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PhenoGlad model and the zoning of gladiolus planting dates in the State of Santa Catarina, Brazil

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ABSTRACT

The objective of this study was to evaluate the PhenoGlad model for its use in SC climatic conditions and to propose the zoning of the best planting dates of gladiolus, aiming at marketing for Mother's Day, Valentine's Day, and All Souls' Day in SC, based on the PhenoGlad model and tools of Geographic Information Systems. Initially, we evaluated PhenoGlad model performance to simulate plant development with the phenological data collected in the field and the statistics used were: Root Mean Square Error (RMSE), BIAS Index (BIAS), Pearson's Correlation Coefficient (r), and Index of Agreement (dw). Afterwards, the best planting dates were simulated with the PhenoGlad model. Statistics showed that the model satisfactorily simulated the harvest time with an average RMSE of 3.5 days, BIAS < 0, dw and r > 0.99. Cultivation aiming at harvesting for Mother's Day, in SC, can be carried out in any region without restrictions. For municipalities located in the Midwest, Santa Catarina Plateau, and Santa Catarina North Plateau there is a planting restriction for the Valentine's Day. For All Souls' Day, late cycle cultivars have greater cultivation restrictions than early cycle cultivars. These restrictions are due to the low temperatures that can jeopardize the plant development at the end or beginning of the cycle.

Introduction

Floriculture is a significant part of Brazilian agribusiness, and it is also an option for diversification and income generation in small rural properties, along with olericulture. The commercial part of gladiolus are the floral stems composed of several florets, which can have different colors that are used as floral arrangements, ornamentation of ceremonies (Tombolato et al., 2010; Schwab et al., 2019), and an edible flower (Souza et al., 2021). In Brazil, its main commercialization peak occurs on All Souls' Day, but it is commercialized on Mother's Day, Valentine's Day, Christmas, and New Year's Day (Schwab et al., 2019). Therefore, it is important to consider that the flower harvesting needs to occur before the marketing dates to ensure that the plants are available to customers on peak demand days, guaranteeing income for producers.

Environmental and genotypic conditions interfere with the growth, development, and quality of gladiolus flower stems. Among the environmental conditions that can influence the crop, air temperature stands out (Shillo & Halevy, 1976, Streck et al., 2012). Gladiolus cultivation can be carried out throughout the year, provided that the thermal requirements are met, that is, average air temperatures between 10ºC and 25ºC (Lim, 2014). Plants do not tolerate severe frosts (Lim, 2014, Schwab et al., 2018), and high temperatures above 34ºC are also harmful, since they can cause burns on the sepals and petals and the last florets of the spike may not open (Uhlmann et al., 2017).

The growth and development processes can be characterized by mathematical models, which allow describing the interactions between the plant and the environment and also help in crop management. Studies show the various applications of these models, such as forecasting crop yield (Setiyono et al., 2010; Morell et al., 2016; Leng, 2017; Ojeda et al., 2018), assessing the impact of climate change on crop production (Raymundo et al., 2018; Hernandez-Ochoa et al., 2018), and even for determining the best planting and sowing dates (Andarzian et al., 2015; Tomiozzo et al., 2021).

PhenoGlad is a mathematical model that has been developed to simulate leaf emission and gladiolus developmental stages (Uhlmann et al., 2017). The model simulates the leaf appearance through the daily leaf appearance rate and the development through the accumulation of the daily development rate, both calculated using the approach described in Wang & Engel (1998). The model uses a non-linear response, that is, the relationship between air temperature and crop development rate is non-linear; it also considers specific genotype conditions, such as number of leaves and cycle duration. To perform a simulation, it is necessary for the user to introduce meteorological data of maximum and minimum daily air temperature into the model. The model has field applications due to the simulation of the occurrence day of the development stages, including important dates such as the harvest time. This model was previously calibrated and validated for nine different cultivars and four development cycles in southern Brazil (Uhlmann et al., 2017).

The planting date plays an important role in regulating gladiolus growth and quality (Sudhakar & Kumar, 2015). It is one of the main factors for picking flowers at the desired time, as it results in changes in elements such as air temperature and solar radiation, available to the plant. According to Schwab et al. (2018), gladiolus has its development cycle reduced during periods of high air temperatures and it is prolonged in lower air temperatures.

Therefore, the adoption of planting dates that provide climatic conditions close to those required by the plants is essential for a good productive performance. Delay in harvesting, smaller size of flower stems, and reduction in the number of florets are some characteristics modified by inadequate planting date. Production scheduling is especially important for crops that are more commercialized on specific dates, such as gladiolus. In these cases, the planting date plays a key role so that the plants are at the right time for harvest, and this time should be close to the marketing date (Schwab et al., 2019). For gladiolus, the collection of floral stems is recommended in two moments: the first, when the florets are not yet open, which is ideal for marketing to distant places; and the second, when at least three florets are open, which is ideal for short production circuits (Schwab et al., 2015).

Therefore, the motivations for the development of this scientific study were: i) The PhenoGlad model is a recent tool developed in southern Brazil that efficiently simulates gladiolus development; ii) due to the climate risks identified in the climate risk zoning for gladiolus in Santa Catarina State (SC) (Bonatto et al., 2021), the specification of the gladiolus planting date in the different regions of the State for peak demand periods is necessary in order to stimulate the production planning, ensuring the existence of quality flowers in times of greater market demand.

The purpose of this study was to evaluate the PhenoGlad model for its use in SC climatic conditions and to propose the zoning of the best planting dates, aiming at marketing for Mother's Day, Valentine's Day, and All Souls' Day in SC, based on the PhenoGlad model and tools of Geographic Information Systems.

Material and Methods

This study was carried out for the State of Santa Catarina, located in the center of the southern region of Brazil. According to the Köppen climate classification, 40.1% of the State is Cfa climate, humid subtropical with hot summers, and 59.9% is Cfb climate, humid subtropical climate with mild summers (Alvares et al., 2013).

In this study, 13 field experiments were carried out with different cultivars, planting dates, and locations to analyze the PhenoGlad model performance and to validate the recommended planting dates for Mother's Day, Valentine's Day, and All Souls' Day (Table 1).

Field experiments were conducted according to the drip irrigation system recommendations for crops (Schwab et al., 2019) in three locations in Santa Catarina, representative of different geographic regions: Concórdia

Table 1. Experiments carried out with gladiolus in different locations in Santa Catarina, with different cultivars and planting dates.

Experiment number	Cultivars	Planting date	Municipality
1	Amsterdam[2], Gold Field[4], Green Star[3], Jester[3], Purple Flora[1], White Goddess[3]	06/20/2016	Curitibanos
2	Amsterdam[2], Gold Field[4], Green Star[3], Jester[3], Purple Flora[1], White Goddess[3]	07/22/2016	Curitibanos
3	Black Velvet[3], Gold Field[4], Jester[3], Peter Pears[2], White Goddess[3]	02/09 to 02/22/2017	Curitibanos
4	Black Velvet[3], Gold Field[4], Jester[3], Peter Pears[2], White Goddess[3]	03/02 to 03/11/2017	Curitibanos
5	Amsterdam[3], Jester Gold[4], Red Beauty[3], Rose Friendship[1]	06/28 to 07/24/2017	Curitibanos
6	Amsterdam[3], Jester[3], Jester Gold[4], Red Beauty[3], Rose Friendship[1]	07/28 to 08/09/2017	Concórdia
7	Amsterdam[3], Jester[3], Jester Gold[4], Red Beauty[3], Rose Friendship[1]	07/07 to 08/04/2017	Rio do Sul
8	Jester[3], Red Beauty[3], Rose Supreme[3], White Goddess[3]	02/12/2018	Curitibanos
9	Fidélio[3], Jester[3], Red Beauty[3], Rose Supreme[3], White Goddess[3]	03/03/2018	Curitibanos
10	Fidélio[3], Jester[3], Red Beauty[3], Rose Supreme[3], White Goddess[3]	02/15/2018	Concórdia
11	Fidélio[3], Jester[3], Red Beauty[3], Rose Supreme[3], White Goddess[3]	03/08/2018	Concórdia
12	Jester[3], Red Beauty[3], Rose Supreme[3], White Goddess[3]	02/19/2018	Rio do Sul
13	Fidélio[3], Jester[3], Red Beauty[3], Rose Supreme[3], White Goddess[3]	03/09/2018	Rio do Sul

* [1] Early Cultivars, [2] Intermediate I Cultivars, [3] Intermediate II Cultivars, and [4] Late Cultivars.

(West), Curitibanos (Santa Catarina Plateau), and Rio do Sul (Itajaí Valley). In these experiments, the occurrence dates of vegetative and reproductive development stages were observed according to the gladiolus phenological scale (Schwab et al., 2015). Daily evaluations were carried out to obtain the date of occurrence of the emergence (EM), beginning of heading (R1); first three flower buds at the bottom of the ear show the color – harvest time 1 (R2), and end of flowering (R5) stages. Gladiolus total cycle was divided into two phases: the vegetative phase (EM-R1) and the reproductive phase (R1-R5).

PhenoGlad model assessment

The PhenoGlad model (Uhlmann et al., 2017) was used to simulate the development of gladiolus plants. The model input data were daily minimum and maximum air temperature (°C), planting date, and cultivar, or, if the cultivar is unknown, the development cycle. The model assessment in simulating the stages of development was done with data collected in the field experiments. For each planting date, cultivar, and location, the model was run starting from the emergence date.

The statistics used to evaluate the performance of the model were: Root Mean Square Error (RMSE) (Janssen & Heuberger, 1995), BIAS Index (De Leite & Andrade, 2002), Pearson correlation coefficient and Index of Agreement (Willmott, 1981), and Percent Deviation.

The results obtained through the root mean square error statistics were subjected to analysis of variance at a 5% error probability level, using the R statistical analysis program (R Development Core Team, 2013). The random error was calculated through the coefficient of variation obtained from the difference between the data observed in the field and the data obtained in the model.

Determination and spatialization of the best planting date

Based on the evaluation results of the PhenoGlad model for the SC conditions, the best gladiolus planting date was determined. The input data in the model were maximum and minimum air temperature (°C). In this study, 107 points distributed throughout the State were used, extracted from the daily meteorological variables grid in Brazil (Xavier et al., 2016). The historical temperature series correspond to the period from 1980 to 2013.

The model was run for all years of meteorological data and for the four gladiolus development cycles (early, intermediate I, intermediate II, and late), aiming to find the planting date that would produce plants with stage R2 (first three flower buds of the lower part of ear showing color), from the Schwab et al. (2015), five days before the sale dates of Mother's Day (second Sunday of May), Valentine's Day (June 12), and All Souls' Day (November 2). The period indicated for planting gladiolus was considered the average of the dates found for each year.

After determining the best planting date for each of the 107 points in the State, the QGIS® 2.18 software (QGIS Development Team, 2019) was used to perform the interpolation using the Inverse Distance Weighting (IDW) technique. To carry out the technique, it was necessary to create a shapefile of the municipalities in the State (IBGE, 2018). In order to identify municipalities with a planting date not indicated for a given marketing date, it was necessary to superimpose the maps generated with the Agricultural Climate Risk Zoning for gladiolus (Bonatto et al., 2021).

Interpolation evaluation

After generating the maps, the interpolation was evaluated using 20 meteorological stations representing the different regions of SC: Araranguá, Blumenau, Caçador, Campos Novos, Chapecó, Concórdia, Curitibanos, Dionísio Cerqueira, Florianópolis, Itajaí, Ituporanga, Joaçaba, Joinville, Lages, Major Vieira, Ponte Serrada, Rio do Campo, Rio Negrinho, São Miguel do Oeste, and Xanxerê.

The maximum and minimum air temperature data obtained from the meteorological stations of the National Institute of Meteorology (INMET), the Brazilian Agricultural Research Corporation (EMBRAPA), and the Environmental and Hydrometeorology Information Center of Santa Catarina (CIRAM/EPAGRI) underwent a triage to identify discrepant data and failures in the analyzed period. Missing data for the 1980-2013 period were filled in with data from Xavier et al. (2016), and the points used to fill in the observed stations were not previously used to obtain dates for interpolation. For periods prior to 1980 and between 2014-2017, the filling was carried out with the daily average of the time series for each location. Results evaluation was performed by calculating the error as described by Dirks et al. (1998).

Results and Discussion

PhenoGlad model assessment

The statistics confirm that the PhenoGlad model managed to capture the variations in the harvest time of the existing flower stems between the different regions of SC. The index of agreement and the correlation coefficient were greater than 0.99, the BIAS index was close to zero, and the RMSE did not differ statistically in the three regions where the experiments were carried out, with an average of 3.5 days (Table 2), showing that the PhenoGlad model has a high capacity to predict the occurrence date of the crop development stages when used in different climate conditions in SC.

In the 13 experiments carried out in three different municipalities in SC, totaling 26 different planting times, the development stages were simulated with an RMSE of 6.9 days (Figure 1A). When analyzing only the model prediction by simulating the vegetative stages (Figure 1B), the RMSE was 7.1 days, and in the simulation of the reproductive stages the RMSE was 6.6 days (Figure 1C). The model had a greater error when simulating the stages of vegetative development. One hypothesis for this result is that, initially, in the crop development there is formation of a structure called cataphyll (Schwab et al., 2015), that can be easily confused with the leaf. Therefore, if at some point this structure was counted as a leaf, this may have influenced the model's prediction (Figure 1B).

Table 2. PhenoGlad model performance statistics for simulating the harvest time (R2) of gladiolus in representative regions of the sites with field experiments in Santa Catarina.

Region	RMSE (days)[NS]	BIAS	dw	r
Santa Catarina Plateau	3.9	-0.0017	0.9994	0.9989
West	3.1	-0.0012	0.9996	0.9995
Itajaí Valley	3.4	0.00460	0.9995	0.9991
Average	3.5	0.00057	0.9995	0.9992

* NS – Means do not differ according to ANOVA, at the 5% probability level

The prediction of the R2 stage, that is, the time used to harvest the stems, showed satisfactory model performance with indices of agreement close to unity, BIAS close to zero, correlation coefficient of 0.99, and RMSE of 3.5 days (Figure 1D). Through the percent deviation, that ranged in this phase from -4.06 to 4.22, we observe a model tendency to overestimate this stage. Furthermore, in a total of 54 observations, the model overestimated 54% of them, 5.5% were exact, and 40.5% were underestimated. Due to the greater overestimation tendency, we considered that for the indicated flower stems harvesting date to be safer, it would be necessary to add a period of five days before the date of sale in the simulations. Therefore, we considered the estimation error for the three-day model when simulating the R2 development stage, and two more days for the grower to prepare the product for sale after harvesting. The percentage of the harvest date underestimation is not as critical as the overestimation, since advancing the harvest time allows managements that make it possible to postpone the opening of the flowers until the desired date by storing them in a cold chamber (Schwab et al., 2019).

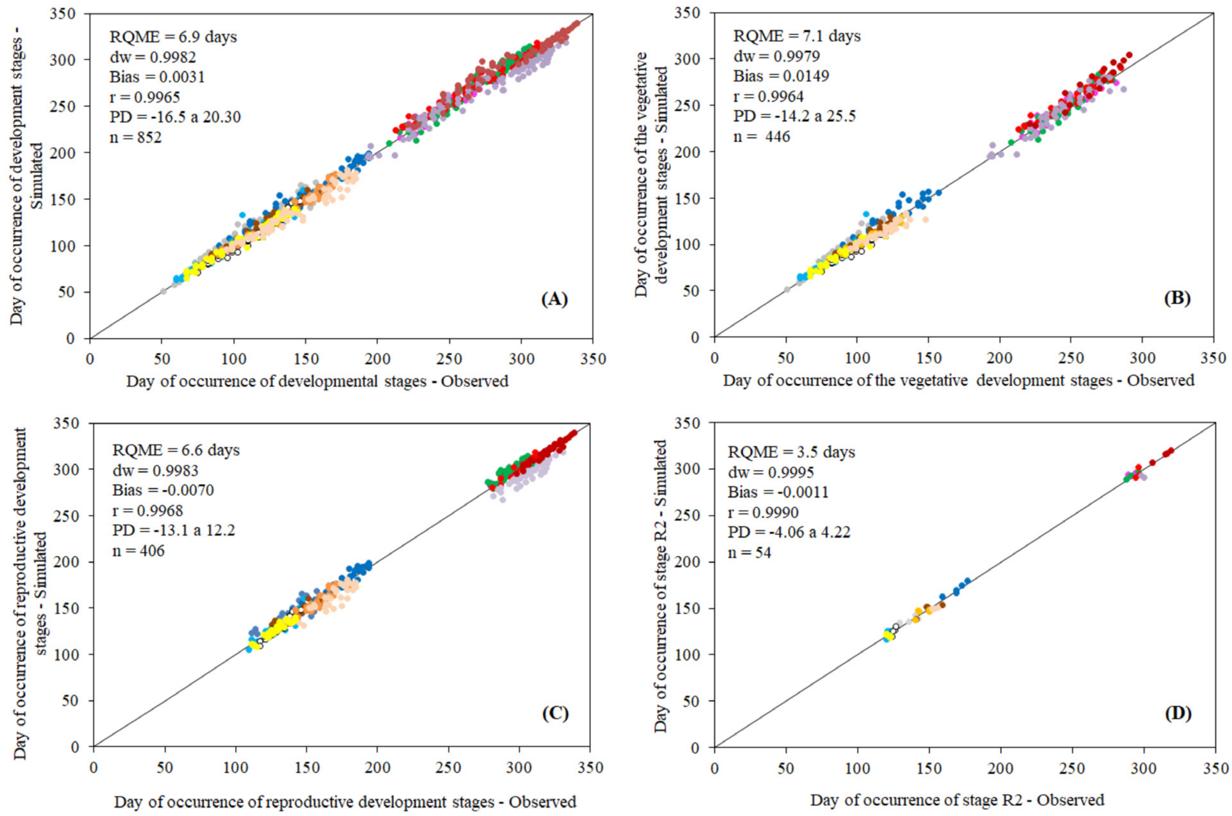
The 89.6% random error showed that the errors found in the simulation are difficult to clarify, since they were caused by variable elements (in space and time) that happen unpredictably and cannot be controlled, or that were not controlled, such as soil temperature, meteorological elements already mentioned, and distance between the meteorological station and the location of the experiments (Rosa et al., 2015; Uhlmann et al., 2017).

In recent evaluations of the PhenoGlad model carried out for the State of Paraná (PR), the RMSE was 3.4 days in the total cycle duration simulation and 2.6 days in the harvest time stage simulation (Becker et al., 2023). In Rio Grande do Sul State, the RMSE for the reproductive phase ranged from 4.8 to 5.2 days (Ulhmann et al., 2017). In Santa Catarina, the model performed similarly to the location of its development and calibration (RS) and to the locations tested in PR, demonstrating stability and accuracy for different locations in southern Brazil.

Zoning of the best planting dates

For the early development cycle gladiolus plants to be ready for harvesting in order to be marketed on Mother's

Figure 1. Results simulated with the PhenoGlad model and observed in the field for all development stages (A), for the vegetative development stage (B), the reproductive development stage (C), and the R2 development stage (time used to harvest the stems - D). Each experiment (E) is represented by a color, purple (E1), burgundy (E2), gray (E3), dark blue (E4), red (E5), pink (E6), green (E7), light blue (E8), brown (E9), yellow (E10), salmon (E11), white (E12), and orange (E13). RQME = Root mean square error (RMSE); dw = Index of agreement; BIAS = BIAS index; r = Pearson's correlation coefficient; PD = Percent deviation; n = Number of observations.



Day, the best planting dates are between February 17th and March 2nd. For the intermediate I cycle, the dates are between February 13th and 27th; for intermediate II, between February 8th and 22nd; and for the late cycle, between January 29th and February 16th (Figure 2).

For marketing on Valentine's Day, planting dates for early cycle cultivars are between March 6th and 25th; for intermediate I cycle, between March 3rd and 23th; for intermediate II cycle, between February 26th and March 18th; and for the late cycle, between February 18th and March 12th (Figure 3).

For All Souls' Day marketing, the indicated harvest dates are between June 29th to August 11th; June 25th to August 5th; June 20th to July 29th; and June 6th to 20th for early development, intermediate I, intermediate II, and late cycles, respectively (Figure 4).

Results show that, regardless of the marketing season, the regions of the Far West, North, and Coast of SC, must carry out later plantings when compared to the Plateau region. This condition occurs due to the climatic specifications of each region. According to the Köppen classification, the Plateau has a Cfb-type climate - humid subtropical with mild summers. Rainfall is well distributed throughout the year, with its accumulation ranging from 1,100 to 2,000 mm, without dry seasons. It has an average air temperature of approximately 22°C in the hottest month, and occurrence of frequent frosts from 10 to 25 days, annually (Alvares et al., 2013; Pandolfo et al., 2002). However, the West and the Coastal region have a Cfa climate, humid subtropical with hot summers; air temperatures are above 22°C in summer, and the driest month has precipitation above 30 mm (Alvares et al., 2013; Pandolfo et al., 2002). Therefore, municipalities that have a Cfb climate, with milder temperatures that extend the gladiolus cycle duration, need to plant earlier than municipalities with a Cfa climate classification, characterized by higher temperatures that reduce the plant cycle. Since the air temperature is the main element influencing the gladiolus development, when the air temperature increases, there is a reduction in the cycle duration and vice versa (Streck et al., 2012; Schwab et al., 2018).

For marketing on Mother's Day, there is no planting restriction in SC. However, considering the fall beginning, that is, air temperatures in decline at the end of March, there may be a delay in plant development at some point. Therefore, we recommend perform planting in the first dates of the indicated planting period, especially for the municipalities in the Midwest, Santa Catarina Plateau, and Santa Catarina North Plateau regions. For example, for the municipality of Curitibanos, the planting period indicated

Figure 2. Zoning of the best planting dates for the early (A), intermediate I (B), intermediate II (C), and late (D) development cycle, with harvest expected for sale on Mother's Day, in Santa Catarina, Brazil.

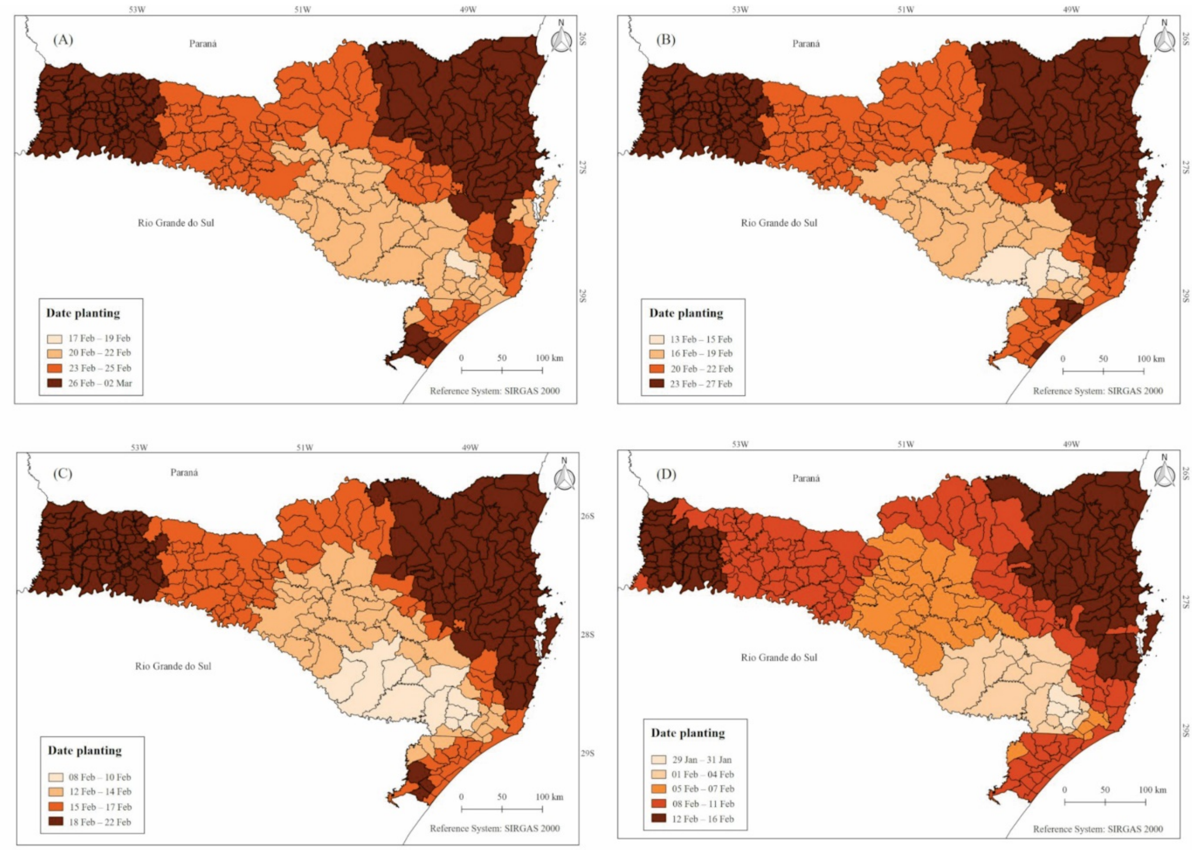


Figure 3. Zoning of the best planting dates for the early (A), intermediate I (B), intermediate II (C), and late (D) development cycle, with harvest expected for sale on Valentine's Day, in Santa Catarina, Brazil.

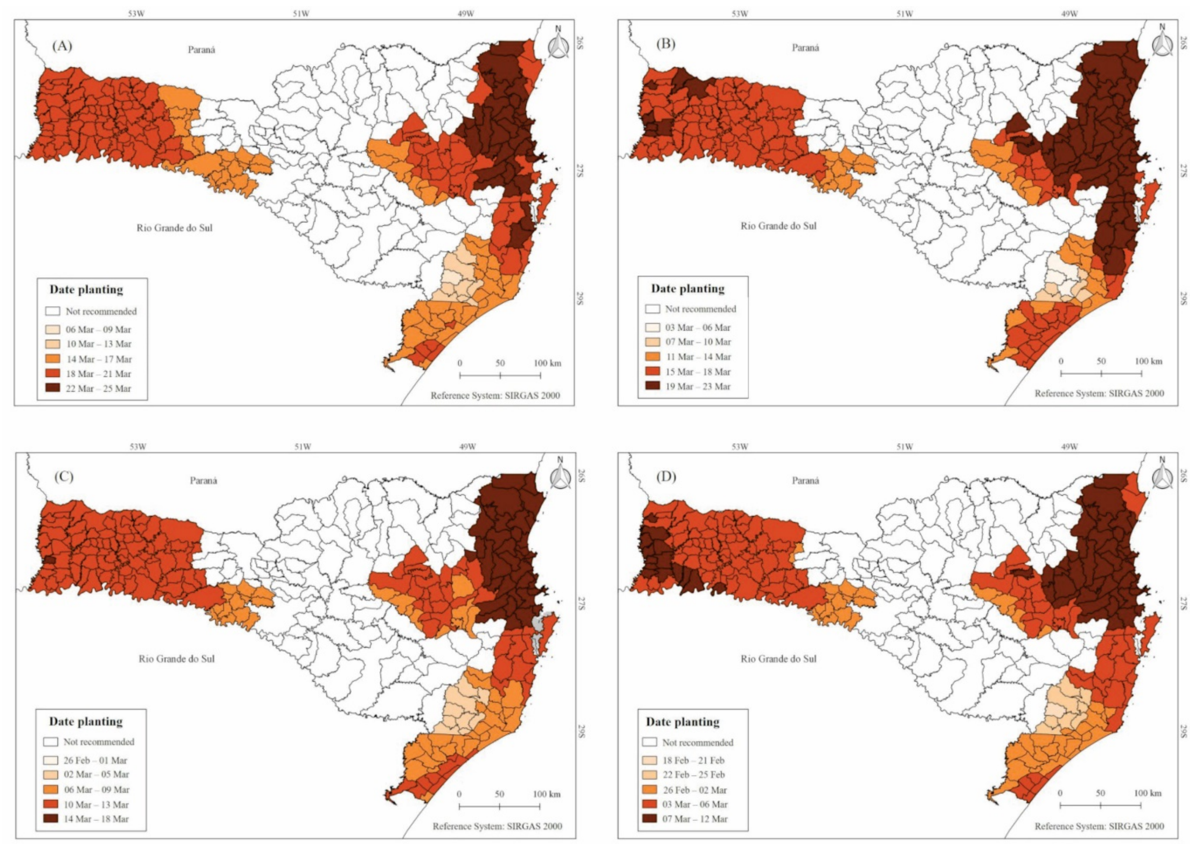
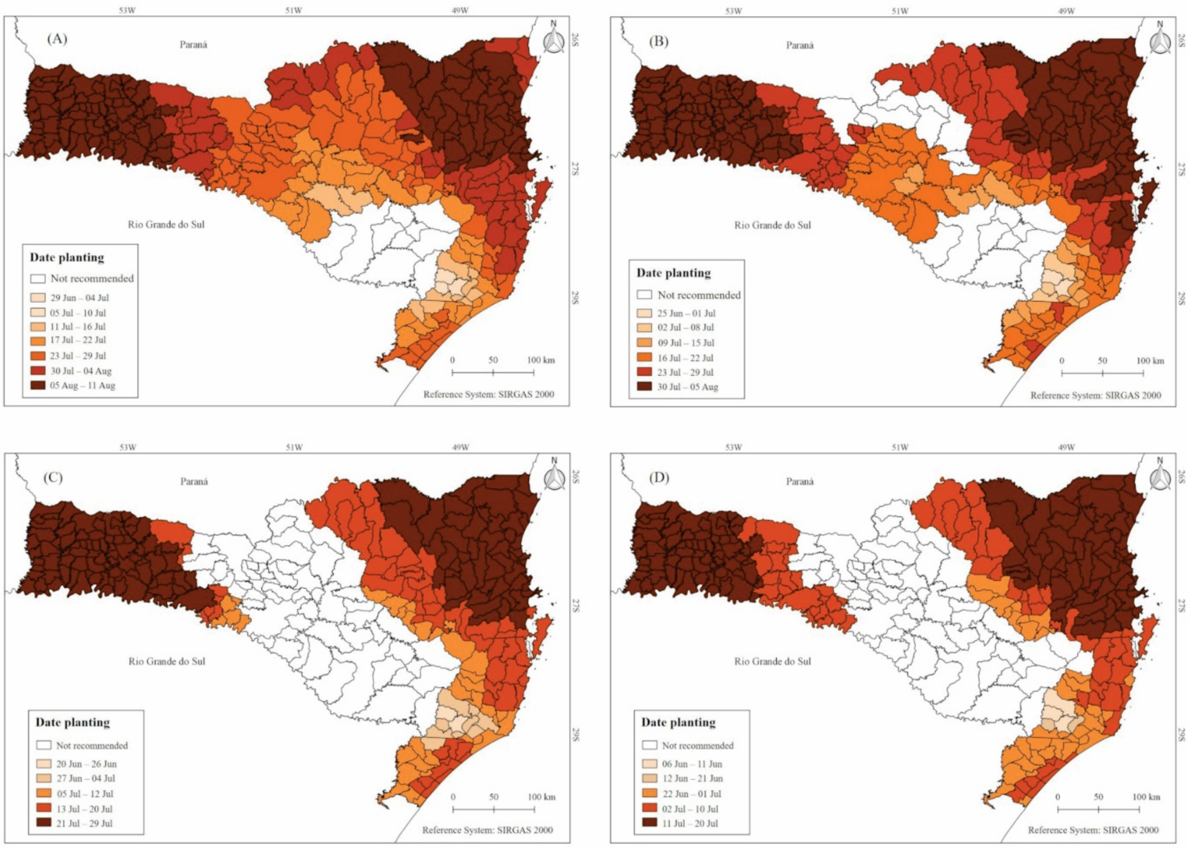


Figure 4. Zoning of the best planting dates for the early (A), intermediate I (B), intermediate II (C), and late (D) development cycle, with harvest expected for sale on All Souls' Day, in Santa Catarina, Brazil.



for cultivars with an early cycle is from February 20th to February 22nd, thus, planting on February 20th should be recommended.

For marketing on Valentine's Day, there is a planting restriction in at least 26% of the municipalities in Santa Catarina for the different development cycles. Planting is possible in the Far West, Coastal, and Itajaí Valley region, as the risk of frost in there is lower. The development period of the plants will occur in March, April, May, and June, with these months inserted in the period when frosts commonly occur in the State, between April and September, being more intense in June and July. In July, the plants will already be in the reproductive phase, almost entering the harvest time, and they become more susceptible to the occurrence of frosts. Thus, Midwest, Santa Catarina Plateau, and Santa Catarina North Plateau regions, which have the Cfb climate, do not allow planting due to the risk of frost during the development period of the plants (Wrege et al., 2018).

For All Souls' Day there is a reduction in the number of sites recommended for planting gladiolus. For the late-cycle cultivars, that is, those with a longer development cycle, cultivation is more restricted, since planting should take place earlier, from late June to mid-July, which is the most critical period regarding frosts in the State. In the municipalities of Irineópolis, Canoinhas, Bela Vista do Toldo, Três Barras, Major Vieira, Monte Castelo, and Mafra, planting is allowed for cultivars of all development cycles. If choosing cultivars with a late cycle, planting should be carried out on the final dates of the indicated period. In the other municipalities, mainly located in the Midwest, Santa Catarina Plateau, it is recommend planting cultivars with a shorter cycle (early), such as White Friendship, Purple Flora, and Rose Friendship. Planting for the All-Souls' Day is not recommended in the municipalities of Capão Alto, Lages, São Joaquim, Bom Jardim da Serra, Urubici, Urupema, Rio Rufino, Bom Retiro, Painel, and Bocaina do Sul, which are the municipalities with the highest altitudes and with the highest risks of frost until the end of September, with risks ranging from 30 to 70% for these municipalities (Wrege et al., 2018).

The error found in the data interpolation for the generation of maps indicating the planting dates (IDW) ranged between 2.4% and 6.1%, with the highest and lowest percentage of errors being attributed to early and late cultivars, respectively, for the All-Souls' Day (Table 3). Therefore, if the cycle length of an early cultivar was 75 days and it was grown for the All-Souls' Day harvest, the error due to data interpolation was 1.8 days. For a late cultivar with a 90-day cycle, this error would have been

Table 3. Error percentage calculated in the interpolation of data used to generate maps indicating the zoning of planting dates for gladiolus, performed using the Inverse Distance Weighting (IDW) technique.

Cycle	Mother's Day	Valentine's Day	All Souls' Day
Early	4.7	4.4	2.4
Intermediate I	3.9	3.9	2.8
Intermediate II	4.5	4.3	3.0
Late	3.0	3.0	6.1
Average	4.0	3.9	3.6

5.5 days.

Conclusion

The PhenoGlad model performs satisfactorily when simulating the development stages of gladiolus in Santa Catarina. The date of the harvest time stage was better simulated than the vegetative and reproductive stages.

In the State of Santa Catarina, there is no restriction on planting gladiolus for Mother's Day harvesting.

The municipalities located in the Midwest, Santa Catarina Plateau, and Santa Catarina North Plateau have a planting restriction for the Valentine's Day due to low the temperatures, while there is no planting restriction for the Far West, Coastal, and Itajaí Valley regions.

For All Souls' Day, late cycle cultivars have greater cultivation restrictions than early cycle cultivars in SC.

Author contributions

L.C. BOSCO, M.I. BONATTO and N.A. STRECK design and guidance from the project. L.T. STANCK, A.G. DE SOUZA, O.B. ROSSATO and M.I. BONATTO driving of the experiment and data collection and revision of the manuscript. M.I. BONATTO, L.C. BOSCO and C. PANDOLFO performance of data analysis, statistical analyses, original writing of the manuscript.

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Modelo PhenoGlad e o zoneamento de datas de plantio para gladíolo em Santa Catarina

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RESUMO

O objetivo deste estudo foi avaliar o modelo PhenoGlad para sua utilização nas condições climáticas de SC e propor o zoneamento das melhores épocas de plantio de gladíolo, visando a comercialização para o Dia das Mães, Dia dos Namorados e Finados em SC, com base no Modelo PhenoGlad e ferramentas de Sistemas de Informação Geográfica. Realizou-se a avaliação do desempenho do modelo PhenoGlad para simular o desenvolvimento das plantas com dados fenológicos coletados a campo, sendo as estatísticas utilizadas: Raiz do quadrado médio do erro (RMSE), Índice BIAS (BIAS), Coeficiente de correlação de Pearson (r) e Índice de concordância (dw). Com o modelo PhenoGlad simulou-se as melhores datas de plantio. O modelo simulou satisfatoriamente o ponto de colheita com RMSE médio de 3,5 dias, BIAS < 0, dw e r > 0,99. O cultivo visando colheita para o Dia das Mães em SC pode ser realizado em qualquer região sem restrições. Para municípios no Meio-Oeste, Planalto Serrano e Planalto Norte há restrição de plantio para o Dia dos Namorados. Para Dia de Finados as cultivares de ciclo tardio têm maior restrição que as cultivares de ciclo precoce. Essas restrições decorrem das baixas temperaturas que podem comprometer o desenvolvimento das plantas no final ou no início do ciclo.

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