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Validation of the PhenoGlad model and determination of planting dates of the gladiolo

Validação do modelo PhenoGlad e determinação de datas de plantio do gladíolo

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Highlights

The determination of gladiolus planting dates was performed by PhenoGlad.
Model validation occurred with field gladiolus crops in several locations.
The PhenoGlad model was accurate in simulating gladiolus development.
Extreme temperature damage to flower stems was predicted by PhenoGlad.

Abstract

Mathematical models that simulate crop development are important tools to help growers plan management practices and harvest time for cut flowers such as gladiolus. This study aimed to validate the gladiolus phenology model, named PhenoGlad for the State of Paraná and determine the planting date for marketing flowers for the All Souls' Day and the quality of the floral stems. The validation of the PhenoGlad model was conducted in 2019 through field tests with different cultivars in five towns in the State of Paraná: Cascavel and Santa Helena (cultivar T704), Dois Vizinhos (cultivar White Goddes), Marechal Cândido Rondon (cultivars White Goddes and T704), and Palotina (cultivars T704 and Red Beauty). To estimate planting dates, the PhenoGlad model was run for 20 towns in different regions of the state, based on the periods of weather data available at each weather station, and for early, intermediate II, and late development cycles. The planting date was determined based on the average of the dates (Julian days) in each simulated year. The variables

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analyzed were the stages of development according to the phenological scale of the culture, number of leaves, average number of florets, and classification of floral stems according to the quality standards of Veiling Holambra. The PhenoGlad model was accurate in simulating the stages of development of gladiolus culture in the state of Paraná and suitable for predicting the damage caused by extreme temperatures in floral stems, which was confirmed by the damage caused to sepals and petals of gladiolus, cultivar T704, in field experiments in the towns of Cascavel, Palotina, and Santa Helena, and cultivar White Goddess for Dois Vizinhos. The best model performance was observed when simulating the vegetative period of the crop, with a low error of 0.54 leaf. In the state of Paraná, for the production of floral stems for the All Soul's Day, the PhenoGlad model simulated the planting dates for the 20 towns, from August 1 to August 23 for early cycle, July 18 to August 14 for intermediate II cycle, and July 7 to August 6 for late cycle. The towns of Cascavel and Marechal Cândido Rondon presented a higher number of florets and higher quality floral stems than the other towns evaluated.
Key words: *Gladiolus* x *grandiflorus* Hort. Mathematical models. cut flower.

Resumo

Modelos matemáticos que simulam o desenvolvimento das culturas são ferramentas importantes para ajudar produtores no planejamento das práticas de manejo e épocas de colheita de flores de corte, como o gladíolo. O objetivo deste trabalho foi validar o modelo fenológico gladiolus, denominado PhenoGlad para o Estado do Paraná, determinar a data de plantio para comercialização de flores para o dia de Finados, e a qualidade das hastes florais. A validação do modelo PhenoGlad foi através de ensaios de campo durante o ano de 2019, com diferentes cultivares em cinco municípios do Estado do Paraná: Cascavel e Santa Helena (cultivar T704), Dois Vizinhos (cultivar White Goddes), Marechal Cândido Rondon (cultivares White Goddes e T704), e Palotina (cultivares T704 e Red Beauty). Para estimar as datas de plantio o modelo PhenoGlad foi rodado para 20 municípios das diferentes regiões do estado, com base nos períodos de dados meteorológicos disponíveis em cada estação meteorológica, e para os ciclos de desenvolvimento precoce, intermediário II e tardio. A data de plantio do gladíolo foi determinada por meio da média das datas (dias julianos) para cada ano simulado. As variáveis analisadas foram os estádios de desenvolvimento de acordo com a escala fenológica da cultura, número de folhas, número médio de floretes e classificação das hastes florais de acordo com os padrões de qualidade de Veiling Holambra. O modelo PhenoGlad apresentou acurácia ao simular os estádios de desenvolvimento da cultura do gladíolo no Estado do Paraná e também é apropriado para predizer os danos por temperaturas extremas nas hastes florais, o que se confirmou com os danos causados nas sépalas e pétalas do gladíolo, cultivar T704, nos experimentos de campo nas cidades de Cascavel, Palotina e Santa Helena, e para cultivar White Goddess em Dois Vizinhos. O melhor desempenho do modelo foi observado ao simular o período vegetativo da cultura, apresentando baixo erro de 0,54 folha. No Estado do Paraná, para produção de hastes na data de Finados, o modelo PhenoGlad simulou as datas de plantio, para as 20 cidades estudadas, de 1 a 23 de agosto para ciclo precoce, 18 de julho a 14 de agosto para o ciclo intermediário II, e 7 de julho a 6 de agosto para o ciclo tardio. As cidades de Cascavel e Marechal Cândido Rondon apresentaram maior número de floretes e qualidade de hastes superior aos demais municípios avaliados.
Palavras-chave: *Gladiolus* x *grandiflorus* Hort. Modelos matemáticos. Flor de corte.

Introduction

Gladiolus (*Gladiolus* x *grandiflorus* Hort.) is considered a species of great commercial importance, propagated through corms, and cultivated as a cut flower with a great diversity of colors (Schwab et al., 2015; Uhlmann, 2018). In Brazil, the main sales peak occurs on all Souls' days (November 2) (Tomiozzo et al., 2021).

Floriculture has stood out in small rural properties, presenting a good insertion; however, it differs in terms of production and importance among Brazilian states (Junqueira & Peetz, 2015). In Paraná, floriculture stands out because of several advantages in the production of flowers and ornamental plants, owing to its favorable climate for cultivation, in addition to regions already consolidated in this activity; however, some regions have presented problems in production and commercialization (Anacleto, 2016).

Gladiolus cultivation can be carried out throughout the year, with average air temperatures between 10°C and 25°C (Lim, 2014). In the vegetative period, it tolerates temperatures of up to 50°C, but it can be damaged if the minimum temperature is lower than 3°C for three consecutive days or the maximum temperature is greater than or equal to 34°C for three consecutive days in the reproductive period (Uhlmann et al., 2017).

As with other flowering crops, one of the possible factors that affect the production and commercialization of gladiolus in the State of Paraná is the difficulty of providing flower stems at the desired time for commercialization, as the culture responds to climatic factors, such as air temperature and luminosity, which may anticipate or delay flowering.

The cultivars found in the market are hybrids (Tomiozzo et al., 2021) and are distinguished by the color of the florets and the duration of the cycle. The gladiolus crop development cycle is divided into three phases: bulb sprouting, vegetative, and reproductive (Schwab et al., 2015) and these are the environmental conditions that interfere with the growth, development, and quality of the stems. The air temperature is the most influential factor (Streck et al., 2012).

Growth and development can be characterized using mathematical models, which are widely used tools to simulate the growth and development of a crop in response to the environment, thus helping in crop management (Streck et al., 2003). The applications of these models are wide, including determination of the best date for planting and harvesting flowers (Becker, 2017).

The mathematical Model PhenoGlad, developed to simulate the emission of leaves and the development of the gladiolus crop, was calibrated and validated using field data collected in the states of Rio Grande do Sul and Santa Catarina (Uhlmann et al., 2017). Leaf appearance and development were calculated by accumulating the daily development rate using the approach described by Wang and Engel (1998). The model uses a non-linear response, and to simulate planting dates, it is necessary to inform the model of meteorological data of daily air temperatures (maximum and minimum) (Uhlmann et al., 2017).

The determination of the planting date through the PhenoGlad model is essential for the producer to be able to make the correct schedule and plan the production of stems, thus having the species offered at the desired time for commercialization. Cultivation varies between regions and seasons; in which in periods of high air temperatures above 34°C, the cycle is reduced, and in periods of air temperatures below 34°C, the cycle lengthens (Schwab et al., 2018). For adequate production performance and supply of stems at the desired time, it is important to determine the dates for planting the gladiolus, which concentrates on commercialization at specific times, such as Mother's Day, All Souls' Day, weddings, and graduations.

For the State of Paraná, validation of the PhenoGlad mathematical model has not yet been carried out. In this sense, the validation of the model will be a technical and technological contribution, as it will allow the flower producer to program the production and commercialization of floral stems of gladiolus culture using this free management tool.

The objective of this study was to validate the PhenoGlad model for the State of Paraná and determine the planting date and quality of gladiolus flower stems for their commercialization, for All Souls' Day, a date of significant commercialization of gladiolus flowers.

Material and Methods

Experiments

Field experiments were conducted in five towns in the State of Paraná: Cascavel, Dois Vizinhos, Marechal Cândido Rondon, Palotina, and Santa Helena, representing the mesoregions (Southwest and West) and microregions of Cascavel, Toledo, and Francisco Beltrão (Instituto Paranaense de Desenvolvimento Econômico e Social [IPARDES], 2021) (Table 1 and Figure 1). According to the Köppen classification, the climate of the studied towns was humid subtropical climate with hot summers (Cfa) (Alvares et al., 2013). The experiments were conducted in 2019, and the planting dates (Table 1) were simulated using the PhenoGlad model (Uhlmann et al., 2017).

The experiments in the town of Cascavel (Microregion of Cascavel) were conducted in the experimental area of the Centro Universitário da Fundação Assis Gurgacz (FAG). The meteorological conditions include an average annual temperature of 19.6°C and a total annual rainfall of 1632.8 mm (Wrege et al., 2012). The soil is classified as typical dystroferric red latosol (Bhering et al.,2008).

The experiments in Dois Vizinhos (Microregion of Francisco Beltrão) were conducted in the experimental area of the Universidade Tecnológica Federal do Paraná (UTFPR), Campus Dois Vizinhos, and with an average annual temperature of 21°C and a total annual rainfall of 2000 mm (Wrege et al., 2012). The soil is classified as Distroferric Red Nitosol (Bhering et al., 2008).

Table 1
Experiments conducted in different locations in Paraná with different gladiolus cultivars and planting dates

Experiments	Cultivars	Planting data	Towns
1	White Goddess[2]	21/03/2019	Dois Vizinhos
2	T704[1]	09/08/2019	Cascavel
3	White Goddess[2]	13/08/2019	Dois Vizinhos
4	T704[1]	23/08/2019	Santa Helena
5	White Goddess[2] e T704[1]	10/09/2019	Marechal Cândido, Rondon
6	T704[1] e Red Beauty[2]	14/09/2019	Palotina

[1]Cycles Intermediate I, [2]Intermediate II.

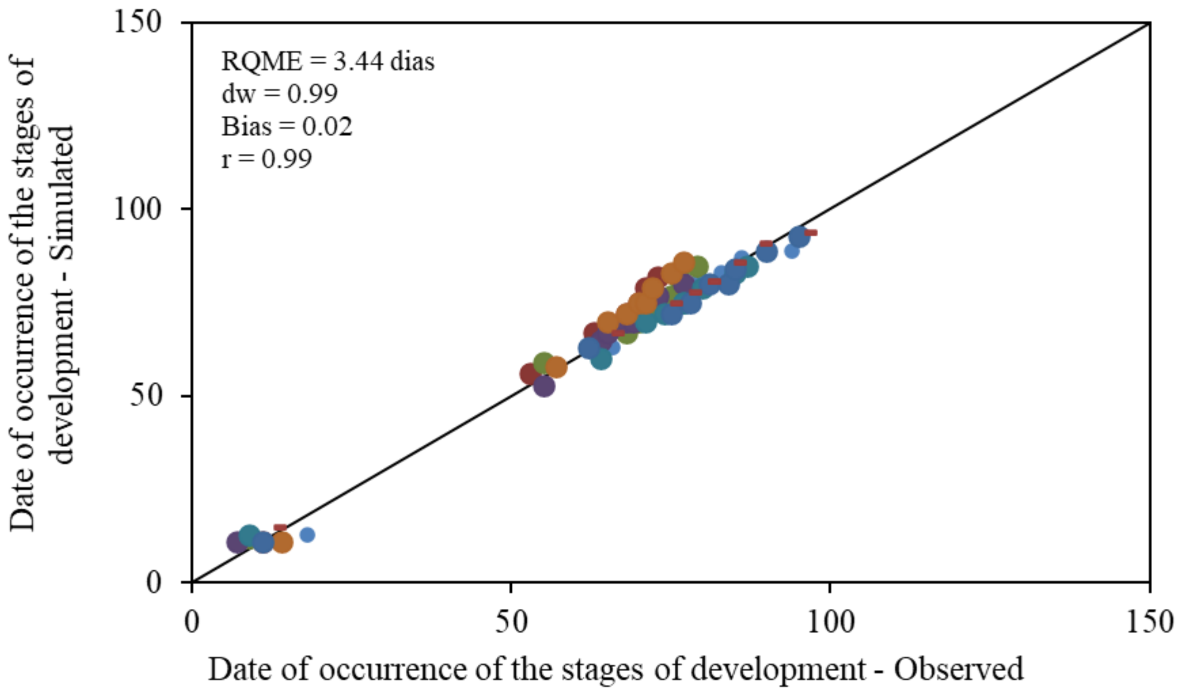

Figure 1. Development stages simulated with the PhenoGlad model and observed during the development of gladiolus plants in the field, from each experiment evaluated in the different towns of Paraná. RQME = root mean square error, dw = agreement index, BIAS = BIAS index, and r = Pearson's correlation coefficient. Each color represents a cultivation site.

The experiments in Marechal Cândido Rondon (Microregion of Toledo) were conducted in the experimental area of the Universidade Estadual do Oeste do Paraná (UNIOESTE), and with an average annual temperature of 22°C and a total annual rainfall of 1722.2 mm (Wrege et al., 2012). The soil is classified as Distroferric Red Latosol (Bhering et al., 2008).

The experiments in Palotina (Microregion of Toledo) were conducted in the experimental area of the Universidade Federal do Paraná (UFPR), with an average annual temperature of 21.2°C, and a total annual rainfall of 1712.5 mm (Wrege et al., 2012). The soil was classified as eutrophic red-yellow argisol (Bhering et al., 2008).

The experiments in Santa Helena (Microregion of Toledo) were carried out in the experimental area of the Universidade Tecnológica Federal do Paraná (UTFPR), Campus Santa Helena. The meteorological conditions include an average annual temperature of 25°C and a total annual rainfall of 1800.0 mm (Wrege et al., 2012). The soil is classified as a nitosol (Bhering et al., 2008).

The cultivars used in the experiments were White Goddess, intermediate cycle II, average number of 10 leaves, and white florets (Dois Vizinhos and Marechal Cândido Rondon) (Gladiolus phenology [PhenoGlad], 2023). Intermediate cycle I, T704, average number of nine leaves and lilac-colored florets (Cascavel, Marechal Cândido Rondon, Santa Helena, and Palotina) (PhenoGlad, 2023). Red Beauty, intermediate cycle II, average number of nine leaves, and red florets (Palotina) (Table 1) (PhenoGlad, 2023). The cultivars evaluated in each town were chosen at random according to the availability of bulbs by the company and the flower color preference of the institutions participating in the field experiments.

Gladiolus was cultivated at all the evaluation sites in beds with the opening of the planting furrow with a line marker. Vernalized bulbs measuring 12-14 cm in perimeter, vernalized, were purchased from Terra Viva. The bulbs were planted in two rows per bed, with a spacing of 0.4 m between rows and 0.2 m between plants, with a planting depth of 0.1 m.

Gladiolus does not have a fertilization recommendation; therefore, the recommendation for the culture of cut chrysanthemum (*Dendranthema* sp.) from the fertilization manual of the Brazilian Society of Soil Science (SBSC) of the state of RS and SC was used, as the State of Paraná does not present a recommendation for this culture in its manual. Fertilization at planting was 75 kg ha^{-1} urea, 30 kg ha^{-1} P_2O_5, and 80 kg ha^{-1} K_2O. For fertilization at the V3 stage (third visible leaf), 75 kg ha^{-1} of urea and 30 kg ha^{-1} of potassium chloride were used in all growing seasons.

Irrigation was by drip using a Schneider® BC 91S biphasic motor pump with a pressure of 28 mca and a flow rate of 126.7 L min^{-1}, a flow rate of 1.60 L h^{-1} and a flow rate of 0.03 L min^{-1} for each dripper. Irrigation management was based on soil water matric potential, determined by tensiometers installed at a depth of 10 cm and at a tension of 19 kPa (Uhlmann, 2018).

Weed control was performed manually, and for insect control (Pseudoplusia includens), when pest attack was observed, the insecticide with the active ingredient deltamethrin was used at a dose of 30 mL per 100 L of water, and two applications were made using a 20 L capacity knapsack sprayer, with a 15 day interval. This management was carried out only in Dois Vizinhos.

When the plants had 6 to 7 leaves, staking was carried out with a polyethylene ribbon, gray in color and 2.5cm wide, the first ribbon being 30 cm horizontally from the ground and the second ribbon 70cm from the ground (Uhlmann et al., 2017).

Plant development assessments

The five towns in the state that cultivated gladiolus followed the methodology of evaluating the stages of development according to the phenological scale of the culture (Schwab et al., 2015) in 12 central plants, each of which was marked and considered a repetition. After planting, daily monitoring was performed, and when 50% of the plants were above ground level, the date of emergence was considered (stage VE). In the vegetative phase, the number of leaves was counted twice a week until flag leaves emerged. In the reproductive phase, monitoring was performed daily to obtain the date of occurrence of the following stages: beginning of heading (R1.0), complete heading (R1.2), harvest point 1 (R2), harvest point 2 (R3), half of the open florets (R3.4), first senescent florets (R3.5), half of the senescent florets (R3.6), last open florets (R4), and end of senescence (R5).

Validation of the PhenoGlad model

The PhenoGlad model was used (Uhlmann et al., 2017). The model input data were daily maximum and minimum air temperature, planting date, cultivar, or cycle. The simulations were based on planting date and cultivar. Meteorological data were obtained from the INMET meteorological station located in the town of Dois Vizinhos (near the experiment) and from data loggers installed in the experimental area, from the meteorological station located at FAG in Cascavel, the UNIOESTE meteorological station located in Marechal Candido Rondon, from the SIMEPAR meteorological station located in the town of Palotina, and from the SIMEPAR station located in the town of Santa Helena.

To evaluate the performance of the model in simulating each stage of development, the data collected in the field at each location was compared with the data simulated by the model. The statistics that evaluated the performance of the model were the Root Mean Square Error (RQME) (Equation 1) (Janssen & Heuberger, 1995), BIAS Index (systematic deviation from the real value) (Equation 2) (Leite & Andrade, 2002), Pearson's Correlation Coefficient (Equation 3) (Willmott, 1981) and Index of Agreement (Equation 4) (Willmott, 1981).

$$RQME = \left[\frac{\sum(Si-Oi)^2}{n}\right]^{0,50} \qquad \text{Equation (1)}$$

$$BIAS = \frac{(\sum Si-\sum Oi)}{\sum Oi} \qquad \text{Equation (2)}$$

$$r = \frac{\sum(Oi-\bar{O})\mathrm{x}(\mathrm{Si}-\mathrm{S})}{\sqrt{\sum(\mathrm{Oi}-\bar{O})^2}x\sum(Si-S)^2} \qquad \text{Equation (3)}$$

$$w = 1 - \frac{\left[\sum(Si-Oi)^2\right]}{[\sum(Si-\bar{O})+(Oi-\bar{O})^2} \qquad \text{Equation (4)}$$

Where:

Si - Simulated values

S - Average of simulated values

Oi - Observed values

Ō - Average of observed values

n - number of observations

Determining the planting date for harvesting flowers for the All Souls' Day

To determine the planting date for the commercialization of floral stems on All Souls' Day (November 2), 20 towns (Apucarana, Bela Vista do Paraiso, Cambará, Cândido de Abreu, Ibiporã, Joaquim Távora, Londrina, Cianorte, Umuarama, Laranjeiras do Sul, Cascavel, Cerro Azul, Palotina, Morretes, Antonina, Guaraqueçaba, Pato Branco, Fernandes Pinheiro, Clevelândia, and Lapa) (Table 2) in the state of Paraná were studied, different towns from those used for the validation of the model. The choice of these towns is justified by the availability of meteorological data from all meteorological stations, thus covering all climatic types in the state. The model used was PhenoGlad (Uhlmann et al., 2017) available at https://www.ufsm.br/cursos/pos-graduacao/santa-maria/ppgagro/phenoglad/.

Table 2
Dates of gladiolus planting, for early, intermediate II, and late cycle cultivars, for commercialization of floral stems for the All Souls' Day, in different towns of Paraná

		Planting Cycles and Datas		
Growing regions	Towns/Paraná	Early	Intermediate II	Late
North	Apucarana	19/8	10/8	2/8
	Bela Vista do Paraiso	22/8	13/8	4/8
	Cambará	22/8	14/8	5/8
	Cândido Abreu	17/8	7/8	28/7
	Ibiporã	23/8	14/8	6/8
	Joaquim Távora	22/8	13/8	3/8
	Londrina	21/8	12/8	3/8
Northwest	Cianorte	22/8	13/8	4/8
	Umuarama	22/8	12/8	5/8
Mid West	Laranjeira do Sul	12/8	2/8	22/7
West	Cascavel	15/8	4/8	26/7
	Cerro Azul	18/8	7/8	29/7
	Palotina	19/8	10/8	2/8
Metropolitan	Morretes	17/8	7/8	30/7
	Antonina	16/8	6/8	27/7
East	Guaraqueçaba	17/8	8/8	29/7
Southwest	Pato Branco	11/8	31/7	21/7
Southeast	Fernandes Pinheiro	6/8	23/7	12/7
South	Clevelândia	3/8	21/7	8/7
	Lapa	1/8	18/7	7/7

The model input data were air temperature (daily maximum and minimum), using historical series of each location, with data obtained from conventional weather stations of the Rural Development Institute of Paraná (IDR). The percentage of years with damage (%) was also evaluated during the estimates, where the model considered a minimum temperature below -2°C for three consecutive days and a temperature greater than or equal to 34°C for three consecutive days (Uhlmann et al., 2017).

The model was run for each location and period of meteorological data available at each weather station in the towns studied and early, intermediate II, and late cycles of gladiolus, with a forecast of the harvest for the All Souls' Day (November 2), so that the plants were in R2 (first three flower buds) showing the color, considering three days before, that is, October 30, aiming at safety, so that the producer had flowers before the desired date. The planting date was determined based on the average of the dates (Julian days) for each simulated year. The risks were considered to be above 10%, which is the minimum level considered the most appropriate because it is an ornamental culture (Uhlmann et al., 2020).

Quality of floral stems

The quality of the floral stems was evaluated when the plant was at harvest point 1, which corresponds to the R2 stage, where the total length of the plant was measured (from the base of the plant to the tip of the spike), and rachis length (from the insertion of the first leaf to the tip of the spike), with a millimeter ruler. The spike diameter was measured at the insertion of the first floret with a pachymeter. The final number of florets in each stem was counted.

Stems were classified according to the standards established by the cooperative Veiling Holambra (2013). The plants were classified into the following classes: class 75, flower stems with a length of 75 cm; class 90, flower stems with a length of 90 cm; and class 110, stems with a length of 110 cm. In addition, the thickness of the floral stem was also categorized according to length: class 75, minimum thickness of 0.5 cm; class 90, minimum thickness of 0.8 cm; and class 110, minimum thickness of 1.0 cm. In this sense, floral stems shorter than 75 cm and/or those that did not meet one of the criteria of minimum diameter or rachis size, which should be at least 40% of the total length of the stem, were classified as not marketable.

Results and Discussion

PhenoGlad model evaluation

In the five towns evaluated in the state of Paraná (cultivate x location x planting date) the RQME for the simulated development stages was 2.08 days (for all stages) and 2.60 days (for the R2 stage) (Figures 1 and 2). These results suggest that if the stems were at the harvest point (R2) before the commercialization period, for example 2.60 days before the planned sale), the floral stems could be stored; however, if this error was four days after the commercialization date, the producer would not have flowers to sell on the scheduled date and market losses.

The storage of gladiolus stems is a possibility for the production of flowers but requires investments in refrigeration structures. For the conservation of gladiolus stems, it is recommended they preserve them at temperatures between 5 and 8°C for up to 15 days (Uhlmann et al., 2017). Storage is considered one of the fundamental steps for maintaining the balance between the distributor and consumer market of cut flowers, such as the gladiolus (Dias-Tagliacozzo et al., 2005). It is important to emphasize that cut flowers are highly perishable, wilting quickly because of the physiological degradative processes that occur more intensely after harvest (Spricigo et al., 2010). In this sense, storage with refrigeration allows the prolongation of the useful life of the flowers, commercialization of dates with greater demand, and better remuneration for the producer.

The RQME values found were similar to those found by other authors in the literature, from 6.9 days for gladiolus in Santa Catarina (Bonatto, 2019), from 4.8 to 5.2 days for gladiolus in RS and SC (Uhlmann, 2016).

The correlation values between the dates of occurrence of the development stages of gladiolus, simulated and observed was 0.99 for the development stages of vegetative and reproductive phases, and 0.76 for the R2 stage. The BIAS was close to zero, and the agreement index (DW) was close to one for all crop stages.

Analyzing the simulated data for all the developmental stages of the gladiolus, we observed adequate correlation results, such as BIAS and DW, demonstrating that the performance of the PhenoGlad model is consistent when simulating the development stages of the gladiolus for the state of Paraná (Figures 1 and 2).

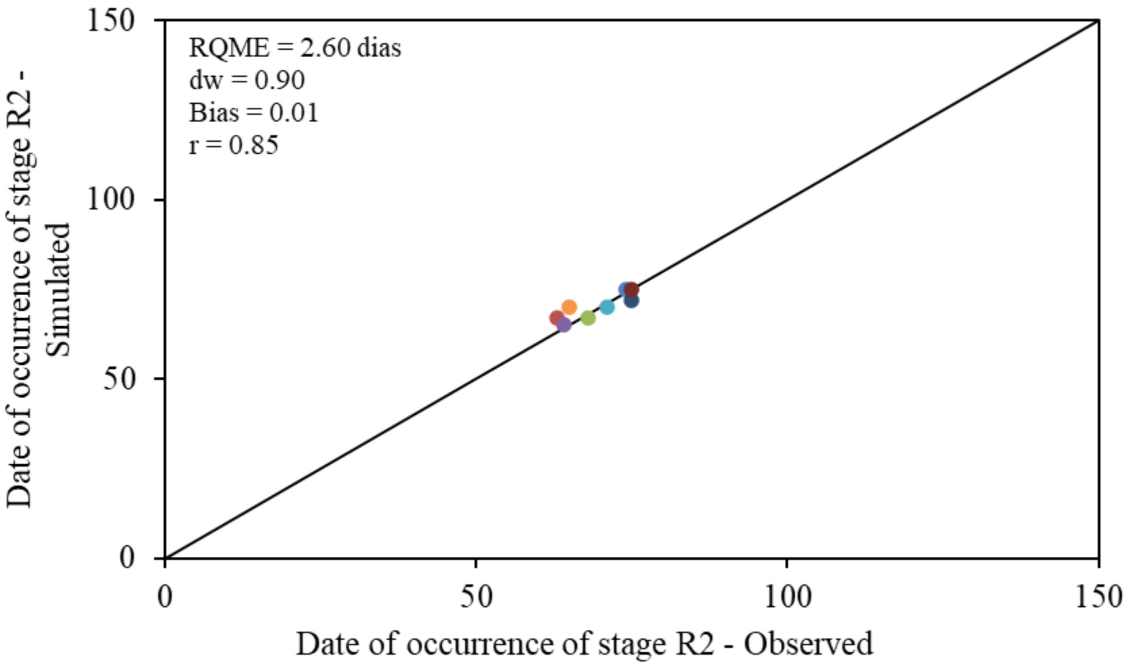

Figure 2. R2 development stages simulated with the PhenoGlad model and observed during the development of gladiolus plants in the field, from each experiment evaluated in Paraná. RQME= root mean square error, dw= agreement index, BIAS= BIAS index and r= Pearson's correlation coefficient. Each color represents a cultivation site.

The error (RQME) for leaf number (CLN) evaluated in all experiments was 0.54 leaf, that is, less than one leaf. The results of the present study were similar and consistent with those obtained by Uhlmann (2018), who evaluated eight gladiolus cultivars (Jester, Rose Friendship, White Friendship, Purple Flora, Green Star, Amsterdam, Peter Pears, and T704) and verified an RQME ranging from 0.4 to 0.8 leaves.

Analyzing the RQME results for Dois Vizinhos, with the cultivar White Goddess in experiment 1, the error (RQME) in days was 2.1 days and for CLN of 0.4 and, in experiment 2, 1.25 days and for CLN of 0.39 leaf (Figure 3). The model was effective in simulating crop development under the climatic conditions of this study. It is important to emphasize that in Experiments 1 and 2, the occurrence of the stages with the model simulation would occur earlier than observed in the field, that is, the field experiments were delayed in relation to what was simulated by the model. This type of occurrence would be critical for flower production because it would result in delayed flowering of the floral stems, not being at the harvesting point in the ideal period for commercialization.

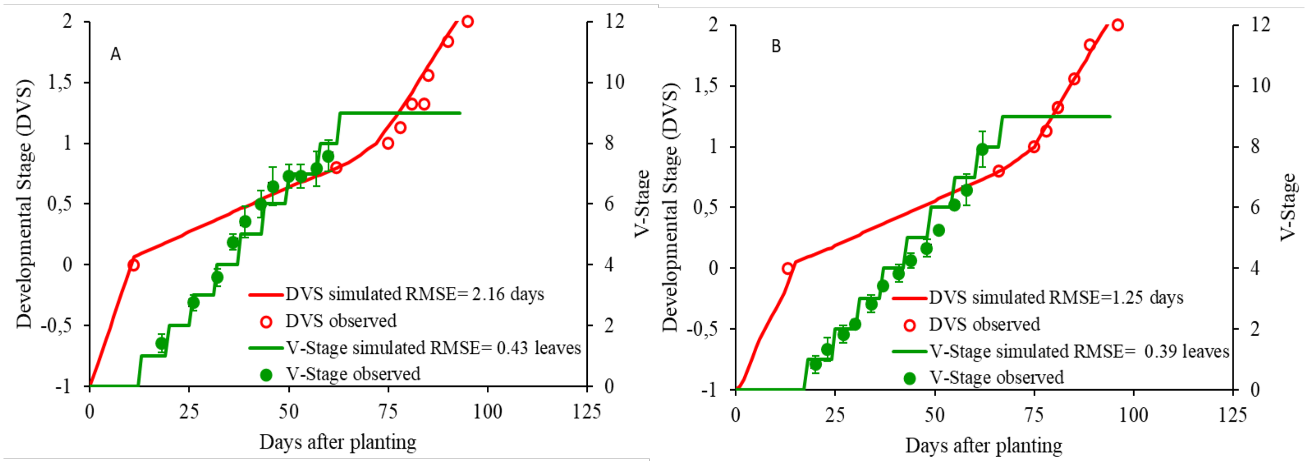

Figure 3. Developmental stage (DVS) and vegetative stage (V-stage) of gladiolus in days after planting, simulated by the PhenoGlad model and observed in the field, in experiments 1 (A) and 2 (B) in Dois Vizinhos.

The RQME for cultivar T704 in the different locations showed a variation from 2.65 (Cascavel) to 5.64 days (Santa Helena). The CLN varied from 0.28 (Palotina) to 1.12 leaf (Cascavel) (Figure 4). The cultivar White Goddess (Marechal Cândido Rondon) showed an error of 3.43 days and 0.26 leaf. The cultivar Red Beauty showed an error of 2.45 days and 0.96 leaf. The gladiolus stages in the field occurred earlier than those simulated by the model (Figure 4). According to Uhlmann et al. (2017), an error of up to five days is acceptable for the gladiolus. For example, if the model predicts the time to market and in the field, this stage occurs earlier, the flower producer can store the floral stems (5-8°C) for up to 15 days and subsequently market without incurring losses (Uhlmann et al., 2017).

The errors observed at the different growing sites were low and similar (Uhlmann, 2018), because of the location of the experiments, where they were concentrated in the same climate (Cfa) with similar soil and climate conditions. Variability in cultivars, planting date, and location is important for phenological studies and for evaluating the performance of mathematical models in simulating developmental stages (Uhlmann, 2018).

The PhenoGlad model was accurate and consistent in simulating the developmental stages from planting to considering the cultivar. In the present study, no simulations were performed from emergence on, and one of the hypotheses is that when simulating from emergence on, the error would be smaller than that found when simulating from planting. This is because in the model, germination is dependent on air temperature and other factors, such as soil type, soil temperature and moisture, planting depth, and internal bulb factors, all of which interfere with crop emergence.

One of the most important developmental stages for gladiolus cultivation is R2 (harvest point), in which the model was simulated with great accuracy, presenting a small error (2.60 days). The model also demonstrated differences between locations and cultivars (Figures 3 and 4), confirming the importance of considering the climatic conditions of each location when simulating planting dates.

The PhenoGlad model is a support tool for gladiolus cultivation in the state of Paraná, assisting in the definition of planting dates, and thus the production of floral stems, in the desired commercialization period.

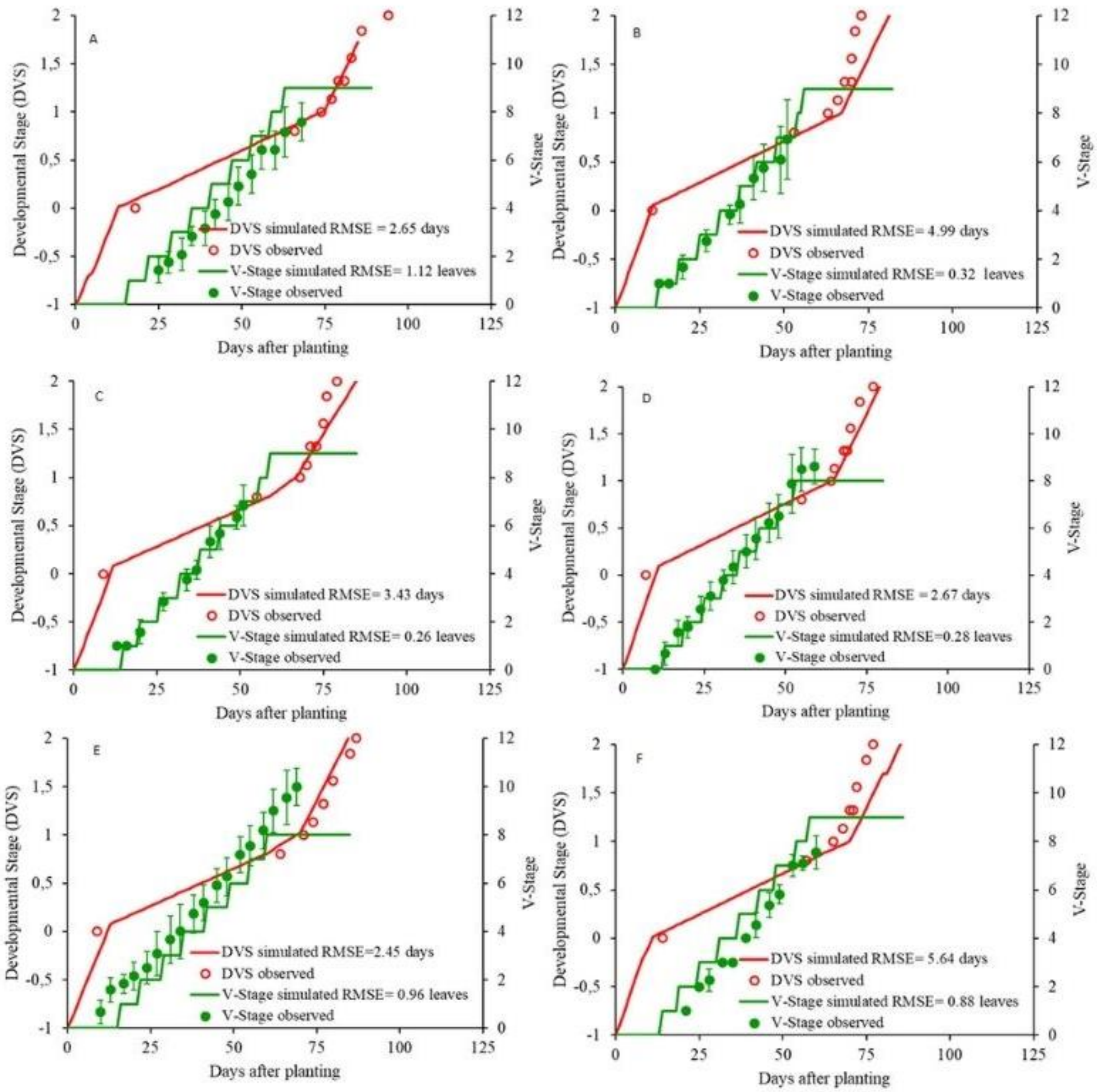

Figure 4. Developmental stage (DVS) and vegetative stage (V- stage) in days after planting, simulated by the PhenoGlad model and observed in the field in (A) Cascavel, (B) and (C) Marechal Cândido Rondon, (D) and (E) Palotina, (F) Santa Helena.

The environmental conditions were distinct at different locations and in different growing seasons. The maximum temperature varied from 31.2°C to 40.5°C and the minimum temperature varied from 1.4°C to 12.6°C, considering all the locations and growing seasons evaluated (data not presented).

The damages were injuries such as burns of the sepals and petals, included temporary wilting of floral stems, caused by extreme temperatures was identified in the crops grown in the towns of Cascavel, Palotina and Santa Helena for cultivar T704 (Figure 5), and Dois Vizinhos for cultivar

White Goddess. The damage observed in the field was caused by the high temperatures at the time of cultivation. Schwab et al. (2018) reported that the crops can present damage when temperatures are above 34°C for three consecutive days, which was observed in the crops in these towns.

Figure 5. High temperature damage observed to the sepals and petals of the gladiolus flower stems, cultivar T704, in the experiments (A) Cascavel, (B) Santa Helena, and (C) Palotina.

When evaluating the experiment conducted in Cascavel, the model alerted high temperature damage on day 286 (October 13), when temperatures were above 34°C for three consecutive days, being 34.4°C; 35.4°C and 36.4°C. The effect of high temperatures on the crop was confirmed by field cultivation in this municipality, where damage was observed to the sepals and petals of the gladiolus (Figure 5A).

In Dois Vizinhos, no damage to floral stems was observed in the autumn crop. In the winter-spring experiment (March-May), the model warned of damage due to high temperatures (above 34°C), and damage to the sepals and petals was confirmed in the field crop.

In the experiment conducted in Marechal Cândido Rondon, there was no model alert, and no damage was observed in the field, even with occurrences of temperatures above 34°C, but at no time above this reference value, for three consecutive days.

In the experiment conducted in Santa Helena, the model alerted high temperature damage on days 299 (October 26) and 304 (October 31), when temperatures were above 34°C for three consecutive days, being 34.7°C; 37.7°C and 37°C and for the second alert 37°C, 40°C, and 37°C. Damage to the model was confirmed in field cultivation, with damage observed on sepals (Figure 5B).

For the trials conducted in Palotina, the model alerted for high temperature damage on day 308 (November 04), when temperatures were above 34°C, for three consecutive days, being 36.3°C; 36.6°C and 37.7°C. The damage alert was confirmed in the field crop, where high temperatures caused damage to petals (Figure 5C).

When simulating the cycle of gladiolus in the towns evaluated, the model issued damage warnings were confirmed with the data collected in the field in all the experiments in the different locations, demonstrating the accuracy of the model in predicting possible damage that may occur in crops in the towns of Paraná. Damage caused by high temperatures was observed in the field in experiments conducted at different locations in the state; however, at low temperatures, it was not observed. We found that gladiolus flower stems have sensitivity to high temperatures (above 34°C for three consecutive days) or low temperatures (less than 3°C for three consecutive days), causing damage that compromises stem quality during marketing (Schwab et al., 2018).

Damage to sepals and petals affects the visual appearance of gladiolus flowers, and depending on the degree of severity, can disqualify the floral stem for marketing, resulting in price losses in marketing (Schwab et al., 2018). Similar results, including temporary injuries, wilting of floral stems, and burns in the sepals of the florets due to high air temperatures (36.2°C) on the gladiolus plant cultivar Jester, were also observed by Schwab et al. (2018).

Dates of gladiolus planting for commercialization of flower stems for the All Souls' Day

The planting dates were simulated by the PhenoGlad model for the development cycles of gladiolus (early, intermediate II, and late) in Paraná, by town, for the commercialization peak for All Souls' Day (November 2) (Table 2). In the state of Paraná, the variations in planting dates in the different towns were from August 1 to August 23 for the early cycle, July 18 to August 14 for the intermediate II cycle, and July 7 to August 6 for the late cycle, which demonstrates the range of planting in the state, justified by the different climatic conditions of each location.

The results show that at the same commercialization peak, the planting date is different for the evaluated towns because of the different environmental conditions of each cultivation location (Becker, 2017; Bonatto, 2019; Uhlmann, 2016). In colder regions with a humid subtropical climate with mild summers (Cfb), planting should be anticipated regardless of the cycle, due to the lower temperatures, and in Cfa (humid subtropical climate with hot summers) climate municipalities, planting is later.

In regions with Cfa, climate temperatures are higher and may present risks of damage to sepals and petals in the cultivation of gladiolus for commercialization on All Souls' Day (Table 3). The towns of Cambará, Ibiporã, Joaquin Távora, Londrina, Cianorte, Umuarama, and Cerro Azul presented a risk of above 10% for the cultivation season on All Souls' Day (Table 3).

Table 3
Estimated risks for different cycles of gladiolus cultivation, aiming the commercialization for the All Souls' Day, in different regions and towns of Paraná

		Risks (%)		
Growing regions	Towns/Paraná	Early	Intermediate II	Late
North	Apucarana	0,0	0,0	0,0
	Bela Vista do Paraiso	0,0	0,0	12,5
	Cambará	20,5	20,5	20,5
	Cândido Abreu	0,0	0,0	0,0
	Ibiporã	15,0	15,0	15,0
	Joaquim Távora	14,0	25,6	16,3
	Londrina	14,0	11,6	23,3
Northwest	Cianorte	3,7	11,1	3,7
	Umuarama	6,8	11,4	11,4
Mid West	Laranjeira do Sul	0,0	0,0	0,0
West	Cascavel	0,0	0,0	0,0
	Cerro Azul	12,5	20,8	12,5
	Palotina	0,0	0,0	26,3
Metropolitan	Morretes	0,0	0,0	2,0
	Antonina	4,8	4,8	4,8
East	Guaraqueçaba	0,0	0,0	0,0
Southwest	Pato Branco	0,0	2,7	0,0
Southeast	Fernandes Pinheiro	2,1	0,0	0,0
South	Clevelândia	2,6	0,0	0,0
	Lapa	0,0	0,0	0,0

According to (Ministério da Agricultura, Pecuária e Abastecimento [MAPA], 2018), a site is considered suitable for planting when the risk of loss is less than 20% and, in some situations, risks greater than 30%, but a floriculture risk above 20% is considered a high risk. In the southern region of Brazil, the state of Rio Grande do Sul (Uhlmann, 2018) and the state of Santa Catarina (Bonatto, 2019) have climate risk zoning for the gladiolus crop; however, in the state of Paraná, it is not yet available. Thus, information on planting dates and risk assisted the gladiolus producer in planning the crop, avoiding losses during the commercialization of floral stems.

Quality of gladiolus flower stems

Regarding the quality of floral stems, we observed superior quality in the towns of Cascavel (58.3%) and Marechal Cândido Rondon (58.3%) for the cultivars T704 and White Goddess, respectively, with a greater number of stems in the 110 classes (Figure 6) as well as the highest final number of florets 16 and 17, respectively (Table 4). These towns presented the best quality of floral stems due to the growing season and favorable climatic conditions, a good thermal amplitude for the growth and development of the culture, not presenting long periods with temperatures above 34°C for more than three consecutive days. According to Zubair et al. (2006), the quality of the gladiolus floral stem depends on the season and climatic conditions at the planting location.

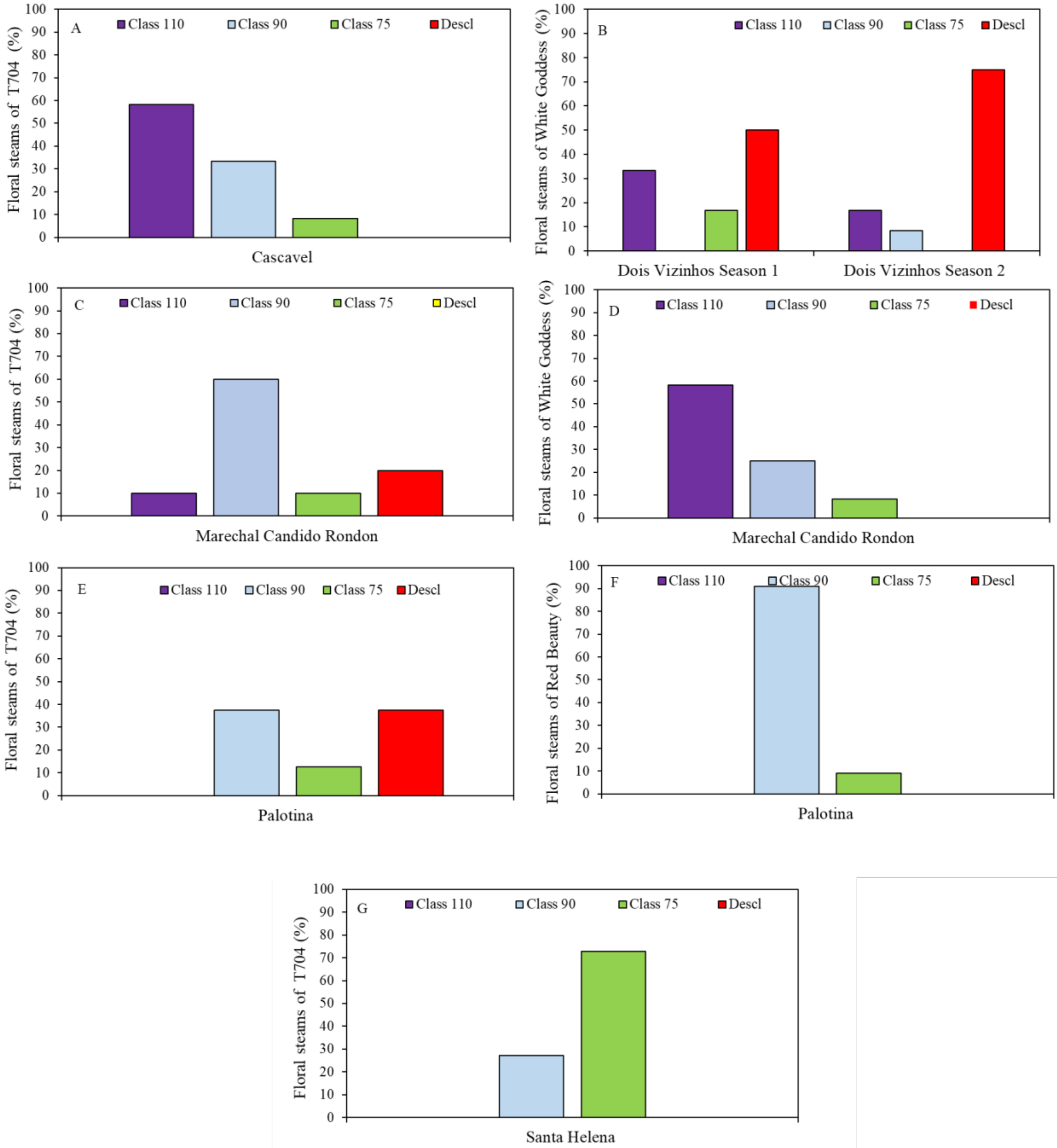

Figure 6. Commercialization classes of gladiolus floral stems according to Veiling Holambra (2013) standards for (A) Cultivar T704 - Cascavel; (B) Cultivar White Goddess - Dois Vizinhos experiments 1 and 2; (C) Cultivar T704 - Marechal Cândido Rondon ; (D) Cultivar White Goddess - Marechal Cândido Rondon; (E) Cultivar T704 - Palotina (F) Cultivar Red Beauty - Palotina and (G) Cultivar T704 - Santa Helena.

Table 4
Average final number of florets of different gladiolus cultivars, in different towns of the state of Paraná

	Average Final Number of Florets		
Towns/Paraná	Early	Intermediate II	Late
Palotina	18	15	-
Santa Helena	-	15	-
Marechal Cândido Rondon	-	14	17
Dois Vizinhos	-	-	17
Cascavel	-	16	-

No floral stems were disqualified for cultivation in the towns of Cascavel and Marechal Cândido Rondon (White Goddess cultivar), Palotina (Red Beauty cultivar), and Santa Helena (T704). In Dois Vizinhos, in both growing seasons, there was a high rate of declassified floral stems of 50 and 75% for seasons 1 and 2, respectively; however, a high (17) average final number of florets (Table 4) was observed. Therefore, the climatic conditions of the location may have contributed to the high percentage of declassified stems. The two growing seasons had lower maximum temperatures than did the other growing locations. In addition, the climatic conditions were not favorable (low solar radiation and low temperatures during the growing season) for the formation of long stems (Zubair et al., 2006).

It is important to emphasize that the cultivation of gladiolus on small farms (family farming) and the sales of floral stems are made in local trade and open fairs; that is, the producer does not classify the stems according to the standards of Veiling Holambra (2013). Even if the stems are smaller than the standard, producers sell them in fairs and local trading centers.

The data obtained from experiments conducted in the southwest region of Paraná (Cfa climate) indicate that for the production of gladiolus flower stems in the quality standards in class 110, we suggest the cultivars T704 and White Goddess, of intermediate cycles I and II, respectively. These cultivars have better adaptation to climatic conditions and produce long and high-quality stems when exposed to ideal growing conditions.

Conclusions

The PhenoGlad model was validated and showed accuracy in simulating the stages of development of the gladiolus crop in the state of Paraná, which is an important tool for flower producers to reliably schedule the planting date. This model is suitable for predicting extreme temperature damage to floral stems. The best performance of the model was observed when simulating the vegetative period of the crop, with a low level of error.

In the state of Paraná, for production of floral stems for the All Souls' Day, the PhenoGlad model simulated the planting dates in the different towns studied from

August 1 to August 23 for early cycle, July 18 to August 14 for intermediate II cycle, and July 7 to August 6 for late cycle. Planting dates were defined according to the different climatic conditions in each region of the state.

The towns of Cascavel and Marechal Cândido Rondon presented the highest number of florets and stem quality, which was higher than the other towns evaluated.

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