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Climate risk zoning for gladiolus production under three climate change scenarios[1]

Zoneamento de risco climático para gladíolo em cenários de mudança climática

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HIGHLIGHTS:

Warmer regions have the shortest recommended period for planting throughout the year in the three climatic scenarios.
Colder regions will be favored in climate change scenarios as there will be less damage from low temperatures.
Strategies need to be developed to minimize damage by high temperatures in gladiolus.

ABSTRACT: The objective of this study was to develop a climate risk zoning for damage to gladiolus due to low and high temperature under climate change scenarios projected by the end of the century in the Rio Grande do Sul State, Brazil. The PhenoGlad model was used in this study to determine the recommended periods for planting gladiolus throughout the year across the Rio Grande do Sul State. The model was run for daily planting dates (from 01 January to 31 December), for different gladiolus developmental cycles (Early, Intermediate I, Intermediate II and Late). The climate change scenarios were from CMIP5: RCP2.6, RCP4.5 and RCP8.5, representing optimistic, intermediate and pessimistic scenarios of greenhouse gases emission, respectively. Planting dates were considered recommended when crop damage, due to high or low temperatures, occurred in less than 10% of the years. Warmer regions like Uruguaiana and Iraí have the shortest recommended time for planting throughout the year in the three climate change scenarios. Plantings between August and December are predicted to be the most affected and are not recommended because of the higher chance of damage from high temperatures. Colder regions like Bom Jesus will be favored in climate change scenarios since there will be an extended recommended period for planting in the seasons of the year that currently suffer damage by low temperatures. To meet demands of gladiolus during the hottest period of the year, it will be necessary to develop techniques to reduce damage from high temperatures in the crop, such as more tolerant cultivars or the use of shading screens on the crop.

Key words: *Gladiolus* x *grandiflorus* Hort., rising temperature, heat injuries, planting date

RESUMO: Objetivou-se neste estudo desenvolver um zoneamento de risco climático para a cultura do gladíolo nos cenários de mudança climática previstos para o final do século no Rio Grande do Sul, considerando a ocorrência de danos causados por altas e baixas temperaturas. O modelo PhenoGlad foi utilizado neste estudo para determinar os períodos recomendados para plantio ao longo do ano em todo o Rio Grande do Sul. O modelo foi rodado para datas de plantio diários (de 01 janeiro a 31 dezembro), para diferentes ciclos de desenvolvimento da cultura (Precoce, Intermediário I, Intermediário II e Tardio). Os cenários de mudança climática utilizados foram do CMIP5: RCP2.6, RCP4.5 e RCP8.5, representing optimist, intermediate and pessimist scenarios of greenhouse gases emission, respectively. As datas de plantio foram consideradas recomendadas quando danos na cultura por altas ou baixas temperaturas ocorreram em menos de 10% dos anos avaliados. Regiões mais quentes como Uruguaiana e Iraí apresentam o menor período recomendado para plantio ao longo do ano nos três cenários climáticos. Plantios entre agosto e dezembro não são recomendados devido a maior chance de danos por altas temperaturas. Regiões mais frias como Bom Jesus serão favorecidas nos cenários de mudança climática, pois haverá uma ampliação do período recomendado para plantio nas épocas do ano que atualmente sofrem danos por baixas temperaturas. Para atender à demanda de gladíolo durante os períodos mais quentes do ano, será necessário desenvolver técnicas para reduzir os danos por altas temperaturas na cultura, como cultivares mais tolerantes ou o uso de telas de sombreamento sobre a cultura.

Palavras-chave: *Gladiolus* x *grandiflorus* Hort., aumento da temperatura, danos por calor, data de plantio

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Introduction

Gladiolus (*Gladiolus* x *grandiflorus* Hort.) is one of the most important bulb flower crops worldwide (Thakur et al., 2015). In Brazil, gladiolus has become an important cut flower for small farmers, because it is an easy-to-produce crop that requires low initial cost and can be cultivated in the open field. These farmers sell their flowers weekly at local fairs together with other products produced locally with fair price to the consumer and good profit to farmers (Uhlmann et al., 2019). In addition, the expansion in flower production in the state of Rio Grande do Sul, Brazil, is important for meeting the demand of the State, which currently imports about 90% of cut flowers (IBRAFLOR, 2019).

Ornamental plants, especially those grown in open fields such as gladiolus, are greatly dependent on environmental conditions during the growing season. Changes in temperature may cause major losses in ornamental plants because the market requires that flowering must occur within a rather narrow time window to meet market demand (Snipen et al., 1999; Fisher & Lieth, 2000; Munir et al., 2015), and heat stress or frost may cause injuries on the floral stem, killing plants or reducing flower quality (Uhlmann et al., 2017; Schwab et al., 2018). The climatic risk zoning is a tool to assist farmers in defining the best periods for the production of quality floral stems, considering damage by high and low temperatures in the floral stem (Uhlmann et al., 2020).

The latest report of the Intergovernmental Panel on Climate Change (IPCC) indicates an average global temperature increase of 0.85 °C during the period from 1880 to 2012, with the largest increase in the 1900s (IPCC, 2013). Longterm responses of crops to climate change may drive policy makers' decisions, management practices, and breeding programs. It is important to provide farmers with information on how climate change will affect suitable and unsuitable areas for gladiolus cultivation throughout the year due to the occurrence of damage by high and low temperatures. Therefore, the objective of this study was to develop a climate risk zoning for gladiolus under climate change scenarios projected by the end of the century in the state of Rio Grande do Sul, Brazil, considering damage due to low and high temperatures.

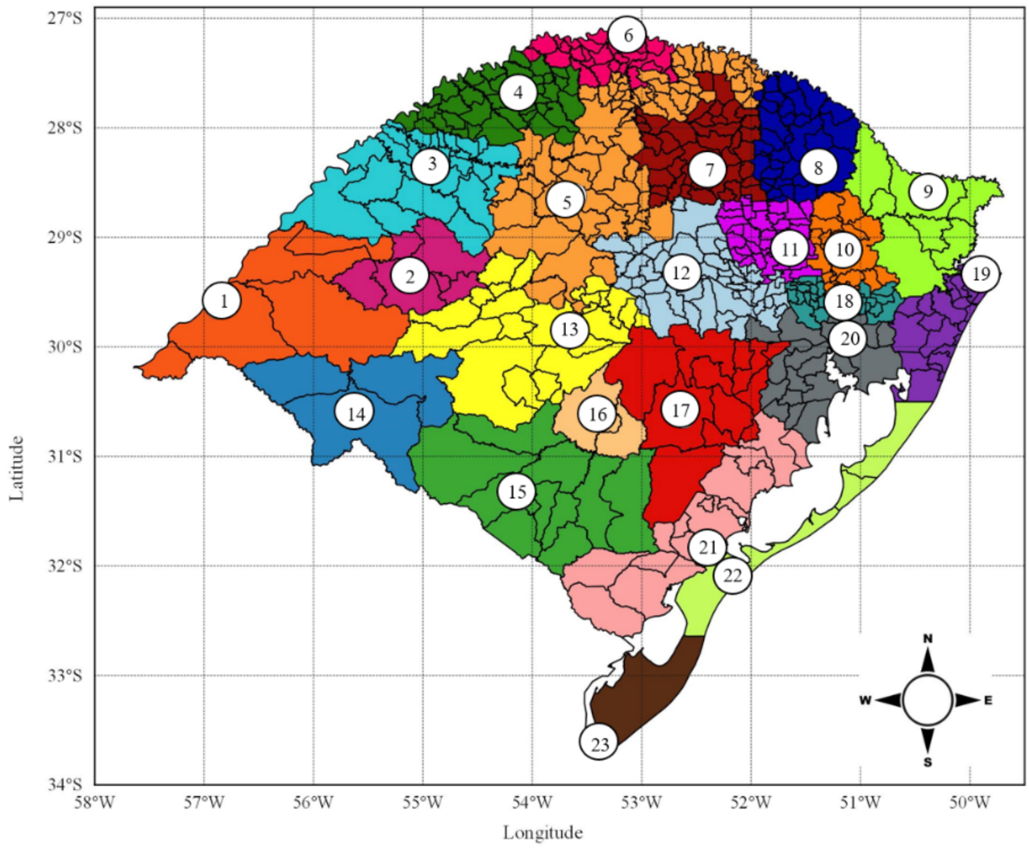
Material and Methods

The recommended and non-recommended periods for planting gladiolus were determined for three climate change scenarios from the Assessment Report Five (AR5) of the IPCC, derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5). The scenarios were RCP2.6, RCP4.5 and RCP8.5 (RCP stands for Representative Concentration Pathway), representing optimistic, intermediate and pessimistic scenarios of greenhouse gases emission, respectively. Climate scenarios were generated with the global ocean-atmosphere HadGEM-ES model (Jones et al., 2011) with 250 km of spatial resolution and used as a boundary condition for downscaling to a regional basis with 81 km of resolution with the RegCM4 (Regional Climate Model, version 4). The projection of an increase in temperature and CO_2 concentration until 2100 is 1.7 °C and 421 ppm for the RCP2.6 scenario, 2.6 °C and 538 ppm for the RCP4.5 scenario, and 4.8 °C and 936 ppm for the RCP8.5 scenario (IPCC, 2013). Two periods were used for each grid points: 1976 to 2005 (baseline period) and 2070 to 2098 (for each climatic scenario).

The current climate risk zoning in RS (Uhlmann et al., 2020) was developed using a high-resolution meteorological data set of minimum and maximum daily air temperatures of 34 years (1980-2013) proposed by Xavier et al. (2016). These data were used because of the low density of meteorological stations across the state. The 497 municipalities of the RS were grouped into 23 homogeneous regions and, 23 points by Xavier et al. (2016) were selected for the study, these being close to the existing weather stations.

The PhenoGlad model (Uhlmann et al., 2017), a dynamic process-based gladiolus phenology model that was previously calibrated and validated with different cultivars, planting dates, years and locations from experiments conducted in two states in Southern Brazil, Rio Grande do Sul and Santa Catarina, was used in this study. Input data required to run the PhenoGlad model included daily minimum and maximum air temperatures, planting or emergence date and cultivar or developmental cycles (Early, Intermediate I, Intermediate II and Late). The PhenoGlad model also simulates the occurrence of crop injuries caused by low (freezing) and high (heat) temperatures. When the daily minimum temperature (Tmin) is lower than −2 °C during at least three days in a row from emergence to the R5 stage (end of florets senescence), then the crop is killed by frost. If the minimum temperature is lower than or equal to −2 °C during one day or if −2 °C < T min < 3 °C during four days in a row during the reproductive phase, then the floral stem is killed by frost. Heat injury in PhenoGlad is considered when the maximum temperature is greater than or equal to 34 °C during three consecutive days during the reproductive phase, causing severe burning of sepals (Schwab et al., 2018). If the maximum temperature is higher than 48 °C, the upper lethal temperature is reached, and the crop is killed by heat.

The 497 municipalities of the RS State were grouped into 23 homogeneous regions (Figure 1) regarding the influence of macroclimatic factors, such as altitude, latitude, continentality, oceanity, and relief (Uhlmann et al., 2020), and each region was represented by a meteorological data grid point. The PhenoGlad model was run for daily planting dates from 01 January to 31 December, for the current period and for each climatic scenario and, the four gladiolus developmental cycles (Early, Intermediate I, Intermediate II and Late), which vary in their developmental cycle from 69 to 121 days for early cultivars and from 85 to 148 days for late cultivars (Becker et al., 2021), for the 23 regions of the State. The recommended planting dates were considered when the PhenoGlad model identified the occurrence of high and low temperature damage in less than 10% of the evaluated years. The 10% limit was considered in this study as being stricter and consequently more adequate to define the climatic risk zoning of an ornamental plant such as gladiolus (Uhlmann et al., 2020). The results were presented on maps using QGIS software and the future climate risk zoning was compared with the current climatic risk zoning for the crop.



(1) Uruguaiana, (2) São Francisco de Assis, (3) São Luiz Gonzaga, (4) Santa Rosa, (5) Cruz Alta, (6) Iraí, (7) Passo Fundo, (8) Lagoa Vermelha, (9) Bom Jesus, (10) Bento Gonçalves, (11) Caxias do Sul, (12) Soledade, (13) Santa Maria, (14) Santana do Livramento, (15) Bagé, (16) Caçapava do Sul, (17) Encruzilhada do Sul, (18) Igrejinha, (19) Torres, (20) Porto Alegre, (21) Pelotas, (22) Rio Grande and (23) Santa Vitória do Palmar

Figure 1. Location of the 23 homogeneous regions distributed in the State of Rio Grande do Sul, Brazil, used in this study to determine the climate risk zoning of gladiolus in climate change scenarios

Results and Discussion

The recommended periods for planting gladiolus throughout the year in six representative regions of Rio Grande do Sul, considering the current climatic risk zoning, the baseline period and the three possible climatic scenarios for the end of the century are shown in Figure 2. These six regions of the State have the greatest climate contrast on air temperature, altitude, continentality and oceanity.The recommended period for planting gladiolus in the current zoning (black lines on Figure 2) is much larger than the baseline period, mainly for the regions of Uruguaiana (Figure 2A), Iraí (Figure 2B), Santa Maria (Figure 2D) and Bagé (Figure 2E). This can be explained because the minimum temperatures are lower in the current zoning (Figures 3A, C, G, I) and maximum temperatures are much higher in the baseline period than in the current zoning (Figures 3B, D, H, J). This indicates that, for the baseline period, a shorter period throughout the year is recommended for planting due to the higher occurrence of damage caused by high temperatures that coincide with the reproductive phase of the crop (Uhlmann et al., 2017). Therefore, plantings from July until January are not recommended for the baseline period.

In the Bom Jesus (Figure 2C) and Rio Grande (Figure 2F) regions, the recommended planting period is very similar between the current zoning (black lines on Figure 2) and the baseline period because, although extreme temperatures (minimum and maximum) occur, they are less frequent and do not occur during the critical periods of the crop (Figures 3E, F, K, L). Warmer regions of the State such as Uruguaiana (Figure 2A) and Iraí (Figure 2B) have the shortest recommended period for planting throughout the year in the three future climate change scenarios. This is because the temperatures are even higher and increase the occurrence of damage the gladiolus crop by high temperatures (Figures 3A, B, C, D). In order to meet demands of gladiolus during the hottest period of the year, it will be necessary to develop techniques to reduce damage by high temperatures, such as more tolerant cultivars or even the use of shading screens.

With increasing air temperature there is a tendency to change the recommended planting period as a more pessimistic scenario is considered. Due to cold temperatures, plantings between the months of March and May are not recommended in most regions according to the current zoning, yet in future climatic scenarios this period is recommended for planting, mainly in the RCP4.5 and RCP8.5. Plantings from August to December are not recommended due to the higher chance of damage caused by high temperatures during the flowering period of the crop. The Rio Grande region does not show large variations in the minimum and maximum temperatures between the scenarios and the current period and, therefore, maintains the entire period of the year recommended for planting.

With respect to different developmental cycles of gladiolus, the tendency is that Late cultivars need to be planted earlier than Early cultivars to escape the occurrence of high-temperature damage during the reproductive period of the

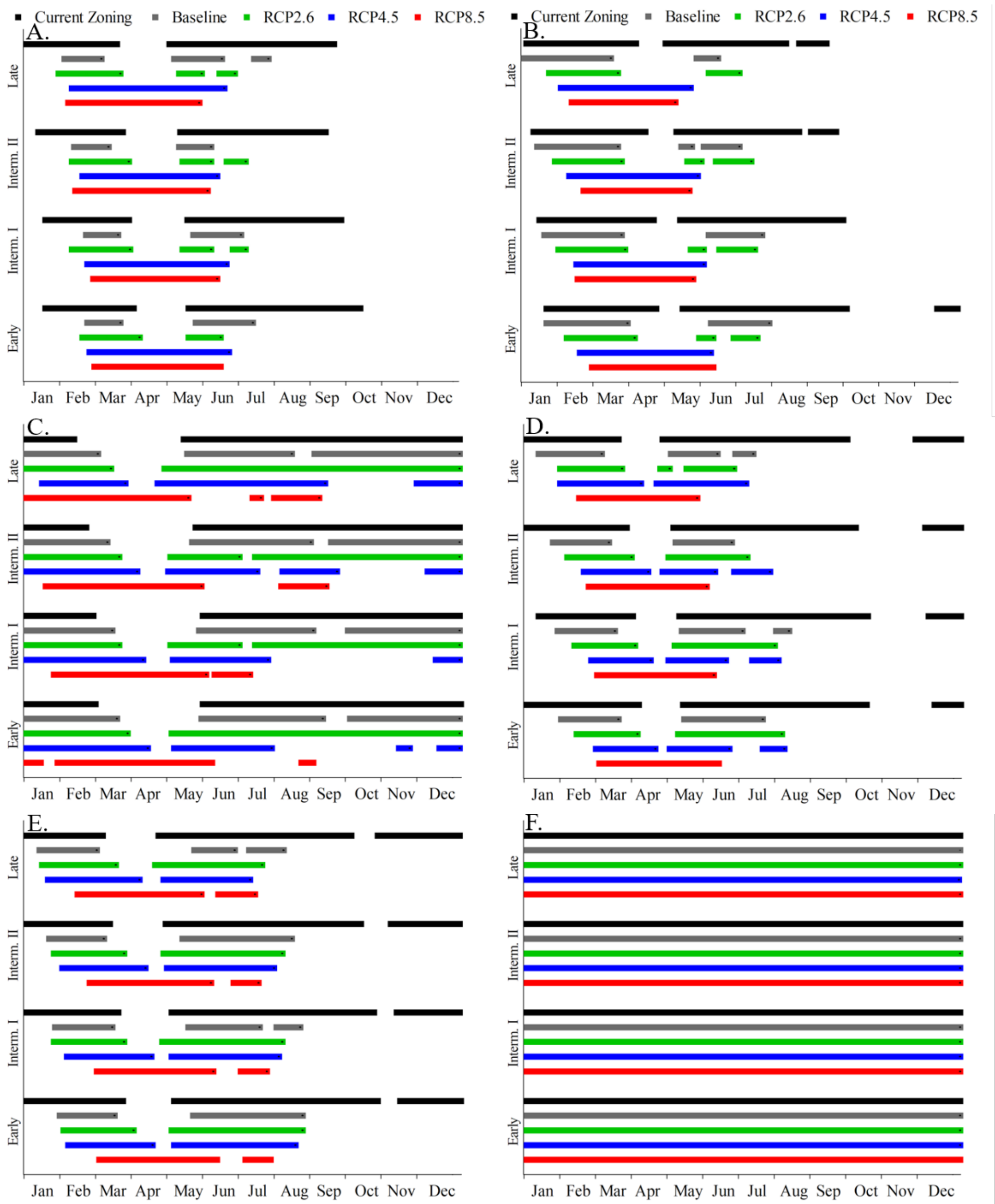


Figure 2. Recommended (solid lines) and non-recommended (gaps within the solid lines) planting periods in (A) Uruguaiana region, (B) Iraí region, (C) Bom Jesus region, (D) Santa Maria region, (E) Bagé region and Rio Grande region (F) for Early, Intermediate I, Intermediate II and Late gladiolus under the current zoning, baseline period and RCP2.6, RCP4.5 and RCP8.5 scenarios

crop. For example, for the Santa Maria region (Figure 2D), in the RCP8.5 scenario, the recommended planting period is from 09 February to 20 May for Late cultivars, from 22 February to 30 May for Intermediate II cultivars, from 01 March to 05 June for Intermediate I and from 03 March to 09 June for Early cultivars. Therefore, in order to avoid a period of extreme temperatures, the planting of Late cultivars must begin before and be ended before the planting of Early cultivars.

It is also noted that there will be a greater gap in production of gladiolus to meet certain seasons of the year in some regions such as Uruguaiana, Iraí, Santa Maria and Bagé, even if the less pessimistic scenario occurs (RCP2.6). To meet the demands during the hottest period of the year it will be necessary to develop techniques to reduce damage by high temperatures, like burned sepals (Schwab et al., 2018), such as more tolerant cultivars or the use of shading screens. The use of screens reduces the occurrence of sunburned peppers during the summer months in Southern Spain (López-Marin et al., 2011) and its effect on gladiolus crop still needs to be studied.

Colder regions such as Bom Jesus will be greatly favored in climate change scenarios and they will have an increase in the recommended period for planting gladiolus in the months that damage previously occurred due to low temperatures in the crop (Figure 2C). In scenarios 4.5 and 8.5, these colder regions will suffer more from high temperatures, so no plantings between June and December are recommended for

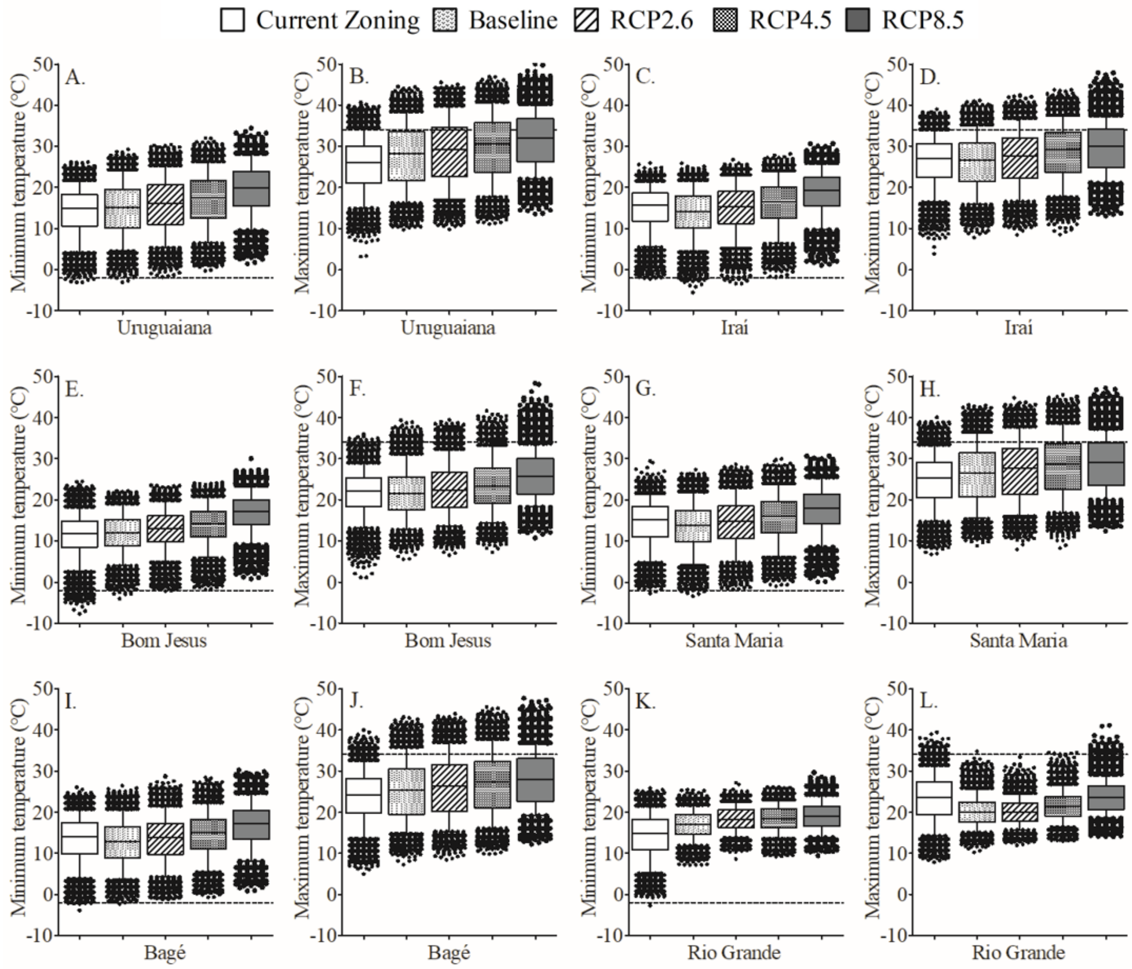


Figure 3. Minimum and maximum air temperatures during the current zoning (1980 to 2013), during the baseline period (1970 to 2005) and for three climate change scenarios RCP2.6, RCP4.5 and RCP8.5 (2070 to 2098) in six regions of the state of Rio Grande do Sul: (A) and (B) Uruguaiana, (C) and (D) Iraí, (E) and (F) Bom Jesus, (G) and (H) Santa Maria, (I) and (J) Bagé, (K) and (L) Rio Grande. The dotted line at the bottom of the minimum temperature panels indicates the threshold of -2 °C below which the crop is killed by frost. The dotted line at the top of the maximum temperature panels indicates the threshold of 34 °C above which causes severe burning of sepals.

both developmental cycles in scenario 8.5. Similar results were obtained for rice in the State of Rio Grande do Sul, which had better conditions for cultivation in the Southern region due to the reduction of damage caused by low temperatures, while in the Western region the increase in temperature projected by climate change scenarios increases the spikelet sterility (Walter et al., 2014).

The quality of flowers is the most important factor that must be taken into account in the production of ornamental crops, unlike other field crops in which studies aim to find alternatives to improve productivity (Rio et al., 2015; Wang et al., 2015a, b). Most ornamental crops, unlike gladiolus, are grown in greenhouses, where the air temperature is modified (Moccaldi & Runkle, 2007), so studies on the effect of climate change scenarios are commonly performed for field crops (Bhattarai et al., 2017; Cera et al., 2017).

For gladiolus, the effect of climate change on flower stems production for two peaks of consumption, Mother's Day (Second Sunday of May) and All Souls' Day (02 November) has been previously studied (Becker et al., 2021). In order to meet the demand for floral stems on All Souls' Day, plantings should occur later in the growing season than is currently recommended, due to the shortening of the crop development cycle, and also a higher occurrence of damage due to high temperatures. In a similar way, this study shows that plantings in September, aiming to harvest for All Souls' Day, are included in climatic risk zoning as not recommended in the Uruguaiana, Iraí, Santa Maria and Bagé regions in both scenarios of climate change. For Bom Jesus it is still possible to grow gladiolus to meet the demand of All Souls' Day in the RCP2.6 scenario.

Planting of gladiolus to meet Mother's Day demand (planting in February) results in a lower occurrence of damage by high temperatures (Becker et al., 2021) since flowering occurs between April and May. In the zoning presented in this study, it was considered the 10% level which is more judicious, therefore, planting for Mother's Day is recommended only in the Rio Grande, Bom Jesus, and Bagé regions. For the Uruguaiana region, the cultivation is more restricted, mainly in scenarios of greater heating, like the RCP8.5 scenario. In Iraí it is still possible to produce gladiolus for this peak of consumption of Mother's Day in the RCP2.6 and RCP4.5 scenarios.

In order to better visualize the regions and periods recommended for planting, the climate risk zoning maps for

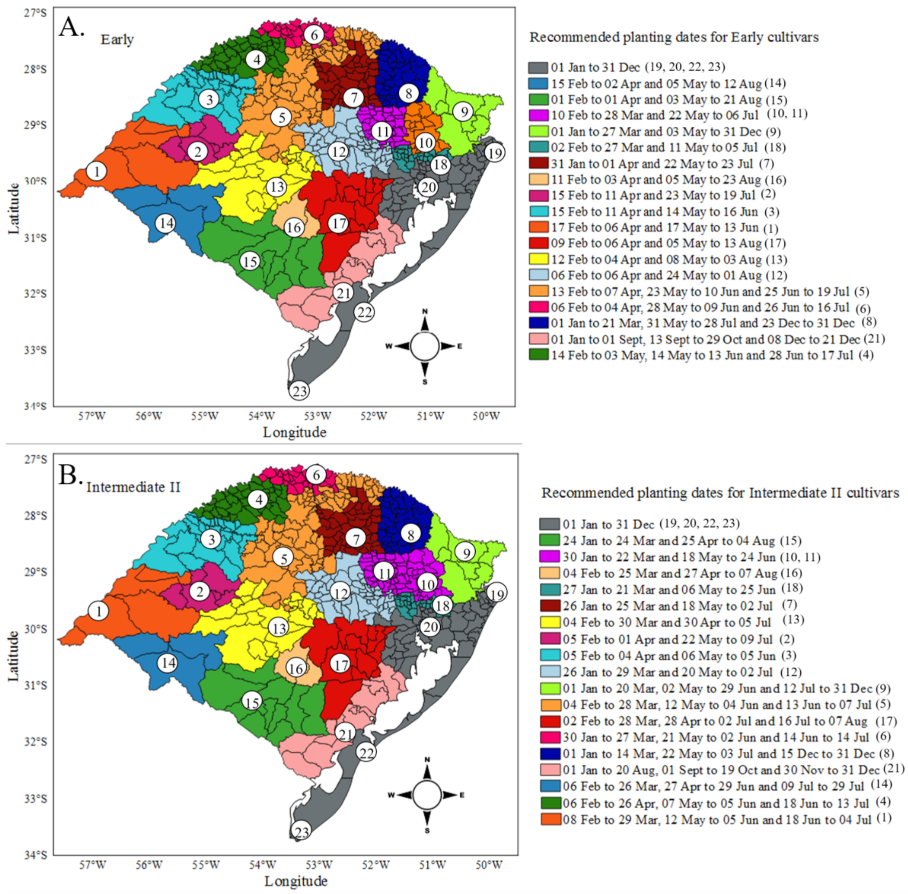


Figure 4. Climate risk zoning in the RCP2.6 optimist scenario of greenhouse gases emission for Early (A) and Intermediate II (B) gladiolus cultivars in the Rio Grande do Sul State. For name of the homogeneous region see Figure 1

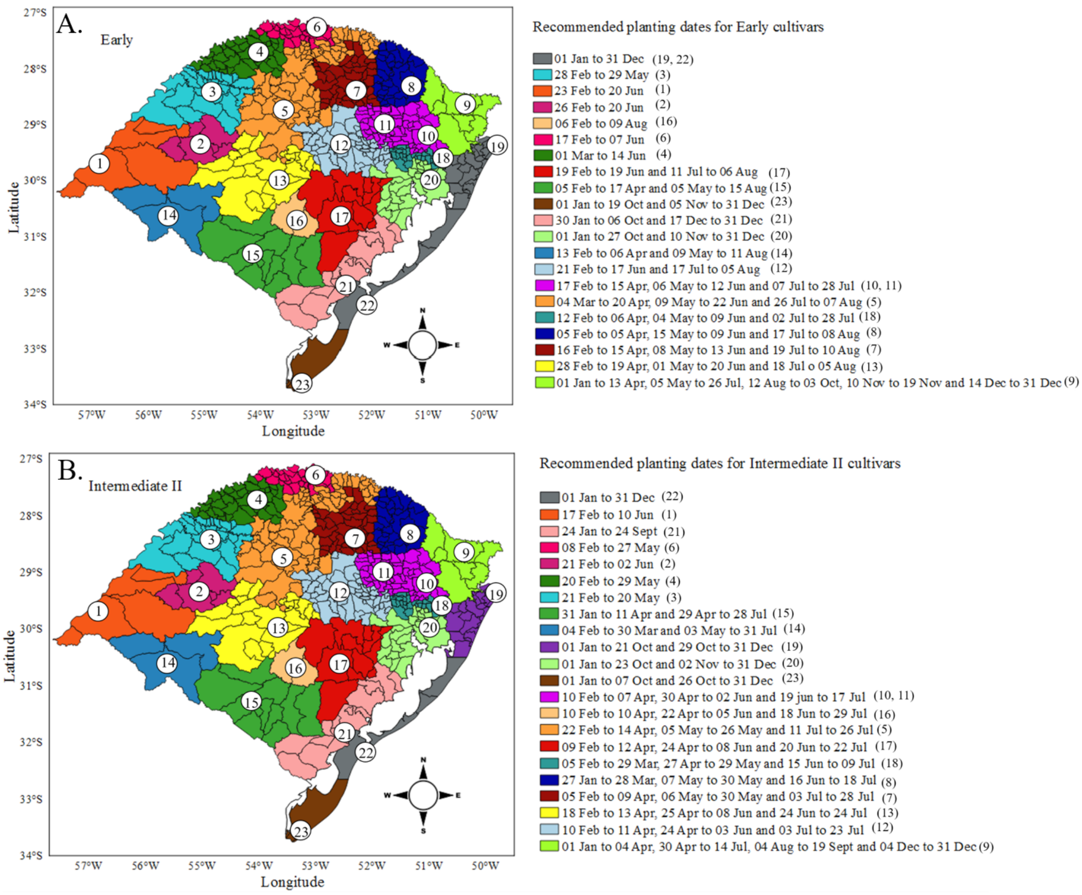


Figure 5. Climate risk zoning in RCP4.5 intermediate scenario of greenhouse gases emission for Early (A) and Intermediate II (B) gladiolus cultivars in the Rio Grande do Sul State. For name of the homogeneous region see Figure 1

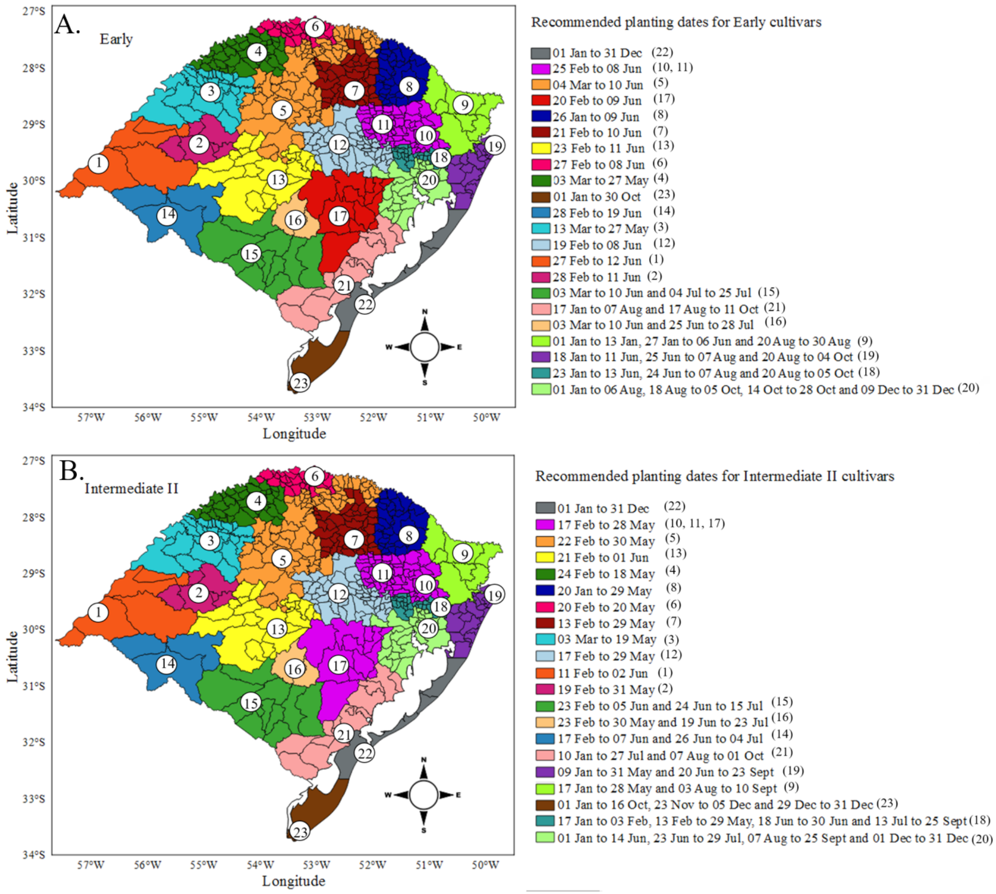


Figure 6. Climate risk zoning in the RCP8.5 pessimist scenario of greenhouse gases emission for Early (A) and Intermediate II (B) gladiolus cultivars in the Rio Grande do Sul State. For name of the homogeneous region see Figure 1

the climate change scenarios RCP2.6, RCP4.5 and RCP8.5 are presented below. In the RCP2.6 scenario (Figure 4), Early and Intermediate II cultivars can be planted throughout all the year in three regions of the State: Porto Alegre, Torres, Santa Vitória do Palmar and Rio Grande. From June (or August) to January, Early cultivars are not recommended for planting in the RCP2.6 scenario in most regions (Santa Rosa, São Francisco de Assis, Bento Gonçalves, Soledade, Santa Maria, Encruzilhada do Sul, Uruguaiana, São Luiz Gonzaga, Caçapava do Sul, Passo Fundo, Igrejinha, Caxias do Sul, Bagé and Santana do Livramento). This scenario, even though it is the least pessimistic, is already very worrisome, since there are 14 regions not recommended for planting gladiolus during seven months of the year. For the Intermediate II cultivars, the results are similar for plantings from June until December. Only the regions of Rio Grande, Torres, Porto Alegre, Santa Vitória do Palmar and Pelotas are recommended for planting from March to April due to the lower occurrence of low temperature damage (<10%).

In the RCP4.5 scenario (Figure 5), São Luiz Gonzaga, Uruguaiana, São Francisco de Assis, Iraí and Santa Rosa regions have recommended periods for planting Early cultivars only between February and June. In the RCP8.5 scenario (Figure 6), the same conditions are observed for the Caxias do Sul, Bento Gonçalves, Cruz Alta, Encruzilhada do Sul, Lagoa Vermelha, Passo Fundo, Santa Maria, Santana do Livramento and Soledade regions. Regions such as Bom Jesus, Igrejinha and Torres have recommended periods for planting Early cultivars only until August and October, due to the high occurrence of days with temperatures higher than 34 °C. The RCP8.5 scenario was also the most damaging to winter wheat in Australia because the lower frequency of cold days affects the process of vernalization (Wang et al., 2015a).

For Intermediate II cultivars, gladiolus plantings in the entire State of Rio Grande do Sul are recommended only between February and May. It is noteworthy that a large number of regions are not recommended for planting gladiolus in August and September, a time that aims to meet the demand for flower stems for All Souls' Day.

In the State of Rio Grande do Sul, the cultivated area with floriculture products is 1360 ha and consumption per capita is R$ 38.29 or US$ 9.57 (IBRAFLOR, 2019). However, about 90% of the cut flowers consumed in the state are imported from other Brazilian regions, to supply gladiolus demand. So, studies like these are of great importance and have practical applications for seeking adaptative strategies to enable the production of gladiolus by small farmers and ensure access to flowers produced locally in Southern Brazil.

Conclusions

1. Warmer regions of the Rio Grande do Sul State such as Uruguaiana and Iraí have the shortest recommended period for planting throughout the year in the three climate change scenarios.

2. Plantings from August to December are the most affected and not recommended due to the higher chance of damage

caused by high temperatures during the crop flowering under climate change scenarios.

3. Colder regions such as Bom Jesus will be greatly favored for gladiolus production since they will have increase in the recommended period for planting in the months that previously had crop damage caused by low temperature.

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