



Long-term changes in the optimum planting date of gladiolus in southern Brazil

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ABSTRACT. The objective of this work was to test long-term trends in the planting date of gladiolus to ensure marketing of these flowers on Mother's Day and All Souls' Day in Santa Maria (latitude: 29° 43' S, longitude: 53° 43' W, and altitude: 95 m), Rio Grande do Sul State, Brazil. Minimum and maximum air temperature data from 106 years were used (1912-2017) to simulate the optimum planting date indicated through the PhenoGlad model, aiming to harvest floral stems for both market dates for early, intermediate I, intermediate II and late cultivars. The homogeneity of the historical series was tested using the run test, and the historical trend was tested by the Mann-Kendal test. The magnitude of the trend was estimated with simple linear regression, and the descriptive statistics were calculated. For marketing on Mother's Day, there was no historical trend that implied a change in the planting date of gladiolus for any of the development cycles. For marketing on All Souls' Day, there was a positive historical trend only for the early and intermediate cycles I and II; thus, the increase in air temperature implied a delay of 9.2 days, 9.5 days and 6.9 days for the planting date, respectively, indicating that a shortening of the gladiolus development cycle occurred, mainly in late winter/early spring.

Keywords: *Gladiolus x grandiflorus* Hort.; climate change; crop calendars; agricultural management.

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Introduction

How will climate change affect agricultural production? Answering this question is of wide interest, including to future generations of farmers for mitigating climate change risks. The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) was released, reporting that the impact of the past decades of climate change on agriculture has been widespread and negative (IPCC, 2013). Agriculture is a more vulnerable sector of the economy because crop growth and development are affected by a strong genotype x environment interaction, which is highly driven by air temperature and its in-season variability.

The effect of temperature change has been demonstrated on several crops, including rice (Streck, Uhlmann, & Gabriel, 2012a), maize (Xiao et al., 2015; Tao et al., 2016), rye (Blecharczyk, Sawinska, Malecka, Sparks, & Tryjanowski, 2016), potato (Pulatov, Linderson, Hall, & Jönsson, 2015; Tryjanowski et al., 2018), and wheat (Rezaei, Siebert, Hüging, & Ewert, 2018). For ornamental crops, however, the effect of temperature change has not been studied. Gladiolus (*Gladiolus x grandiflorus* Hort.) is an important cut flower worldwide, and in Brazil, the peak demand of this flower is on Mother's Day (second Sunday in May) and All Souls' Day (November 2nd). Gladiolus is an open field crop, and its developmental rate is mostly driven by air temperature so that the developmental cycle from planting to harvest decreases as temperature increases (Streck et al., 2012b; Schwab et al., 2015a).

Cut flower farmers need to plan planting times so that flowers are ready on specific days. Therefore, an important implication of climate change is that increases in temperature may affect the optimum planting date for flowers that need to be ready on target days. The objective of this study was to test long-term changes in the optimum planting date of gladiolus with the aim of marketing the flowers on Mother's Day and All Souls' Day in Santa Maria, Rio Grande do Sul State, Brazil.

Material and methods

Daily data of minimum and maximum air temperature from January 1st, 1912 to December 31st, 2017 measured at the meteorological station of Instituto Nacional de Meteorologia (INMET) in Santa Maria (latitude: 29° 43' S, longitude: 53° 43' W, and altitude: 95 m), Rio Grande do Sul State, Brazil, totalling 106 years, were used.

Historical data from Xavier, King, and Scanlon (2016) were used where there were missing data, and additional missing data in the remaining periods were addressed based on climatology considering each of the El Niño Southern Oscillation (ENSO) phases (El Niño, La Niña, and Neutral). Two growing seasons were considered: from February to May (for selling the flowers on Mother's Day) and from July to October (for selling the flowers on All Souls' Day). When missing data covered more than 7 days in a row during each growing season, that year was removed from the analysis, resulting in 5.6% of the years for Mother's Day and 8.5% of the years for All Souls' Day being removed from the analysis.

Version 1.1 of the gladiolus PhenoGlad Model (available for free download at <http://coral.ufsm.br/phenoglad/>) proposed by Uhlmann et al. (2017) was used to simulate the optimum planting date to ensure flower stems would be ready for marketing on Mother's Day (second Sunday in May) and All Souls' Day (November 2nd) for 106 years of the historical weather series. Input data for running the PhenoGlad model were daily minimum and maximum air temperature, which were used to calculate the daily mean temperature that in turn was used in a nonlinear model by Wang and Engel (1998) to simulate the daily rate of gladiolus development.

The optimum planting date was assumed to be the planting date that enabled the R2 stage (first three florets at the bottom of the spike show the colour of the petals) of the Schwab et al. (2015b) phenological scale to be reached three days before the target day of selling the flowers (Mother's Day and All Souls' Day).

The homogeneity of the time series of the optimum planting day was tested by the non-parametric run (Z) test at 5%, in which the Z value was between -1.96 and 1.96 (Back, 2001). The trend in the time series of the optimum planting date that was not autocorrelated with the run test was tested by the nonparametric Mann-Kendall (MK) test (Sansigolo & Kayano, 2010). For the time series with a significant trend, a simple linear regression was tested to estimate the rate of the trend; i.e., the slope of the linear regression represented the change rate of the time series (Back, 2001). For the historical series of optimum planting dates, the descriptive statistics were calculated as the mean, minimum and maximum absolute value, standard deviation and coefficient of variation.

Results and discussion

Figure 1 shows the historical series (1912-2017) of the minimum and maximum air temperature variables with the linear regression equations in which the regression coefficient was significant. For Mother's Day, the linear regression (Figure 1) identified an increasing trend (positive) in minimum air temperature for February of 0.13°C per decade (Figure 1A) and a decreasing (negative) trend of 0.16°C and 0.12°C per decade for maximum air temperature in the months of February and March (Figure 1A and B), respectively.

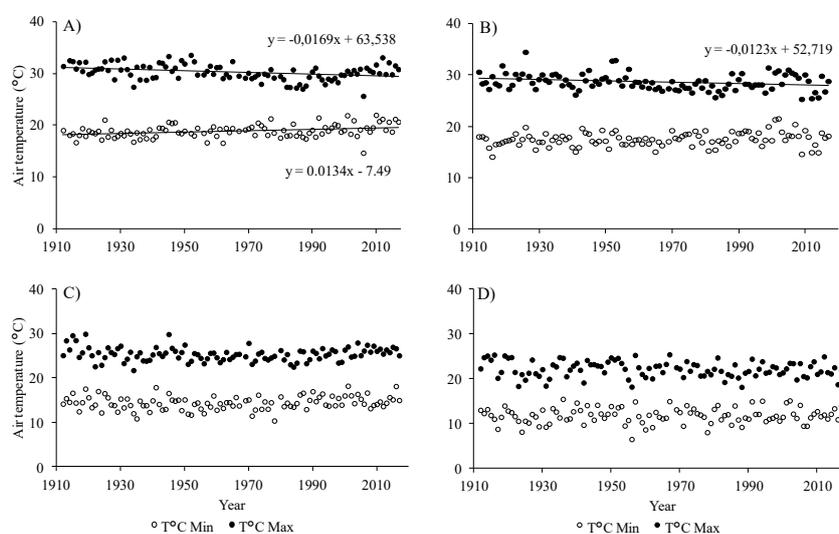


Figure 1. Maximum and minimum air temperature during 1912 - 2017 for the months of February (A), March (B), April (C), and May (D) (to Mother's Day harvest) in Santa Maria, Rio Grande do Sul State, Brazil.

For April and May, there was no significant increasing or decreasing trend for the minimum and maximum air temperatures (Figure 1C and D). For the All Souls' Day, there was a positive trend in the historical series of minimum air temperature for August (Figure 2B), September (Figure 2C), and October (Figure 2D), with an increase in magnitude of 0.19, 0.11, and 0.23°C per decade, respectively. For July (Figure 2A), there was no significant trend in the minimum and maximum air temperature. In August (Figure 2B), the maximum air temperature also showed an increasing trend of 0.11°C per decade.

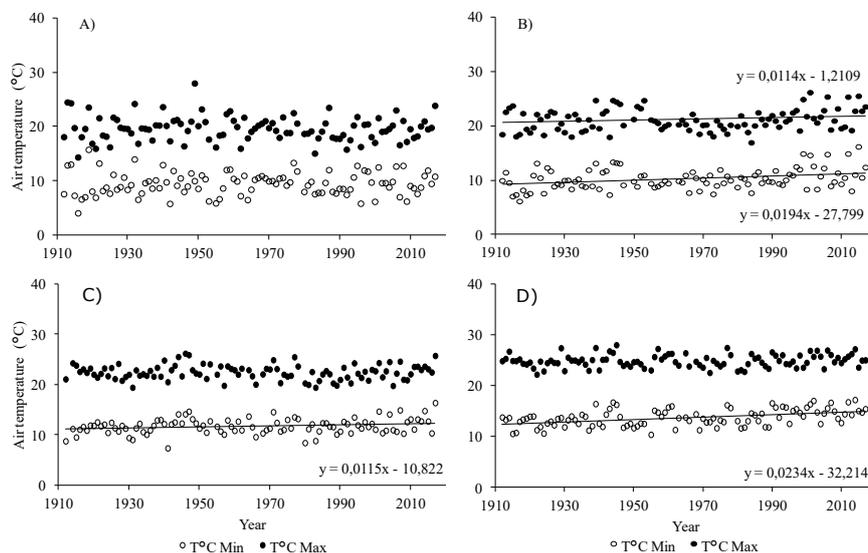


Figure 2. Maximum and minimum air temperature during 1912 - 2017, for the months of July (A), August (B), September (C), and October (D) (to All Souls' Day harvest), in Santa Maria, Rio Grande do Sul State, Brazil.

According to Streck, Gabriel, Buriol, Heldwein, and Paula (2011), for trend analysis studies, the use of long historical series (over 50 years) is recommended as the anthropic actions are taken into account in these studies. The increasing trend in minimum air temperature found in this study corroborates the results found by Sansigolo and Kayano (2010), who identified an increase of 0.17°C in the minimum temperature during 1913-2006 and no increasing trend in maximum air temperature in Rio Grande do Sul, and those of Marengo and Camargo (2008), who verified that from 1960 to 2002, the average annual minimum temperature increased from 0.5 to 0.8°C per decade and the maximum temperature was 0.4°C per decade in southern Brazil.

The Z test (Table 1) indicated that for both dates, the historical series of planting dates was homogeneous; that is, the value of Z for both situations remained within the range of -1.96 and 1.96 as noted in Back (2001). Thus, there was no heterogeneity in the data, indicating that the data were independently distributed for all developmental cycles of the gladiolus.

The MK test and linear regression (Table 1) did not identify a significant trend for changes in planting date for Mother's Day; therefore, in Figure 3, which presents the historical series for the optimal planting date (day of the year) aiming for harvest on this date, the trend lines are not presented. Thus, over 106 years, there was no significant tendency to delay or anticipate the planting date; that is, the planting date of gladiolus for harvest on Mother's Day is currently the same as a century ago.

Table 1. Sequence test or run test (Z), Mann-Kendall test (MK) and their probabilities and the linear regression confidence interval applied to the historical series of planting dates for each gladiolus developmental cycle for the Mother's Day and All Souls' Day in Santa Maria, Rio Grande do Sul State, Brazil, in 1912 - 2017.

Date	Cycle	Z	MK	Probability	Confidence Interval
Mother's Day	Early	-0.910	0.0658	0.3595	-0.008 - 0.020
	Intermediate I	-0.340	0.1106	0.1246	-0.008 - 0.021
	Intermediate II	0.914	0.1001	0.1591	-0.004 - 0.029
	Late	-1.103	0.0024	0.9736	-0.016 - 0.014
All Souls' Day	Early	-0.490	0.2614	*0.0004	*0.041 - 0.143
	Intermediate I	-1.745	0.2490	*0.0002	*0.037 - 0.152
	Intermediate II	-1.688	0.1292	0.0647	*0.003 - 0.134
	Late	-0.666	0.1133	0.1053	-0.004 - 0.122

*Significant tests with a 5% probability of error.

This stationary response occurred because during this growing season, despite the increase observed in minimum air temperature in February (Figure 1A), there was also a significant decrease in maximum air temperature in February and March (Figure 1A and B), and these changes were not sufficiently large to change the planting date.

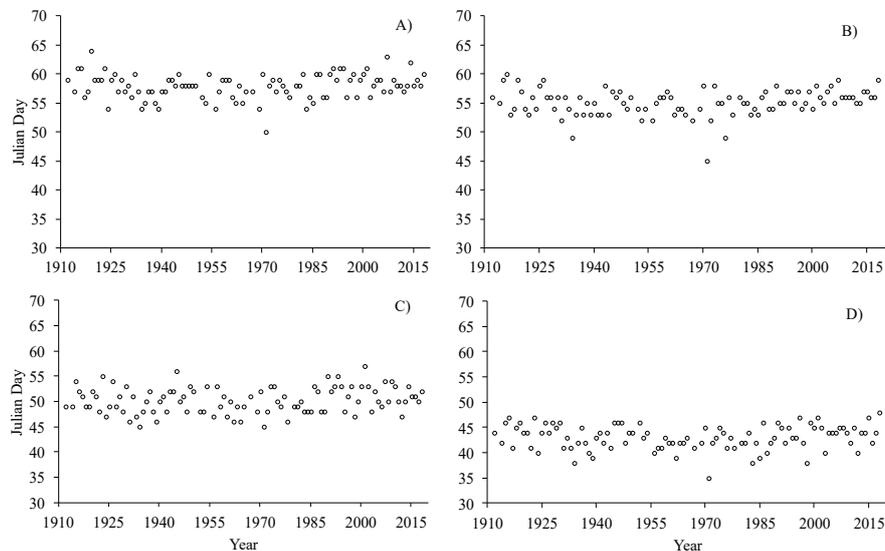


Figure 3. Planting date for R2 occurrence three days before Mother's Day for gladiolus cultivars with A) early, B) intermediate I, C) intermediate II, and D) late developmental cycles, during 1912 – 2017, in Santa Maria, Rio Grande do Sul State, Brazil.

The historical series of optimum planting dates (day of the year) for the All Souls' Day developmental cycles are presented in Figure 4. For the early (Figure 4A) and intermediate I cycles (Figure 4B), according to the MK and linear regression (Table 1), there was a significant positive trend in the series.

The regression analysis between the analyzed years and their respective planting dates (in day of the year) (Figure 4A and B) showed that for the early cycle, there was a delay of 0.92 days per decade, and for the intermediate cycle I, the delay was 0.95 days per decade. Intermediate cycle II did not present a significant trend with the MK test but was significant with the linear regression (Table 1), so the trend line is shown in Figure 4C, indicating a delay of 0.69 days per decade at the optimal planting date. For the late cycle (Figure 4D), there was no significant trend in the change in the planting date; thus, the trend line was not presented.

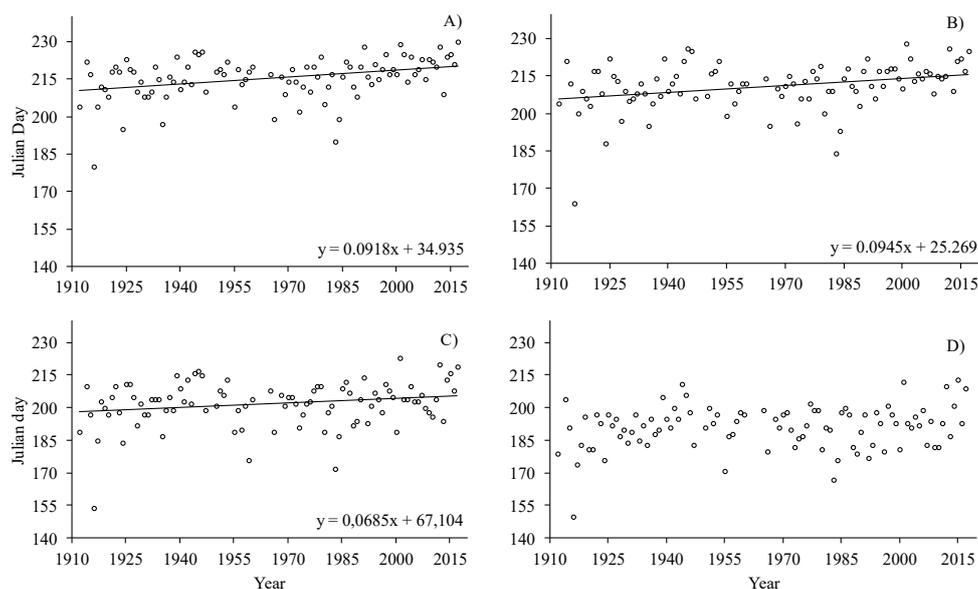


Figure 4. Planting date for R2 occurrence three days before All Souls' Day for gladiolus cultivars with A) early, B) intermediate I, C) intermediate II and D) late developmental cycles, during 1912 – 2017, in Santa Maria, Rio Grande do Sul State, Brazil.

The occurrence of the positive historical trend for the early, intermediate I and intermediate II cycles and no significant trend for the late cycle may have been related to the growing season of the crop because at higher temperatures, the duration of the developmental phases was relatively shorter and the growth was faster, anticipating the harvest (Tryjanowski et al., 2018). Therefore, there was a relationship between the modification of the planting date and the increase in the minimum air temperature during the end of winter and early spring, when the minimum air temperature tends to increase from August and continues to increase in September and October, as shown in Figure 2(B, C, and D).

An increase in minimum air temperature results in an increase in the mean air temperature, which directly affects gladiolus development, increasing the developmental rate and shortening the cycle. The acceleration of the developmental rate as a function of the increase in mean air temperature has also been verified for annual crops and fruit trees (Chmielewski, Müller, & Bruns, 2004; Siebert & Ewert, 2012).

In comparison to the other cultivars, early and intermediate I and II cycles cultivars have their development more affected by this period of increasing air temperature since their cultivation takes place in late July and early August, as opposed to the late cycle cultivars, which are planted at the beginning of July, a month that does not show an increasing tendency in temperature, maintaining a developmental rate lower than that of the others. Thus, a delay in planting date should occur (to harvest on All Souls' Day) for early and intermediate I and II cycles since there was a tendency to shorten the developmental cycle.

In terms of time scale, the delay should be 9.2 days for the early cycle, 9.5 days for the intermediate I cycle and 6.9 days for the intermediate II cycle; that is, currently, the optimal planting date of gladiolus for All Souls' Day is 7 to 10 days later than it was a century ago. This change occurred because at higher temperatures, the gladiolus cycle length decreased (Streck et al., 2012b), requiring a shorter time to produce floral stems for All Souls' Day. These results corroborate those of Uhlmann et al. (2017), which indicated that the later the planting date is, the shorter the duration of the developmental cycle due to the natural increase in the air temperature at this time of the year in southern Brazil.

Streck et al. (2012a) identified long-term increasing trends in air temperature for rice (*Oryza sativa*), which led to an anticipation in the crop, which reduced the yield potential of the crop, especially when development occurred during the final spring/early summer. Similar results were also found by Blecharczyk et al. (2016) for winter rye, with a significant delay of 5 days at sowing, and by Mo et al. (2016), who identified a delay of 3 days per decade for the sowing date of spring wheat, and in both cases, this delay was specifically due to the increase in temperature.

When analyzing the variability in the historical series in relation to the average planting date (Table 2), for Mother's Day, the planting date ranged from 8 and 6 days (to early cultivars) to 10 and 5 days (to intermediate I) to 5 and 7 days (to intermediate II) to 6 and 4 days (to late cultivars).

The lowest variability occurred for the late cycle (10 days), and the highest variability occurred for the intermediate II cycle (15 days). For the All Souls' Day, the planting date varied from 35 to 15 days, 46 to 18 days, 48 to 21 days, and 41 to 22 days in relation to the average planting date, for the early, intermediate I, intermediate II, and late cycles, respectively. Thus, the lowest variability occurred for the early cycle (50 days), and the highest variability occurred for the intermediate II cycle (69 days).

Comparing both commemorative dates, the greatest variability occurred for All Souls' Day, based on the increased trend in air temperature in this study (Figure 2B, C, and D), and this was period with greatest influence of the El Niño-Southern Oscillation (ENSO) (Grimm, Barros, & Doyle, 2000; Berlato & Fontana, 2003) and the Pacific Decadal Oscillation (PDO) (Streck et al., 2011), which bring changes in rainfall and temperature patterns that directly affect the development of crops over the years.

Table 2. Descriptive statistics of the historical series of the optimum planting date (on Julian Day) of gladiolus for harvest on Mother's Day and All Souls' Day in Santa Maria, Rio Grande do Sul State, Brazil, in the period of 1912 – 2017.

Special Date	Cycle	Planting date (Julian day)			SD	CV (%)
		Minimum	Maximum	Mean		
Mother's Day	Early	50	64	58	2.20	3.80
	Intermediate I	45	60	55	2.26	4.10
	Intermediate II	45	57	50	2.59	5.15
	Late	35	47	43	2.37	5.50
All Souls' Day	Early	180	230	215	8.42	3.91
	Intermediate I	164	228	210	9.47	4.49
	Intermediate II	154	223	202	10.40	5.15
	Late	150	213	191	9.97	5.21

*Significant tests at 5% probability of error. SD = standard deviation of mean values; CV (%) = coefficient of variation.

In this study, air temperature was the main meteorological factor considered in the analysis as a condition of climate change, and a strong correlation between this variable and the duration of the developmental cycle of the cultivars was clearly observed. Changes in this factor were sufficient to suggest changes in the planting date of gladiolus in the long term to adjust the harvest date.

With the reduction in the length of gladiolus cycle over the years, a strategy to mitigate potential losses is to adjust the planting date by delaying it to ensure that flowering takes place in time for the desired marketing date. Another strategy to increase the chance of success of achieving the preferred harvest date would be to change the planting date, especially when the objective is to market on All Souls' Day, varying the planting date more and for less in relation to the indicated average value in Table 2.

Planting date influences the timing of all subsequent phenological events in a crop (Siebert & Eweet, 2012). Thus, although shortening of a developmental cycle occurs, management practices, such as the application of cover fertilization and staking, should be implemented according to crop phenology, as recommended by Schwab et al. (2015b), in V3 and V6, respectively.

Management markers by dates, for example, in days after planting, are not recommended since this work confirms that there are variations in the duration of the developmental cycle of gladiolus plants over the years. Currently, farmers can access free digital tools, such as PhenoGlad software, that aid in planting and managing gladiolus production (Uhlmann et al., 2017).

In general, the results of this work update the information on the effect of the changes in the air temperature over the years on ornamental crops, mainly at the planting date, assisting producers in decision making regarding the management of growing season calendars to enable the marketing of gladiolus flower stems on special dates. In addition, the results help in understanding the vulnerability of this crop, especially to air temperature, and identifying specific characteristics of the cultivars of different cycles.

Conclusion

The change in air temperature over the years has had a greater influence on the planting date of gladiolus for harvest on the All Souls' Day than for harvest on Mother's Day, for which the planting date is stationary.

During the last ten decades, delays in the planting date of 9.2 days for the early cycle, 9.5 days for the intermediate I cycle and 6.9 days for the intermediate II cycle were identified for the harvest of the floral stems for All Souls' Day.

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