
$T7\text{-}GA1000_{2DAT}$	3	2	3	0	4	0	4	0	14	2
$T8\text{-}GA1000_{2\text{-}30DAT}$	4	0	3	0	4	0	4	2	15	2

R1 = is the first replication of the experiment; R2 = is the second replication; R3 = is the third replication; R4 = is the fourth replication; SP = surviving plants; PF = plants with the first visible flower stem.

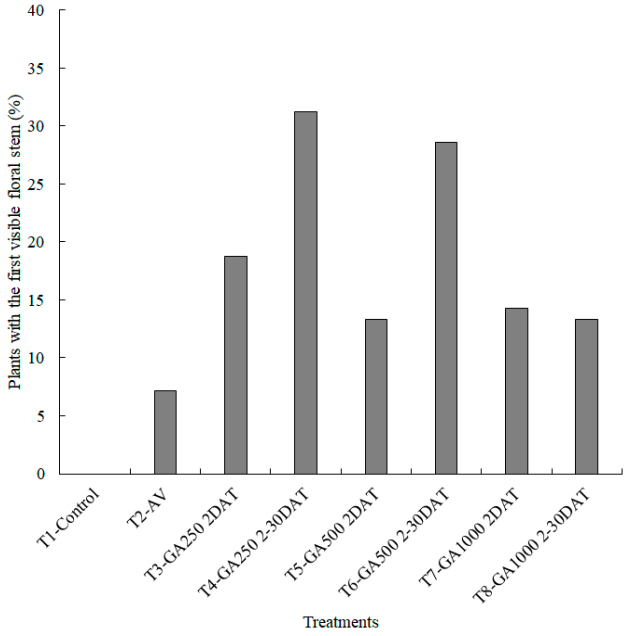

Fig. 2. Percentage of plants with the first visible floral stem (FVFS) in statice subjected to artificial vernalization and different GA_3 application strategies under tropical semi-arid conditions.

This result corroborates previous studies in *L. sinuatum*, in which GA_3 only partially replaced vernalization, even at higher concentrations (400-500 ppm) (Wilfret and Green, 1975; Wilfret and Raulston, 1975). The low floral induction rate observed (31.3%) indicates that thermal conditions during cultivation (Fig. 1A), especially between 0 and 111 DAT, when minimum temperatures frequently remained above 20 °C, did not fully satisfy the physiological requirements of 'Pastel Shade', since effective vernalization requires exposure to 11-13 °C for three weeks (Semeniuk and Krizek, 1973; Shillo, 1976). Therefore, although GA_3 attenuated thermal limitation, complete replacement of vernalization was not achieved under SFV conditions.

It was expected that treatment T2-AV (Table 2; Fig. 2), a strategy previously successful in other regions, would show higher FVFS values. However, among treatments subjected to floral induction, it presented the lowest percentage of plants with FVFS (7.1%). This result contrasts with Buffon et al. (2021), who observed 80% FVFS in *Limonium sinuatum* cv. 'QIS Yellow' subjected to artificial vernalization at 10 °C for three weeks in southern Brazil. In that study, even non-vernalized plants reached 30% FVFS, a percentage higher than that observed in the present experiment for 'Pastel Shade'. This difference suggests genotypic variability in thermal requirements among cultivars, corroborating findings by Shillo and Zamski (1985) and Tomiozzo et al. (2022), who reported higher cold requirements in purple-flowered cultivars compared to yellow-flowered cultivars.

The hypothesis of devernalization may explain the obtained results, since temperatures above 25 °C may reverse the effects of cold exposure in *L. sinuatum*, compromising the transition from vegetative to reproductive meristems (Shillo and Zamski, 1985). In the present experiment, maximum temperatures reached 35.8 °C during cultivation (Fig. 1A), which may have compromised vernalization even in treatment T2-AV (Table 2; Fig. 2). Additionally, blue- and purple-flowered cultivars show greater sensitivity to thermal inhibition of flowering compared to yellow- and white-flowered cultivars (Semeniuk and Krizek, 1973; Tomiozzo et al., 2022), reinforcing the possibility that 'Pastel Shade' may present intermediate thermal requirements that were not fully satisfied under SFV conditions.

Commercial breeding programs for statice have historically prioritized ornamental traits such as flower color rather than standardized physiological attributes (Wilfret and Raulston, 1975). This uncontrolled genetic variability complicates the extrapolation of management protocols among cultivars and regions, reinforcing the need for local validation of GA_3 doses and application timing, which was one of the main objectives of this study.

The period between transplanting and emergence of the first visible floral stem (TP-R1.1) was 20 days in treatment T2-AV (artificial vernalization), whereas in the remaining treatments, the observed intervals ranged from 62 days ($T5\text{-}GA500_{2DAT}$) to 156 days ($T8\text{-}GA1000_{2\text{-}30DAT}$) (Fig. 3A and 3B). However, in T2-AV, only one of the 14 surviving plants (7.1%) produced a visible floral stem during the experimental period (Table 2; Fig. 2). Thus, the 20-day TP-R1.1 value represents the observation for a single flowering plant and was analyzed descriptively. Therefore, this result should not be

interpreted as evidence of an earlier flowering response at the population level. Nevertheless, the occurrence of floral stem emergence 20 days after transplanting provides an indication of a potential response to artificial vernalization.

This observation is consistent with Shillo (1976), who reported a response to vernalization at 13 °C in statice seedlings, although the low proportion of flowering plants observed in the present study limits the strength of this comparison. In contrast, Buffon et al. (2022) reported TP-R1.1 intervals ranging from 153 to 158 days in cultivars grown in southern Brazil under autumn–winter transplanting conditions. Further studies with a higher proportion of flowering plants and individual-level observations are needed to determine whether artificial vernalization consistently accelerates floral initiation in *L. sinuatum* 'Pastel Shade'.

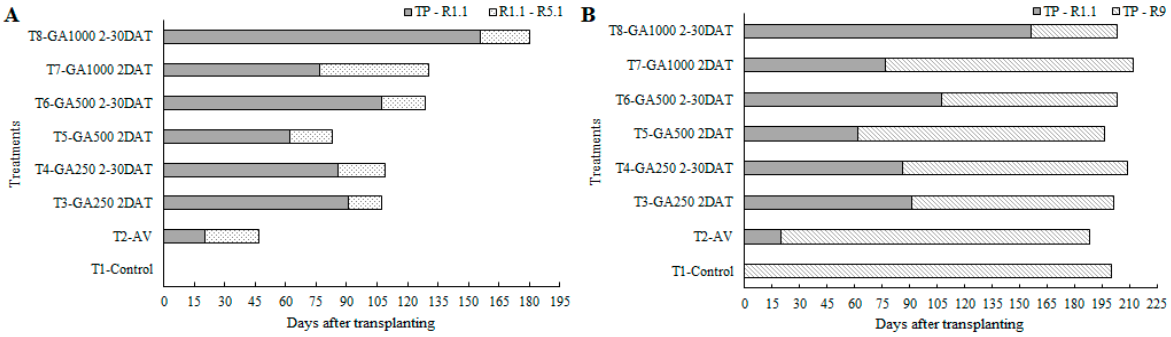

Fig. 3. Duration of phenological periods in statice subjected to artificial vernalization and different GA_3 application strategies under tropical semi-arid conditions. Period between transplanting and first visible floral stem (TP-R1.1) (A and B), first visible floral stem and 90% flower opening (R1.1-R5.1) (A), and transplanting to complete senescence (TP-R9) (B).

The interval between stage R1.1 and the stage corresponding to 90% flower opening on the first floral stem (R5.1) ranged from 16.0 days (T3-$GA250_{2DAT}$) to 53.5 days (T7-$GA1000_{2DAT}$) (Fig. 3A). Regarding the total crop cycle, measured from transplanting to complete plant senescence (TP-R9), values ranged from 188.5 days in treatment T2-AV to 212.0 days in T7-$GA1000_{2DAT}$ (Fig. 3B). These results indicate that floral induction strategies did not consistently affect the total crop cycle duration.

The dynamics of leaf emission and senescence followed the expected pattern for indeterminate growth species, characterized by a progressive increase up to approximately 126 DAT (mean of 137.7 leaves $plant^{-1}$), followed by a decline until complete senescence (Table 3; Fig. 4). This behavior was consistent among treatments, indicating that temperature, cultivation season, and genetic characteristics (Buffon et al., 2022; Tomiozzo et al., 2022) exerted greater influence on leaf phenology, whereas floral induction treatments acted specifically on reproductive transition without significantly affecting vegetative dynamics.

Table 3. Number of green leaves per statice plant between 28 and 168 days after transplanting as affected by different floral induction treatments.

Treatment	Number of green leaves $plant^{-1}$					
	28 DAT	56 DAT	84 DAT	112 DAT	140 DAT	168 DAT
T1-Control	15.0	43.9	87.0	127.6	114.4	39.4
T2-AV	15.4	38.4	70.6	123.2	96.2	53.8
T3-$GA250_{2DAT}$	16.7	41.0	90.9	116.2	135.9	86.6
T4-$GA250_{2-30DAT}$	16.1	38.6	70.6	115.2	117.5	83.6
T5-$GA500_{2DAT}$	15.3	35.9	83.5	123.5	122.4	30.3
T6-$GA500_{2-30DAT}$	16.3	33.8	63.3	105.9	122.7	80.0
T7-$GA1000_{2DAT}$	13.7	36.1	67.8	87.6	116.1	73.0
T8-$GA1000_{2-30DAT}$	15.3	37.2	93.1	130.1	149.1	86.9
Treatment	0.9699 ns	0.9714 ns	0.7296 ns	0.8264 ns	0.5803 ns	0.3664 ns
CV (%)	24.37	16.76	37.30	33.99	28.27	62.67

DAT = days after transplanting. CV = coefficient of variation. Values are reported as mean, ns, and * indicate non-significant F-test and significant at $p < 0.05$.

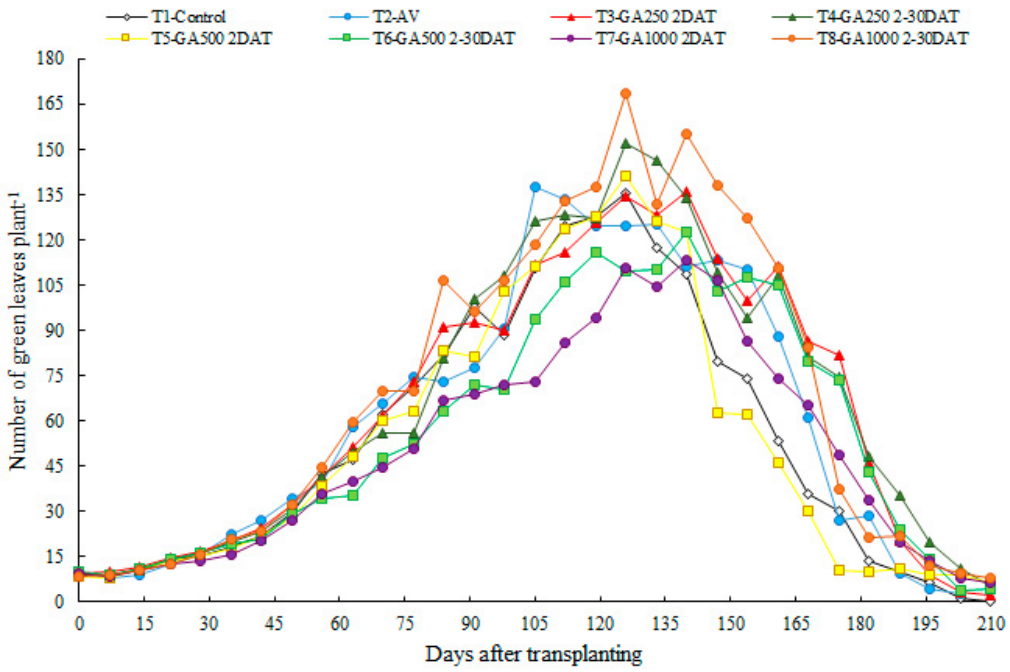

Fig. 4. Number of green leaves per statice plant between 0 and 210 days after transplanting as affected by different floral induction treatments.

Plant productivity was extremely low in all treatments. Treatment T3-$GA250_{2DAT}$ presented the highest production, with 0.4 floral stems $plant^{-1}$, corresponding to 2.5 floral stems m^{-2}, whereas the control treatment (T1-Control) did not produce floral stems (Tables 4 and 5). These results confirm that thermal conditions during the transplanting period were insufficient to induce flowering at commercial levels, even with GA_3 application or artificial vernalization.

Between 0 and 112 DAT, corresponding to the vegetative-reproductive transition period in most treatments, temperatures ranged from 19.1 °C (night) to 35.8 °C (day) (Fig. 1A), values above the ideal range of 22-27 °C (day) and 12-16 °C (night) proposed by Shillo (1976). Specifically, minimum night temperatures remained above the critical threshold of 13-16 °C required for effective vernalization in *L. sinuatum*. This pattern corroborates Tomiozzo et al. (2022), who observed a reduction from 146 to 4 floral stems m^{-2} in cv. 'QIS Purple' when transplanting was performed in December (summer) instead of August (winter) in southern Brazil. Therefore, low productivity was primarily determined by insufficient nighttime cooling, a limitation not fully compensated by the tested exogenous induction strategies.

Floral stem length ranged from 17.6 to 26.0 cm and stem diameter ranged from 2.5 to 5.1 mm among treatments (Fig. 5A-B). The number of branches ranged from 1.0 to 3.2, whereas the number of corymbs ranged from 1.0 to 5.5 among the evaluated treatments (Fig. 5C-D).

Table 4. Total number and number per replication of statice flower stems harvested throughout the production cycle, subjected to artificial vernalization and different GA_3 application strategies under tropical semi-arid conditions.

Treatment	Number of harvested flower stems				
	R1	R2	R3	R4	Total
T1-Control	0	0	0	0	0
T2-AV	0	0	4	0	4
$T3\text{-}GA250_{2DAT}$	0	3	3	0	6
$T4\text{-}GA250_{2\text{-}30DAT}$	0	0	2	2	4
$T5\text{-}GA500_{2DAT}$	0	0	3	0	3
$T6\text{-}GA500_{2\text{-}30DAT}$	1	1	1	1	4
$T7\text{-}GA1000_{2DAT}$	3	0	0	0	3
$T8\text{-}GA1000_{2\text{-}30DAT}$	0	0	0	1	1

R1 = is the first replication of the experiment; R2 = is the second replication; R3 = is the third replication; R4 = is the fourth replication.

Table 5. Floral stem production per plant and estimated productivity per m^2 in statice subjected to artificial vernalization and different GA_3 application strategies under tropical semi-arid conditions.

Treatment	Productivity	
	Floral stem plant^{-1}	Floral stem m^{-2}
T1-Control	-	-
T2-AV	0.3	1.9
T3-GA250$_{2DAT}$	0.4	2.5
T4-GA250$_{2-30DAT}$	0.3	1.8
T5-GA500$_{2DAT}$	0.2	1.3
T6-GA500$_{2-30DAT}$	0.3	1.9
T7-GA1000$_{2DAT}$	0.2	1.4
T8-GA1000$_{2-30DAT}$	0.1	0.4

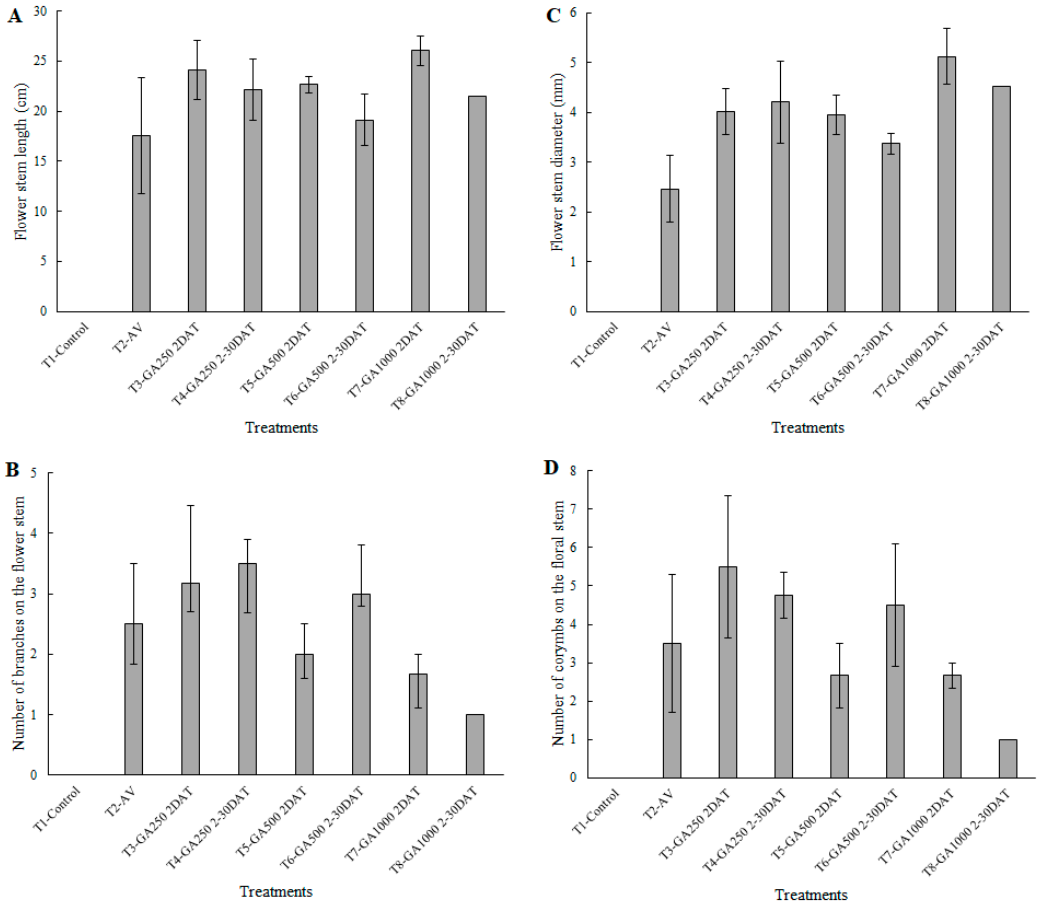

Fig. 5. Characterization of floral stems as affected by different floral induction treatments. Floral stem length (cm) (A). Number of branches on the floral stem (B). Floral stem diameter (mm) (C). Number of corymbs on the floral stem (D).

Overall, floral stem length and diameter presented satisfactory dimensions in relation to the standards proposed by the Flowers for All Project (Tomiozzo et al., 2022). In addition, variation in stem size and in the number of branches and corymbs expands the possibilities for using the flowers in floral arrangements and bouquets of different sizes, according to the desired aesthetic purpose (Fig. 6A-E).

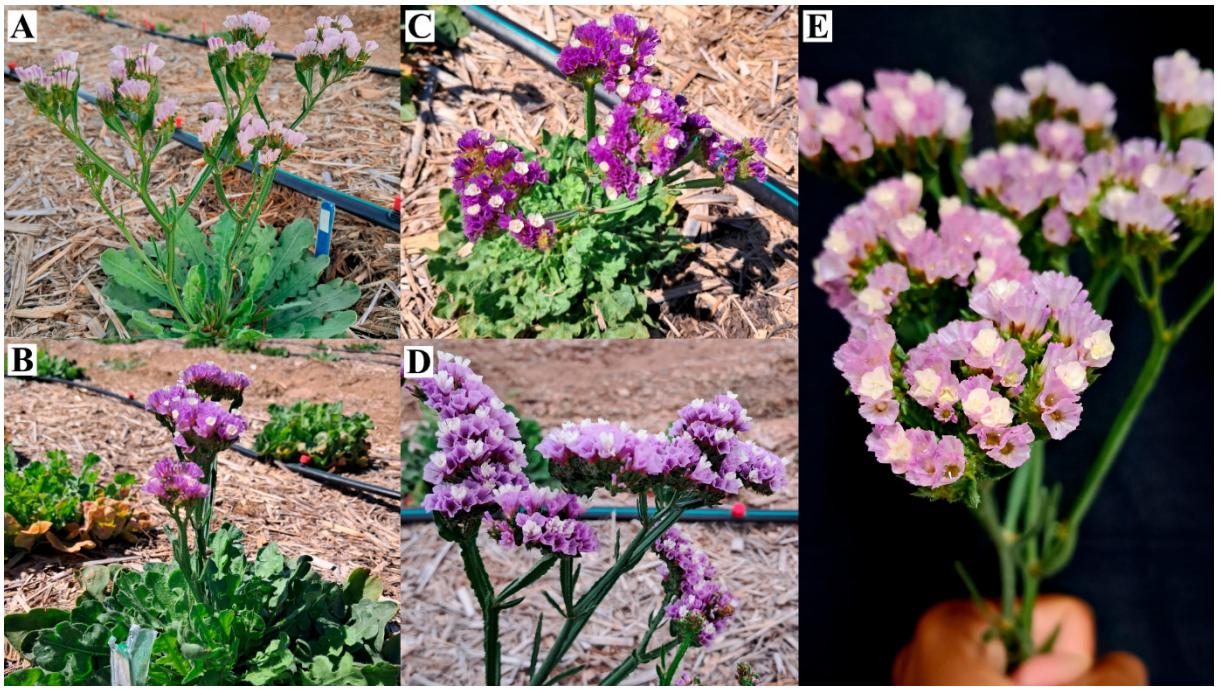

Fig. 6. Statice 'Pastel Shade' plants and flowering stems grown under open-field conditions and subjected to artificial vernalization and GA_3 application treatments, with approximately 50% of the flowers open (A) and at the harvest stage, with 90% of the flowers open (B–D). Harvested flowering stem, highlighting the calyces and corollas of the open flowers (E).

Conclusions

The cultivation of *Limonium sinuatum* 'Pastel Shade' under tropical semi-arid conditions in the São Francisco Sub-middle Valley resulted in floral stem emission in a proportion of plants when artificial vernalization or GA_3 application strategies were used. However, the responses varied among treatments and variables, and the overall reproductive response remained limited.

Artificial vernalization (T2-AV) resulted in floral stem emergence in 1 of 14 surviving plants (7.1%), whereas sequential applications of 250 mg L^{-1} GA_3 at 2 and 30 days after transplanting (T4-$GA250_{2\text{-}30DAT}$) resulted in floral stem emergence in 5 of 16 surviving plants (31.3%). Therefore, these strategies may be considered potential approaches for further investigation of floral induction under the environmental conditions evaluated, but the present results do not provide sufficient evidence to establish either treatment as an effective induction strategy.

Under transplanting conditions during the hot season, flowering remained limited, and the maximum productivity observed was only 2.5 flower stem m^{-2}. The thermal conditions recorded during the experiment, characterized by high daytime temperatures, may have contributed to the low reproductive response. Thus, the results indicate that flowering can occur in some statice plants under the region's semi-arid tropical climate conditions.

These findings provide an initial indication of the possibility of floral stem production under tropical semi-arid conditions and highlight the need for further studies evaluating transplanting periods, cultivars, and alternative or combined floral induction strategies to determine the conditions required for consistent and economically viable production.

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Author Contribution

LGL: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing. **MHBO:** Investigation, Methodology, Data Curation. **AVPS:** Investigation, Methodology, Data Curation. **EAFF:** Investigation, Methodology, Data Curation. **AGPS:** Investigation, Methodology, Data Curation. **LJSD:** Investigation, Methodology, Data Curation. **DKN:** Investigation, Methodology, Data Curation. **LSA:** Investigation, Methodology, Data Curation. **MZBC:** Conceptualization, Supervision, Project Administration, Writing – Original Draft, Writing – Review & Editing. **NAS:** Conceptualization, Supervision.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All the research data is contained in the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process

Statement: During the preparation of this work the author(s) used ChatGPT (OpenAI) to assist with English language revision, grammar correction, and improvement of text clarity and readability. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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