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Scientific Article

Phenology of *Solidago canadensis* L. and *Delphinium elatum* cultivated under greenhouse conditions and association with micro-climate variables

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Abstract

Solidago canadensis L. cv. Tara and *Delphinium elatum*, the hybrid White River are summer flowers with great agronomic potential. The goal of this study was to establish the phenology of these species grown under greenhouse conditions, as well as to determine the correlation between climatic elements (relative humidity - RH, growing degree-days for development - GDD and soil moisture - SM) with growth variables (stem length and diameter, fresh weight FW - and dry weight - DW) in *S. canadensis* and *D. elatum*. The life cycle for *S. canadensis* and *D. elatum* ended when reaching 30% of the flower opening, the stem length reached 118.05 and 123.74 cm, at 94 and 77 days, respectively. The growth of both species showed a logistic curve pattern throughout the crop cycle; *S. canadensis* showed maximum values for absolute growth rate (AGR) and relative growth rate (RGR) at 77 and 42 days after transplanting (DAT), respectively; in contrast to *D. elatum* which occurred at 77 and 28 DAT. On the other hand, for the correlation between climatic elements and growth variables in *S. canadensis*, the GDD and RH were directly correlated with both FW and DW, stem diameter and length, while an inverse correlation occurred for SM. *D. elatum* showed a direct correlation between climatic conditions and growth variables.

Keywords: canadian goldenrod, delphinium, floriculture, summer flowers.

Resumo

Fenologia de *Solidago canadensis* L. e *Delphinium elatum* cultivados em casa de vegetação e associação com variáveis microclimáticas

Solidago canadensis L. Cv. Tara e *Delphinium elatum* híbrido White Rever são flores de verão com grande potencial agronômico. O objetivo foi estabelecer a fenologia destas espécies cultivadas em estufa, assim como determinar o tipo de correlação existente entre os elementos climáticos (umidade relativa - UR, graus-dia de desenvolvimento - GDD e umidade do solo) e as variáveis de crescimento (longitude e diâmetro das hastes, peso fresco e seco). O ciclo de cultivo em *S. canadensis* e *D. elatum*, finalizou quando se tinha 30% de abertura floral, e o comprimento das hastes atingiram 118,05 e 123,74 cm, aos 94 e 77 dias, respectivamente. Ao longo do cultivo o crescimento das espécies estudadas acompanhou um patrão de curva logística, em *S. canadensis* os máximos valores da taxa de crescimento absoluto e a taxa de crescimento relativo foram aos 77 e 42 dias após o transplantio (DAT), respectivamente, sendo que diferença de *D. elatum* aconteceu aos 77 e 28 DAT. Por outro lado, no que se refere à correlação entre os elementos climáticos e as variáveis de crescimento em *S. canadenis,* GDD e UR correlacionaram-se de forma direta com o peso fresco e seco, diâmetro e longitude da haste, em contraste a umidade do solo que teve uma relação inversa. *D. elatum* evidenciou uma relação direta entre as variáveis climáticas e as variáveis de crescimento.

Palavras-chave: delphinium, flores de verão, floricultura, vara de ouro.

Introduction

The cut-flower sector has grown globally in recent years, and still has the potential for further expansion in Ecuador. The main exporters of cut-flowers worldwide are: The Netherlands, Colombia, Ecuador, Kenya and Ethiopia. In Ecuador, cut-flowers represent 7% of non-oil exports, being roses the predominant product with 77%, while summer flowers constitute the remaining 33% of exports, including *Solidago canadensis* and *Delphinium elatum* (Expoflores, 2021).

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Solidago canadensis is a perennial herbaceous plant native to temperate North America; it has been disseminated worldwide as a cut-flower (Qiang et al., 2021). *Delphinium elatum* is a perennial herbaceous plant, which constitutes a good option as commercial cut-flower; most cultivation of this species is covered by hybrid varieties (Dole and Wilkins, 2004).

To provide a favorable growing environment for these two species, in Ecuador, cultivation is carried out under greenhouse (Zhou et al., 2021). That is mostly the reason why it is so essential to study the association between growth patterns and climatic elements. Crop modelling has become an effective means to assess the impact of climate variations on crop yield; additionally, those results have assisted in projecting phenological events. Such projections have successfully informed on the development of adaptation strategies for the crop management (Wang et al., 2018). Being Ecuador, a country located on the equator, a place where climatic conditions are unique compared to temperate climate countries, the environmental conditions during cultivation are determinant for the success or failure of the establishment of a crop, both on the field and in a greenhouse. This study aims to establish the phenology of *S. canadensis* and *D. elatum* cultivated under greenhouse conditions and to determine the correlation between climatic elements and the growth variables for these species.

Materials and Methods

Two independent trials were conducted, from 01/04/2019 to 04/14/2019, for monitoring growth patterns and phenological performance of *Solidago canadensis* L. cv. Tara and *Delphinium elatum* hybrid White River, both cultivated under greenhouse conditions. The *S. canadensis* seedlings were planted at 15 cm between plants and 15 cm between rows in a quincunx arrangement. Artificial light was applied six hours a day since the moment of planting, right after dusk. In order to increase the production of lateral stems, plants were pinched (35 - 40 cm of upper stem) between the fifth and sixth week (Dole and Wilkins, 2004; Yumbla-Orbes et al., 2017). On the other hand, for *D. elatum*, seedlings were arranged at 10 cm between plants and 10 cm between rows, in a rectangular arrangement. Both species, since the beginning of planting had a similar management: protective netting, phytosanitary controls and weeding, according to the crop needs. The fertigation was provided through an automated drip irrigation, three times a day, for 7 minutes. The first irrigation consisted of acidified water with phosphoric acid; for the second and third irrigations, the fertilizers corresponded to potassium nitrate, calcium nitrate, ammonium nitrate, potassium sulfate, magnesium sulfate, monoammonium phosphate and micronutrients. The exact doses could not be reported as those are considered confidential for the flower farm where the research was implemented. Weekly data were recorded for the climatic variables such as maximum, mean, and minimum temperature, relative humidity (RH) and soil moisture (SM) with a Davis Vantage Pro2 sensor, using the Weatherlink program for data collection and storage. Solar radiation was measured with a Kipp and Zonen CM3 global solar radiation pyranometer.

For the identification of phenological stages, observations were made every two days, starting after the first week of establishment until harvest. Phenological identification was performed based on the scale developed by BBCH for weeds (Meier, 2018; Meier et al., 2009), since *S. canadensis* and *D. elatum* are considered as weeds in their respective countries of origin.

For growth monitoring during cultivation, 16 plants were randomly sampled, and their growth was recorded in centimeters (cm) every week until day 91 when length and diameter of the stem was recorded. To determine FW and DW, 16 plants were sampled at 1, 7, 14, 21, 28, 35, 42, 49, 56, 63, 70, 77, 84, 91 and 94 Days After Transplanting (DAT) for *S. canadensis* (Figure 1A-B); for *D. elatum,* 16 plants were sampled at 1, 14, 28, 42, 56, 70 and 77 DAT (Figure 1C-D). For every sampling event, plant parts were separately weighed. The material was then dried in a WSU 100 oven with forced air circulation, at 65 °C, for 96 hours and weighed with a precision scale with a capacity of 2200 g.

For the estimation of absolute growth rate (AGR - g d^{-1}) and relative growth rate (RGR - g g^{-1} d^{-1}), the equations proposed by Brown (1984), were used:

Equation 1:

$$AGR = \frac{DW_2^* - DW_1}{T_2^{**} - T_1}$$

Equation 2:

$$RGR = \frac{\ln DW_2 - DW_1}{T_2 - T_1}$$

* DW_1 and DW_2 - weights 1 and 2
** T_1 and T_2 – time 1 and 2

The equation 3 was used for calculating the growth degree-days for development (GDD - °Cd), using the weekly mean temperature and the base temperature (Bt), which is the minimum temperature for plant development in ornamental species, 7 °C, as recommended by Russelle et al. (1984):

Equation 3:

$$GDD = \left(\frac{T_{max}^* + T_{min}^{**}}{2}\right) - Bt^{***}$$

* T_{max} – maximum temperature
** T_{min} - minimum temperature
***Bt – base temperature (7°C)

For stem length (collected along the plant life cycle) a logistic model was adjusted for its growth, while, for DW of the plant organs and their distribution over time, regression models were adjusted. Those results of significant effect for the F test at 1% and 5% for the probability of biological significance and greater sum of squares (R^2), were selected within the regression equation. To determine the relationship of the independent variables with the dependent variables, the Pearson's correlation was used to resample 6435 samples for *S. canadensis* and 35 samples for *D. elatum*. Statistical analysis was processed using INFOSTAT software (Di Rienzo et al., 2018), and graphs were made with Sigma Plot® software (version 11.0).

Results and Discussion

Development and growth of flower crops under greenhouse conditions

The *Solidago canadensis* crop was grown at temperatures ranging from 7.9 - 32.7 °C, RH of 83%, global solar radiation of 132 W m^{-2}; the radiation from high-pressure sodium lamps was 4 W m^{-2} (between week 1-6). On the other hand, *Delphinium elatum* had a temperature range of 8.3 - 30 °C, RH of 76% and average global solar radiation of 135 W m^{-2} (Table 1).

The geographical location and setting context where the species develop is a conditioning factor for the duration of a phenological stage. A more controlled environment, such a greenhouse will promote uniform phenological progress. For example, for *S. canadensis*, the induction of flowering is more prone to happen at average temperatures ranging from 16 to 22 °C (Went, 1953). For *D. elatum*, natural light was sufficient for plant development which responds best to mean temperatures between 18 to 21 °C (Hanks, 2016). Similarly, Kolar et al. (2017) mention that delphinium germinates very well at temperatures ranging between 23 ºC to 25 ºC during June, July and August when the relative humidity is very high in southern India.

During the 94 days of *S. canadensis* cultivation, five main stages were observed (Table 2A). The evolution from juvenile vegetative to adult vegetative stage required 35 days; whereas from the adult vegetative stage to the transition stage, it took 7 days. From the transition stage to the pre-flowering stage, it took 21 additional days and then, 31 days to reach the flowering stage with a 30% of flower opening. For *D. elatum*, five main stages were observed too (Table 2B); the passage from juvenile vegetative to adult vegetative stage took 40 days, while from adult vegetative to transition stage, it took 2 days. From transition stage to pre-flowering stage, it comprised 6 days, and then 29 additional days were required to reach the flowering stage. It required a total of 77 days to complete the crop cycle.

Table 1. Environmental conditions during the plant life cycle of A) *Solidago canadensis* and B) *Delphinium elatum* grown under greenhouse conditions.

A*) *Solidago canadensis						
Day	**Med t (°C)**	**Max t (°C)**	**Min t (°C)**	**RH (%)**	**SM (cbar)**	**Global solar radiation (W m^{-2})**
1	17.8	26.1	9.5	82.9	16.6	116.1
7	17.5	23.7	11.2	81.7	16.8	109.0
14	19.3	27.7	10.8	76.3	21.5	177.2
21	19.4	28.0	10.8	82.2	24.2	147.6
28	20.6	28.6	12.6	82.6	39.7	141.3
35	19.7	27.3	12.0	83.6	15.9	115.7
42	18.3	26.2	10.4	83.4	17.6	120.8
49	18.6	26.0	11.2	86.1	14.1	128.8
56	19.2	28.2	10.3	84.1	21.2	153.9
63	19.8	28.7	10.9	82.1	13.8	153.6
70	19.1	26.6	11.5	83.2	14.2	132.1
77	19.5	28.4	10.6	84.2	20.0	140.0
84	18.1	24.7	11.5	87.3	17.4	88.3
91	17.9	25.9	9.9	83.7	23.6	113.0
94	19.1	28.0	10.2	80.1	14.8	120.8
B) *Delphinium elatum*						
Day	**Med t (°C)**	**Max t (°C)**	**Min t (°C)**	**RH (%)**	**SM (cbar)**	**Global solar radiation (W m^{-2})**
1	19.2	30.0	8.3	62.0	18.0	127.9
14	18.6	26.5	10.6	77.0	12.5	114.5
28	19.5	28.2	10.8	73.5	12.2	162.4
42	19.9	27.2	12.5	76.7	29.0	124.3
56	18.2	25.5	10.9	82.6	18.9	125.7
70	18.9	27.3	10.6	77.8	46.2	150.9
77	18.2	25.0	11.4	78.9	35.0	134.8

Medium temperature (Med t), maximum temperature (Max t), minimum temperature (Min t), Relative humidity (RH) and soil moisture (SM).

Table 2. BBCH scale for main and secondary stages for A) *Solidago canadensis* and B) *Delphinium elatum* grown under greenhouse conditions.

A) *Solidago canadensis*			
DAT	**Main stage**	**Secondary stage**	**Description**
7	1	11	Leaves: 1 Stem: 3.27 cm.
14	1	12	Leafs: 2
	2	22	Buds or suckers: 2
	3	32	Internodes: 2 Stem: 7.42 cm.
21	1	16	Leafs: 6
	2	24	Buds or suckers: 4
	3	36	Internodes: 6 Stem: 12.46 cm.
28	1	18	Leafs: 8
	2	25	Buds or suckers: 5
	3	38	Internodes: 8 Stem: 22.66 cm
	Thinning by removal of suckers from base		
35	1	19	Leafs: 12
	3	39	Internodes: 12, average length of 2.30 cm Stem: 34.51 cm.
	Removal of apical bud		
DAB	**Main stage**	**Secondary stage**	**Description**
7	2	25	Longitudinal measurements of lateral budding (flower stems of economic interest) were considered. Main stem: 42.48 cm. Side shoots: 5, 0.47 cm.
14			Main stem: 50.50 cm. Side shoots: 5, 3.64 cm
21			Main stem: 51.51 cm. Side shoots: 5, 15.61 cm
28	5	51	Lateral stems: 26.73 cm. Flower organs: Newly emerged panicles and dark green hue.
35	5	55	Lateral stems: 41.23 cm Flower organs: Panicles with closed buds, dark green hue and short secondary rachis. (4mm).
42		59	Lateral stems: 56 cm. Floral organs: Fully developed panicles and 3cm secondary rachis
49			Lateral stems: 68.01 cm.
56			Lateral stems: 71.44 cm. Flower organs: Slight opening, with a greenish-yellow hue on the petals.
59	6	63	Aerial zone of the plant: 118.05 cm. Lateral stems: 71.44 cm. Floral organs: The set of panicles reached 22.21 cm. Enhanced the beginning of flowering with 30% floral opening, petals and stamens of yellow hue (Figure 1).

DAT: Days after transplant

DAB: Days after bud removal

Main stage: 1: Leaf development (main stem); 2: Formation of lateral shoots (suckers); 3: Stem elongation or rosette growth, shoot development (main stem); 5: Emergence of the floral organ (main stem) / emergence of the spikes or panicles (spiking); 6: Flowering (main stem)

Average lengths were used in the description.

B) Delphinum elatum			
DAT	**Main stage**	**Secondary stage**	**Description**
14	1	12	Leaves: 2, petiolate and palmatisect with five lobes.
	3	32	Internodes: 2 Stem: 3.74 cm.
28	1	14	Leaves: 4
	3	34	Internodes: 4 Stems: 10.92 cm.
42	1	19	Leaves: 10
	3	39	Internodes: 10, 2 cm. Stem: 20.65 cm.
	5	51	Floral organ: The floral bud emerged in the apical zone, 0.70 cm.
56	5	53	Stem: 39.05 cm. Floral organ: 4.62 cm. Slight separation of the lower flower buds from the younger leaves.
63	5	55	Stem: 53.98 cm. Floral organ: 15.10 cm The fourth part of the lower area of the bunch with flower buds separated from each other, arranged alternately, unlike the upper area where the buds were still grouped,
70	6	57	Stem: 64.68 cm. Floral organ: 33.84 cm Visibly separated from the upper leaf of the stem, by an average space of 4.70 cm.
77	6	63	Aerial part of the plant: 123.74 cm. Floral organ: 55.63 cm 30% of flower opening. Flowers with a white hue, with two layers of sepals, an inner layer of eight and an outer layer of five sepals. (Fig. 1)

DAT: Days after transplant

Main stage: 1: Leaf development (main stem); 3: Stem elongation or rosette growth, shoot development (main stem); 5: Emergence of the floral organ (main stem) / emergence of the spikes or panicles (spiking); 6: Flowering (main stem)

Average lengths were used in the description.

Kervatkar et al. (2021) and Yumbla-Orbes et al. (2017) verified that *S. canadensis* plants grown under greenhouse conditions, lasted between 35 to 41 days for the onset of panicle formation, while the maximum rate for onset of floral opening, was between 78 and 90 days. The removal of apical bud delays the days for appearance of each phenological stage and it is attributable to the initiation of vegetative phase after the break of apical dominance. Similar results with pinching effect have been reported by Mehta et al. (2015) and Rathore et al. (2018), in *Brassica oleracea* var. Italica L. and *Tagetes minuta*, respectively. For *D. elatum*, Hanks (2016) reported that greenhouse cultivation requires between 125 to 160 days to move from the vegetative to the reproductive stage, concluding that environmental context determines growth patterns.

Regarding *S. canadensis*, during the 21 DAT, growth was slow, with an initial length of 12.46 cm, reaching an average of 117.55 cm at 84 DAT. Growth slowed down when it reached a length of 118.05 cm (Figure 1E), at the end of the lifecycle. In the case of *D. elatum,* slow growth occurred until 42 DAT, reaching a length of 21.10 cm. Between the previous stage and 77 DAT, growth was exponential until reaching the length of 123.74 cm. Later, growth ceased (Figure 1F). In the two species, the length of the aerial zone exceeded the standard lengths 75 and 104 cm for *S. canadensis and D. elatum*, respectively.

The longitudinal growth trend in the two species, followed a logistic model pattern with three characteristic phases: linear, logarithmic and saturation (Figure 1e-f). This behavior matches with the life cycle of plants and plant organs as described in the literature for *Helianthus annuss* (Di Benedetto and Tognetti, 2016; Carrillo and Yumbla-Orbes, 2022).

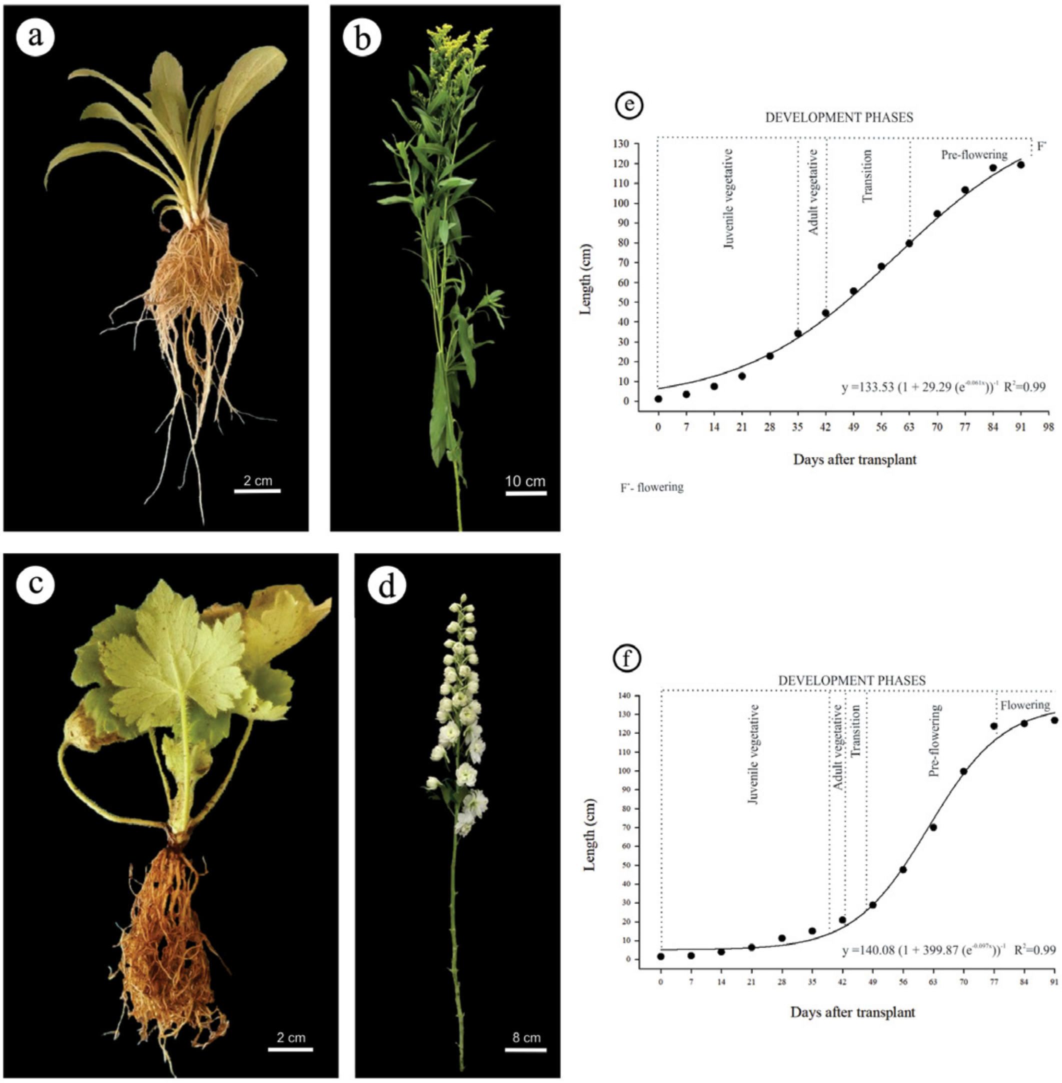

Figure 1. a) *Solidago canadensis* seedlings and b) *S. canadensis* cut point flower stalks. c) *Delphinium elatum* seedlings and d) *D. elatum* cut point flower stalks grown under greenhouse conditions in relation to days after transplanting.

In *S. canadensis*, leaves showed constant growth until 49 DAT, which represents the more salient organ growth, meaning 62.69% of the total DW. After 63 DAT, this behavior changed due to apical removal (pinching), as stated above. On 94 DAT the accumulated DW of inflorescences resulted 64.06% of the total plant dry weight (TPDW), followed by the stem, 20.04%; root, 10.33% and leaves, 5.58 % (Figure 2a).

In *D. elatum,* at 42 DAT the leaves represented 66% of the TPDW, while at 77 DAT a decrease occurred. At the end of the cycle, a distribution pattern of DW was observed among leaves, stem, inflorescences and root, as follows: 38.12%, 25.17%, 20.55% and 16.16%, respectively. On the contrary, the inflorescence influenced only 20.55% of the TPDW, since there was only one flowering stem with 30% of open flowers (Figure 2b).

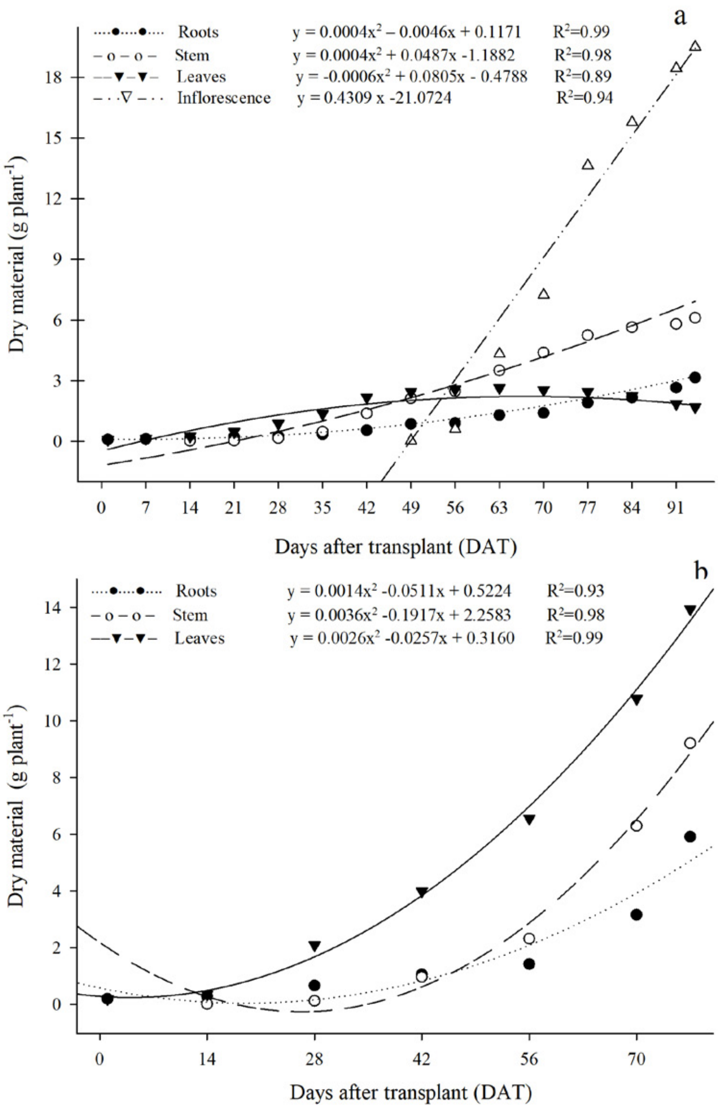

Figure 2. Dry matter distribution throughout the crop in a) *Solidago canadensis* and b) *Delphinium elatum* grown under greenhouse conditions throughout the crop.

As for the DW distribution in the plant structures, it differs in each species. The result of inflorescence predominance in *S. canadensis* resulted from the increase in the number of floral stems (5 lateral stems) because of pinching. This procedure triggers the redistribution of growth regulators around the dormant buds, inhibiting the action of auxins in apical dominance and giving way to cytokinins in the development of axillary buds (Taiz et al., 2018). Such practice is very common in summer flower management; for example, in the case of *Zinnia elegans*, single or double apical topping increased production by 50 - 60% compared to plants without apical pinching (Ullah et al., 2019).

The DW of leaves for *S. canadensis* were the least influenced organs on the final weight, which is attributed to their simple structure, lack of petiole, as well as a reduced number of leaflets (12 leaves plant^{-1}). Additionally, by 49 DAT, inflorescence structures gain more salience compared to leaves weight from TPDW. Therefore, the appropriate balance between vegetative and reproductive growth is a high priority aim in horticulture, as early cropping efficiency gains are required during the vegetative growth along the reproductive development (Elfving, 1988). As mentioned by Taiz et al. (2018) the influence of the foliage at the beginning of the crop was due to the distribution of photoassimilates towards the immature leaves during the vegetative phase. This is an action of preparation and improvement of the photosynthetic apparatus for the subsequent reproductive phase. During the reproductive phase, the photoassimilates are directed towards the flower and fruit development, becoming the new sinks where these substances will be consumed (Aluko et al., 2021). Regarding *Eustoma grandiflorum*, during the vegetative stage, the dry material of the aerial part was determined by the stem and leaves' weight, but when the reproductive stage was reached, the increase in the dry matter accumulation was the result of the formation of flowers and the peduncles elongation (Castillo et al., 2017). On the other hand, in our study, for *D. elatum* the DW of the leaves was determinant in the TPDW along all the life cycle, with an average of

20 leaves/plant. This result is corroborated by Kolar et al. (2017), referring to *Delphinium malabaricum,* where they reported numerous (18-34) palmatisect leaves with long petiole.

The growth rates evidenced maximum points of expression at 77 DAT in both studied species. The highest value of AGR was 1.10 g d^{-1} in *S. canadensis*, while for *D. elatum* it was 1.99 g d^{-1}. In the case of RGR, the maximum value in *S. canadensis* occurred at 42 and 63 DAT with values of 0.09 and 0.08 g $g^{-1}d^{-1}$, respectively. Concerning *D. elatum*, the maximum value of this index occurred at 28 DAT with 0.11 g $g^{-1}d^{-1}$ (Table 3A-B).

Table 3. Absolute growth rate (AGR), relative growth rate (RGR) and growing degree-days for development (GDD) throughout the life cycle of A) *Solidago canadensis* and B) *Delphinium elatum* grown under greenhouse conditions.

A) Solidago canadensis				
DAT		**AGR (g d^{-1})**	**RGR (g $g^{-1}d^{-1}$)**	**GDD (°Cd)**
1	Seedling			11
7	First leaf development- 1 noticeable internode	0.01	0.07	77
14	Juvenile vegetative phase	0.02	0.07	161
21		0.04	0.08	245
28		0.08	0.08	343
35	Development of 9 or more leaves- 9 or more noticeable internodes (juvenile-adult vegetative stage).	0.13	0.08	434
42	Adult vegetative phase	0.27	0.09	511
49	Transition phase	0.19	0.04	595
56		0.16	0.03	679
63	Start of the panicle emergence	0.74	0.08	770
70	Pre-flowering	0.54	0.04	854
77		1.10	0.06	938
84		0.37	0.01	1015
91		0.42	0.02	1092
94	30% of open flowers (flowering).	0.57	0.02	1128
B) Delphinum elatum				
DAT		**AGR (g d^{-1})**	**RGR (g $g^{-1}d^{-1}$)**	**GDD (°Cd)**
1	Seedling			12
14	Development of the second leaf- 2 perceptible internodes	0.02	0.04	161
28	Juvenile vegetative phase	0.16	0.11	343
40	Fase vegetativa juvenil – adulta			494
42	Development of 9 or more leaves- 9 or more noticeable internodes (juvenile-adult vegetative stage).	0.22	0.05	518
48	Transition phase			672
56	Pre-flowering	0.31	0.04	840
70		0.88	0.06	
77	30% of open flowers (Flowering)	1.99	0.07	917

The AGR estimates the peak of demand from the plant, according to the mass increment along the life cycle (Brown, 2015). Using this index, we determined that the period of *S. canadensis* of greatest requirements was associated with the panicle emergence and the primary and secondary rachis growth. With regards to *D. elatum*, the highest demand occurred during the opening of 30% of the flower buds in the bunch.

The production of new meristematic tissue was identified with a marked RGR increment in the formation of lateral buds, formation of flower buds, and new leaves unfolding. This trend matches with Silva et al. (2018) when referring to rose bushes, reporting a rapid accumulation during the first growth followed by a decrease. The RGR values obtained in the present study were close to those reported in the literature during the first five weeks after transplanting *Solidago shortii* (0.124 g $g^{-1}d^{-1}$) and *Solidago altisima* (0.120 g $g^{-1}d^{-1}$; Walck et al., 1999). In addition, the maximum value in *S. canadensis* was influenced by the long days induced with artificial light for six weeks. Meanwhile, the RGR decrease in the two species would be a consequence of the gradual predominance of structural tissue in the plant where there is a constant metabolic activity (increase in the age of the lower leaves), rather than the new meristematic tissue production (Brown, 2015).

In the present investigation, the *S. canadensis* juvenile-adult vegetative, pre-flowering and flowering stages, required 434, 770 and 1128 GDD accumulation, respectively. The vegetative-transitional and reproductive stages accumulated 68% and 32% of the total heat required in the cycle. Meanwhile, for *D. elatum*, in the juvenile-adult vegetative, pre-flowering and flowering stages it required 494, 672 and 917 GDD, respectively, with 73% accumulated in the vegetative-transitional stage and 27% in the reproductive stage (Table 3A-B). For this reason, the environmental control of greenhouse is of utmost importance. Flower growers in Colombia focus their efforts on strategies for optimizing microclimatic conditions for both daytime and nighttime (Villagrán and Bojacá, 2020). The way in which temperature influences the occurrence of a phenological stage is through the GDD. Plants require to accumulate a certain amount of energy over time (Flores et al., 2016); such energy is represented in terms of heat summation (Miller et al., 2001).

Relationship between the growth of the studied floriferous species and climatic elements

In the two studied species, the correlation coefficients between GDD and growth variables are highly significant (Table 4A-B); therefore, the accumulation of a certain amount of heat, is required to complete a development and growth phase in the plants (Di Benedetto and Tognetti, 2016). Temperature is one of the triggering elements of the phenological phases. The development and growth of the plant is reduced when temperature is low, and if this variable drops to Bt, growth stops (Kaya et al., 2021). Susceptibility in plants will occur if extreme temperatures prevail for a prolonged period, affecting mainly the stomatal apparatus, mature and developing leaves (Driesen et al., 2020).

Table 4. Pearson correlation between growth variables and climatic elements for a) *Solidago canadensis* and b) *Delphinium elatum* grown under greenhouse conditions.

A) Solidago canadensis				
		RH (%)	**SM (cbar)**	**GDD (°Cd)**
Aerial section	**Fresh weight (g)**	0.56**	-0.49**	0.97**
	Dry weight (g)	0.5**	-0.45**	0.96**
Stem	**Diameter (cm)**	0.66**	-0.48**	0.99**
	Length (cm)	0.62**	-0.5**	0.99**
B) Delphinium elatum				
		RH (%)	**SM (cbar)**	**GDD (°Cd)**
Aerial section	**Fresh weight (g)**	0.72**	0.89**	0.96**
	Dry weight (g)	0.69**	0.88**	0.94**
Stem	**Diameter (cm)**	0.83**	0.87**	0.99**
	Length (cm)	0.71**	0.91**	0.95**

Correlations for N = 6432 data of *Solidago canadensis* and 35 data of *Delphinium elatum*, for all variables.

Relative humidity (RH), soil moisture (SM) and growing degree-days for development (GDD).

** highly significant with $\alpha < 0,01$, ns = no significant.

Regarding RH, the values of the correlation coefficients in *S. canadensis* were positive but low. In *D. elatum*, moderate correlations were obtained between RH with FW and DW, while the diameter variable resulted in a high correlation (Table 4A-B). The direct trend in RH indicates that, despite being a more constant variable under greenhouse, there may be variations that are perceptible by the plant, especially between midday and night. Growth benefits from high RH, as it increases stomatal aperture; however, an extreme value affects growth due to reduced transpiration and nutrient translocation (Ferrante and Mariani, 2018).

Scarce inverse correlation resulted for SM and growth variables in *S. canadensis*, thus in this species, growth was not restricted by SM. The adaptability to wide humidity regimes for this species is attributed to the origin of its progenitors, which in this case corresponds to ruderals developed in a wide geographical range in North America with a wide climatic tolerance (Guang-Qian et al., 2020). Cao et al. (2018) mention that under conditions of environmental variability, *S. canadensis* invests in biomass production to improve competitiveness and adaptation to the environment. On the other hand, SM and growth variables in delphinium plants had a highly significant correlation, resulting in lower adaptability of the species to moisture variation, thus requiring greater management to keep its productivity. For this reason, the development and growth of *D. elatum* would be adequate in semi-humid soils between 50% - 60% of SM. Consequently, using localized irrigation, which promotes the proliferation of roots in the superficial soil profile, is recommended because the application of small and precise water sheets prevents soil saturation (Suryavanshi et al., 2015).

Conclusions

The developmental stages of the studied species follow a phenological pattern based on the BBCH scale for weeds, which resulted a useful tool for measuring development stages for optimizing crop management, in association with horticultural practices. Throughout the crop cycle, the growth followed a logistic curve pattern, determining the period of greatest demand for photoassimilates with the AGR index. For *S. canadensis*, the highest demand occurred during the emergence of the panicle, while for *D. elatum* it occurred during the opening of 30% of the flower buds. The production of new meristematic tissue was identified with the notable increase in the RGR at the time of lateral buds' formation, flower buds and unfolding of new leaves. The leaves were the organs with the least influence on TPDW for *S. canadensis* while for *D. elatum*, it was not. The climatic conditions (GDD, RH and SM) had different levels of influence on the growth variables on the two studied species grown under greenhouse, except for the SM variable in *S. canadensis*.

Author Contribution

NMC-L: research, methodology, data analysis, writing; **ES:** research, methodology; **ST:** research, methodology; **MA-A.:** writing and editing; **MEÁ-S.:** writing and editing; **MY-O:** research conceptualization and planning, methodology, data analysis, writing, editing and supervising.

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