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Camila Coelho Becker

**APLICAÇÕES PRÁTICAS DO MODELO PhenoGlad E O EFEITO DA
DEFICIÊNCIA HÍDRICA NA CULTURA DO GLADÍOLO**

Santa Maria, RS
2019

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Tese apresentada ao Curso de Pós-Graduação
em Engenharia Agrícola, da Universidade
Federal de Santa Maria (UFSM, RS), como
requisito parcial para obtenção do título de
Doutora em Engenharia Agrícola.

Orientador: Prof. Dr. Nereu Augusto Streck

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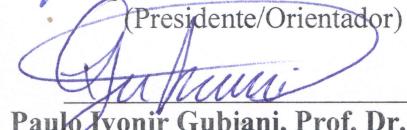
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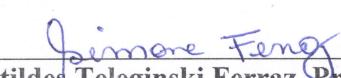
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RESUMO

APLICAÇÕES PRÁTICAS DO MODELO PhenoGlad E O EFEITO DA DEFICIÊNCIA HÍDRICA NA CULTURA DO GLADÍOLO

AUTORA: Camila Coelho Becker
ORIENTADOR: Nereu Augusto Streck

Os principais objetivos desta tese foram (i) desenvolver um zoneamento de risco climático para a cultura do gladiolo nos cenários de mudança climática previstos para o final do século no Rio Grande do Sul; (ii) aplicar a metodologia de previsão de safra para prever a data da colheita do gladiolo; (iii) entender como o déficit hídrico afeta o crescimento e desenvolvimento de gladiolo (iv) compreender como ocorre o declínio na transpiração e no crescimento foliar em função da FATS para diferentes cultivares de gladiolo em diferentes estágios de desenvolvimento. O modelo PhenoGlad foi utilizado para determinar os períodos recomendados para plantio de gladiolo ao longo do ano no RS em três cenários de mudança climática (RCP2.6, RCP4.5 e RCP8.5). O modelo foi rodado para datas de plantio diárias (de 01 janeiro a 31 dezembro) e diferentes ciclos de desenvolvimento da cultura. O PhenoGlad também foi usado para prever a data de colheita das hastes florais através de dados meteorológicos históricos. Foram realizados dois experimentos de campo com quatro cultivares de gladiolo submetidas a dois tratamentos de irrigação: irrigado e não irrigado. Três experimentos foram realizados em vasos, com quatro cultivares de gladiolo em diferentes estágios de desenvolvimento e dois regimes hídricos: sem déficit hídrico e com déficit hídrico. A FATS, a transpiração e o crescimento foliar foram medidos diariamente. Em ambos os experimentos, o desenvolvimento fenológico foi avaliado diariamente e, no momento da colheita, os parâmetros quantitativos das hastes florais foram medidos. Regiões mais quentes como Uruguaiana e Iraí apresentam o menor período recomendado para plantio ao longo do ano nos três cenários climáticos e, 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. Para atender a demanda de gladiolo 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. Nas três primeiras previsões no RS, o RMSE variou de 7 a 4,5 dias. Em SC, o RMSE variou de 5,5 a 3,4 dias. Esses erros são aceitáveis do ponto de vista prático, porque é uma previsão realizada cerca de 45 dias antes da colheita. Com essa metodologia de previsão, os agricultores podem conhecer antecipadamente sobre as chances de o ponto de colheita ocorrer no momento desejado. A duração do ciclo de desenvolvimento do gladiolo foi maior no tratamento não irrigado. O déficit hídrico também afeta a qualidade da flor produzida, devido ao menor crescimento das plantas, no entanto, não afeta a participação da massa seca. Portanto, a irrigação suplementar no gladiolo é essencial para a produção de hastes florais de qualidade. A FATS crítica para NTR é maior quando ocorre próximo à fase reprodutiva e, as hastes florais produzidas têm qualidade inferior. Quando o déficit hídrico ocorre durante a fase vegetativa, a taxa de aparecimento das folhas ocorre mais lentamente, atrasando o ponto de colheita das hastes florais.

Palavras-chave: *Gladiolus x grandiflorus* Hort. PhenoGlad. Força de Dreno. Calendário de Plantio. Agricultura Familiar. Floricultura.

ABSTRACT

PRACTICAL APPLICATIONS OF THE PhenoGlad MODEL AND THE EFFECT OF WATER DEFICIT ON GLADIOLUS

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ADVISOR: Nereu Augusto Streck

The objectives of this thesis were (i) to develop a climate risk zoning for gladiolus in the predicted end-century climate change scenarios in Rio Grande do Sul; (ii) to apply a crop forecasting methodology to predict the date of harvest of gladiolus; (iii) to understand how water deficit affects gladiolus growth and development (iv) to understand how occur the decline in transpiration and leaf growth in a drying soil for different cultivars of gladiolus on different developmental stages. The PhenoGlad model was used to determine the recommended periods for gladiolus planting throughout the year in RS under three climate change scenarios (RCP2.6, RCP4.5 and RCP8.5). The model was run for daily planting dates (01 January to 31 December) and different crop development cycles. PhenoGlad has also been used to predict the harvest forecast of flower stems using historical weather data. Two field experiments were conducted with four cultivars of gladiolus submitted to two irrigation treatments: irrigated and non-irrigated. Three experiments were carried out in pots, with four gladiolus cultivars in different development stages and two water regimes: without water deficit and with water deficit. FATS, transpiration and leaf growth were measured daily. In both experiments, the phenological development was evaluated daily and, at the time of harvest point, the quantitative parameters of the floral stems were measured. Warmer regions such as Uruguaiana and Iraí have the shortest recommended planting period throughout the year in the three climate scenarios, and planting between August and December is not recommended due to the higher chance of damage from high temperatures. Colder regions such as Bom Jesus will be favored in climate change scenarios. To meet the demand for gladiolus during the warmer periods of the year, techniques will need to be developed to reduce damage from high temperatures in the crop, such as more tolerant cultivars or the use of shading screens on the crop. In the first three forecasts in RS, the RMSE ranged from 7 to 4.5 days. In SC, the RMSE ranged from 5.5 to 3.4 days. These errors are acceptable from a practical point of view because they are predicted about 45 days before harvest. With this forecasting methodology, farmers can know in advance about the chances of harvesting at the desired time. The duration of the gladiolus development cycle was longer in the non-irrigated treatment. The water deficit also affects the quality of the flower produced, due to the lower plant growth, however, it does not affect the dry mass partition. Therefore, supplemental irrigation in gladiolus is essential for the production of quality floral stems. The FTSW threshold for NTR is higher when it occurs near the reproductive phase and the floral stems produced are of inferior quality. When the water deficit occurs during the vegetative phase, the rate of leaf appearance occurs more slowly, delaying the harvesting point of the flower stems.

Keywords: *Gladiolus x grandiflorus* Hort. PhenoGlad. Sink Strength. Planting Schedule. Family Agriculture. Floriculture.

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1. INTRODUÇÃO E JUSTIFICATIVA

Modelos agrícolas são uma simplificação da realidade e, quando bem calibrados, permitem sua utilização para auxiliar no manejo das culturas agrícolas, bem como avaliar o efeito da mudança climática nas culturas (do RIO et al., 2016; BECKER et al., 2020b), para realização de previsão de safra (da SILVA et al., 2016) e, na determinação da melhor data de plantio (ANDARZIAN et al., 2015; BECKER et al., 2020a). O modelo PhenoGlad foi proposto para simular o desenvolvimento da cultura do gladiolo na condição potencial (UHLMANN et al., 2017) e, consiste de uma excelente ferramenta para a tomada de decisão e planejamento do produtor. O uso do modelo PhenoGlad é indicado para condições de campo em que a água não é um fator limitante para o crescimento e desenvolvimento da cultura, uma vez que, períodos de seca podem impactar negativamente na qualidade das hastes florais, no crescimento e no desenvolvimento da cultura (PORTO et al., 2014; PEREIRA et al., 2016a; PEREIRA et al., 2016b; MAZZINI-GUEDES et al., 2017).

Recentemente, o modelo PhenoGlad foi utilizado para determinar as melhores datas de plantio de gladiolo, em função da fase do El Niño Oscilação Sul prevista para o período de cultivo, visando comercialização das hastes florais em dois picos de consumo: Dia das Mães e Dia de Finados (BECKER et al., 2020a). O PhenoGlad também foi utilizado para entender os efeitos da mudança climática no planejamento da produção das hastes florais para estes dois picos de consumo (BECKER et al., 2020b). Com a crescente aceitação desta flor de corte no Brasil, como alternativa de renda na pequena propriedade rural e como uma flor de corte disponível em feiras por um preço acessível ao consumidor (UHLMANN et al., 2019), entende-se que é necessário, em um curto período de tempo, ampliar os estudos sobre a cultura afim de fornecer informações aplicadas aos produtores e, ao mesmo tempo, desenvolver estudos visando a melhoria dos modelos no longo prazo, como por exemplo, introduzir o efeito da deficiência hídrica para melhor predizer as condições de campo.

A deficiência hídrica é um fator limitante para o crescimento e desenvolvimento das culturas agrícolas, pois a água representa cerca de 95% do total da planta, participando de processos importantes como a fotossíntese, a abertura de estômatos e o alongamento e crescimento celular (TAIZ; ZEIGER, 2017). Em condições de reduzida disponibilidade de água no solo, as plantas fecham os estômatos, diminuindo a entrada de CO₂ e reduzindo o processo fotossintético e as perdas de água por transpiração (SOUZA et al., 2014; PINHEIRO et al., 2014). Como consequência, a produtividade das culturas agrícolas é reduzida (ALBERTO et al., 2006) e, no caso de culturas ornamentais, como o gladiolo, há redução na

qualidade das hastes florais, que são o produto final da cultura (MAZZINI-GUEDES et al., 2017).

A haste floral do gladiolo é uma espiga composta de vários floretes que abrem de baixo para cima. Para serem comercializadas no Veiling Holambra, principal centro de comercialização de flores e plantas ornamentais da América Latina, as hastes florais precisam atender alguns critérios. Entre os critérios considerados, há parâmetros qualitativos e parâmetros quantitativos de qualidade das hastes florais (VEILING HOLAMBRA, 2013). Os qualitativos referem-se às características visuais não mensuráveis, como danos por doenças e pragas, queimadura do sol e danos mecânicos. Já os parâmetros quantitativos podem ser medidos e são os mais afetados pela deficiência hídrica (PEREIRA et al., 2009), dentre eles: o comprimento da haste floral (que deve variar de 0,75 a 1,10 m), o comprimento do pendão floral (que dever ter no mínimo 40% do comprimento da haste floral), e o diâmetro da haste (que deve ter no mínimo 0,5 cm, 0,8 cm e 1,0 cm para hastes com 0,75 m, 0,90 m e 1,10 m, respectivamente).

Os parâmetros qualitativos podem ser afetados negativamente devido às condições extremas de temperatura do ar (alta ou baixa) que podem ocorrer com maior frequência se os cenários de mudança climática, previstos para o final do século, se concretizarem (BECKER et al., 2020b). A mudança climática também modifica a data ótima de plantio dos cormos visando o planejamento da produção (BECKER et al., 2020a) e, pode também modificar os períodos recomendados e não recomendados para a produção ao longo do ano, bem como as regiões recomendadas para cultivo. Já os parâmetros quantitativos das hastes florais, são reduzidos principalmente pela disponibilidade hídrica do solo, principalmente por se tratar de uma planta ornamental cultivada a céu aberto e, que por apresentar certa rusticidade, não recebe tanta atenção pelos produtores quanto à necessidade de irrigação.

Um conceito bastante utilizado para avaliar a resposta das plantas ao déficit hídrico é a Fração de Água Transpirável no Solo (FATS), que considera que o conteúdo de água no solo consumido pela planta na transpiração está em um intervalo entre o conteúdo de água na capacidade de campo, quando a transpiração é máxima, e o conteúdo de água no solo, quando a transpiração da planta é igual a 10% da máxima (SINCLAIR; LUDLOW, 1986). A FATS tem sido utilizada em modelos agrícolas juntamente com modelos de balanço hídrico para penalizar o crescimento das culturas em condição de déficit hídrico (AMIR; SINCLAIR, 1991; TIRONI et al., 2017).

Por isso, os objetivos desta tese de doutorado foram: (i) desenvolver um zoneamento de risco climático para a cultura do gladiolo 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; (ii) aplicar a metodologia de previsão de safra para prever a data da colheita do gladiolo; (iii) entender como o déficit hídrico afeta o crescimento e desenvolvimento de gladiolo e, consequentemente, a qualidade das hastes florais produzidas e (iv) compreender como ocorre o declínio na transpiração e no crescimento foliar em função da FATS para diferentes cultivares de gladiolo em diferentes estágios de desenvolvimento.

2. REVISÃO DE LITERATURA

2.1. IMPORTÂNCIA DA FLORICULTURA BRASILEIRA

A floricultura brasileira está em constante crescimento (JUNQUEIRA; PEETZ, 2014), passando de um faturamento de 4,8 bilhões de reais em 2012 para mais de 6 bilhões reais em 2015 (IBRAFLOR, 2015). De acordo com o Instituto Brasileiro de Floricultura (IBRAFLOR, 2015), aproximadamente 9000 produtores trabalham na floricultura com uma área total cultivada de cerca de 15000ha e um tamanho médio da propriedade de 1,8ha. A região sudeste do país apresenta a maior área destinada para a produção de flores, com cerca de 9000ha, seguida da região sul do país com cerca de 3000ha. A floricultura representa uma das principais atividades geradoras de emprego e renda para pequenos produtores em todo o país, incorporando importantes parcelas do trabalho feminino rural (JUNQUEIRA; PEETZ, 2014).

Os principais consumidores brasileiros são os estados de São Paulo e Distrito Federal, com um consumo de mais de 43 reais per/capta anual. O Rio Grande do Sul é o terceiro maior consumidor de flores e plantas ornamentais, com um consumo de mais de 38 reais per/capta (LIMA JÚNIOR et al., 2015). Esse valor é maior que o consumo brasileiro que é de aproximadamente 27 reais per/capta (IBRAFLOR, 2015). Mas, apesar do grande crescimento observado, o mercado brasileiro de flores ainda é focado em datas comemorativas como Dia das Mães, Dia dos Namorados, Finados e Natal (JUNQUEIRA; PEETZ, 2008) diferente do mercado Europeu cujo consumo de flores ocorre ao longo de todo o ano e para consumo pessoal (IBRAFLOR, 2015). Segundo Lima Júnior et al. (2015) o consumo de flores e plantas ornamentais varia de acordo com a renda, conjuntura econômica e classe social, sendo que a variação desses fatores ao longo dos anos exerce influência direta na demanda por esses produtos.

A produção de flores e plantas ornamentais no Brasil tem como principal destino o mercado interno. Em 2014, o segmento flores de corte, botões e arranjos para buquês foi responsável por 58% das importações brasileiras, enquanto mudas de plantas ornamentais e plantas vivas foi responsável por 22% e o de folhagens e gramíneas 20% (LIMA JÚNIOR et al., 2015). Por outro lado, o país também é um grande exportador de bulbos de gladiólos, amarílis e caladium (TOMBOLATO, 2010). As exportações estiveram concentradas principalmente nos segmentos de bulbos, rizomas e tubérculos, assim como em mudas de plantas ornamentais e plantas vivas na última década (LIMA JÚNIOR et al., 2015).

O Rio Grande do Sul também necessita importar para atender a demanda interna. Cerca de 90% do que é consumido no estado tem origem em outros estados produtores, como São Paulo, no caso das flores de vaso como o crisântemo e Santa Catarina (LIMA JÚNIOR et al., 2015; IBRAFLOR et al., 2019). A produção de plantas ornamentais no Rio Grande de Sul é dificultada porque o estado tem somente uma safra de cultivo, principalmente de flores de corte como as rosas. Este fato ocorre principalmente pelas condições climáticas do estado. Outra dificuldade é a falta de incentivos e apoio do Estado para a produção (LIMA JÚNIOR et al., 2015).

Apesar de todos esses fatores, nos últimos anos, devido a uma parceria entre a Equipe PhenoGlad e a EMATER-RS/ASCAR, tem sido crescente a adesão dos pequenos produtores rurais à produção de hastes florais de gladiólo para comercialização em feiras municipais, juntamente com outros produtos também produzidos na propriedade (UHLMANN et al., 2019). O projeto de parceria chama-se “Flores para Todos”, porque além de incentivar e auxiliar os pequenos produtores no processo produtivo de hastes florais de gladiólo visando agregar renda na propriedade, permite que muitas pessoas possam adquirir flores semanalmente nas feiras para a decoração de suas residências por um preço acessível.

2.2. A CULTURA DO GLADÍOLO

O gladiólo (*Gladiolus x grandiflorus* Hort.), conhecido como Palma-de-Santa-Rita, é uma planta herbácea propagada através de bulbos sólidos denominados de cormos (BARBOSA, 2011). A parte comercial é uma espiga composta de vários floretes que podem apresentar diversas cores, como branco, rosa, vermelho, amarelo, roxo, laranja e lilás (TOMBOLATO et al., 2010). É amplamente utilizada para a confecção de vasos e arranjos florais para a ornamentação de cerimônias, como flor de corte, e também como planta de jardim.

O cultivo deve ser realizado a pleno sol, podendo em caso contrário não ocorrer florescimento. A causa do não florescimento de gladiólo cultivado em estufa no inverno é devido à combinação de baixa intensidade luminosa e alta temperatura (SHILLO; HALEVY, 1976). Uma prática de manejo importante durante o cultivo é o tutoramento das plantas, cuja finalidade é evitar seu tombamento e consequente entortamento das hastes florais, o que deprecia a qualidade do produto (PAIVA et al., 2012). Para isso, utiliza-se fios de ráfia amarrados a estacas de bambu, que são fixadas nas extremidades dos canteiros e, conforme o

desenvolvimento da planta vai ocorrendo, novos fios são colocados na parte superior (SCHWAB et al., 2015b).

O ponto de colheita do gladiolo é chamado de estágio R2, quando os três primeiros floretes da base da espiga mostram a cor característica da cultivar (SCHWAB et al., 2015a). A colheita neste momento é possível devido à característica da cultura, que permite que a abertura dos floretes ocorra após alguns dias em vaso com água (TOMBOLATO et al., 2005), possibilitando que as hastes florais cheguem ao consumidor com aspecto atraente. Hastes colhidas com floretes abertos podem ser danificadas durante o transporte e armazenamento (PAIVA et al., 2012).

As hastes florais de gladiolo precisam atender alguns critérios de qualidade, segundo o centro de comercialização de flores e plantas ornamentais, Veiling Holambra. Os critérios de qualidade considerados podem ser qualitativos ou quantitativos (VEILING HOLAMBRA, 2013). Os qualitativos referem-se às características visuais não mensuráveis, como danos por doenças e pragas, queimadura do sol e danos mecânicos. Já os parâmetros quantitativos podem ser medidos como o comprimento da haste floral (que deve variar de 0,75 a 1,10 m), o comprimento do pendão floral (que dever ter no mínimo 40% do comprimento da haste floral), e o diâmetro da haste (que deve ter no mínimo 0,5 cm, 0,8 cm e 1,0 cm para hastes com 0,75 m, 0,90 m e 1,10 m, respectivamente).

Estudo realizado em Santa Maria por Schwab et al. (2015b) avaliou a qualidade de hastes florais de gladiolo cultivados ao longo do ano e concluiu que plantios realizados entre o fim do inverno e início da primavera, e entre o fim do verão e início do outono são os mais indicados para essa região. Nos meses de verão há possibilidade de queimadura das sépalas e pétalas, além de murchamento da espiga e, no inverno, pode ocorrer morte da espiga devido a ocorrência de geada. No Brasil, como o principal mercado de gladiolo é no feriado de Finados, o plantio é predominantemente realizado durante a segunda metade de julho até o início de agosto, para que o ponto de colheita ocorra de 2 a 4 dias antes do feriado (SCHWAB et al., 2015a).

As plantas de gladiolo, apesar de não tolerarem o encharcamento do solo, devido a possibilidade de apodrecimento dos cormos (BASTUG et al., 2006), também não devem ficar expostas a longos períodos sem irrigação. A deficiência hídrica pode acarretar em antecipação do florescimento (PEREIRA et al., 2016a; MAZZINI-GUEDES et al., 2017) e levar à redução da porcentagem de florescimento, número de floretes e tamanho da haste floral (BASTUG et al., 2006; PORTO et al., 2014). Recomenda-se a irrigação por gotejamento para evitar

molhamento das folhas e reduzir a incidência de doenças como a ferrugem (SEVERINO, 2007).

2.3.MUDANÇA CLIMÁTICA

A concentração de gases de efeito estufa na atmosfera tem aumentado desde a Revolução Industrial. Atualmente a concentração de CO₂ está em 410 ppm, podendo até o final do século atingir de 490 a 1370 ppm, dependendo do cenário (IPCC, 2013). Apesar de algumas divergências no meio científico sobre as causas (MOLION, 2008), fica evidente no último relatório do IPCC (AR5) que a temperatura global está em ascensão, tanto em nível continental como nos oceanos, e que a área coberta com geleiras no Planeta está em declínio (IPCC, 2013). Durante o século XX, a temperatura média da superfície global teve um aumento médio de 0,85°C no período de 1880 a 2012, e o maior aumento ocorreu entre 1967 e 2000, sendo que a década de 1990 foi a mais quente do último milênio (KERR, 2005; IPCC, 2013).

Diversos estudos relatam que o aumento da temperatura mínima é maior do que o aumento da temperatura máxima, reduzindo a amplitude térmica de regiões como Filipinas (PENG et al., 2004) e China (TAO et al., 2006). No Rio Grande do Sul, estudos foram realizados em Pelotas (STEINMETZ et al., 2005) e Santa Maria (STRECK et al., 2011) e também encontraram tendência de aumento maior da temperatura mínima do ar.

Considerando todo o estado do Rio Grande do Sul, valores crescentes foram encontrados de leste para oeste do estado, variando de 0,8 a 1,8°C, no período de outubro a dezembro (MARQUES et al., 2005). Marengo; Camargo (2008) constataram redução na amplitude térmica diária nos meses de verão no RS e Sansigolo e Kayano (2010) relataram aumento de 1,7°C/100 anos na média anual de temperatura mínima no RS e não observaram tendência na média da temperatura máxima anual.

Projeções até o final deste século indicam aumentos de 0,3 a 4,8°C na temperatura média do ar, dependendo do cenário, em vários locais do Planeta (IPCC, 2013). Devido à grande influência das condições climáticas no desenvolvimento das culturas, muitos estudos vêm sendo realizados a fim de quantificar os efeitos da mudança climática nas culturas agrícolas (WEISS; HAYS; WON, 2003; LI et al., 2015).

Há pelo menos três métodos de geração de cenários climáticos futuros: sintético, análogo e cenários gerados por Modelos de Circulação Global (MCGs) (WEISS; HAYS;

WON, 2003). Cenários sintéticos são desenvolvidos pelo ajuste da baseline através da fixação de um valor, como por exemplo 2°C de aumento na temperatura. Cenários análogos são baseados em registros do passado que pode representar o clima futuro. No presente estudo o MCG HadGEM2-ES (JONES et al., 2011) foi utilizado como condição de contorno que foram regionalizadas por dowscaling dinâmico (HOSTETLER et al., 2011) a partir do modelo RegCM4 (Regional Climate Model versão 4). Além do cenário de referência, foram utilizados os cenários RCP2.6, RCP4.5 e RCP8.5 (CMIP 5 – Climate Model Intercomparison Project 5) do 5º relatório do IPCC (IPCC, 2013).

2.3.1. Mudança climática e as culturas agrícolas

Mudanças climáticas podem afetar muitos setores da economia, mas a agricultura é o setor mais sensível e vulnerável (ALEXANDROV; HOOGENBOOM, 2000; IPCC, 2013). Esta vulnerabilidade é esperada porque a maioria das culturas agrícolas fica exposta aos elementos meteorológicos durante todo o seu ciclo de desenvolvimento e se confirma em trabalhos realizados no Brasil com diferentes culturas como o café (ASSAD et al., 2004), trigo, soja, milho (STRECK; ALBERTO, 2006a,b; do RIO et al., 2016), batata (STRECK et al., 2006) e arroz (LAGO et al., 2008; WALTER et al., 2014), na Bulgária com milho e trigo (ALEXANDROV; HOOGENBOOM, 2000), na China com trigo (LI et al., 2015) em que pequenos aumentos da temperatura já afetam o desempenho dos agroecossistemas, alterando o ciclo de desenvolvimento das culturas e sua produtividade.

Estudo realizado com a cultura do arroz na China identificou redução do ciclo de arroz precoce e aumento do ciclo de arroz tardio como resultado da mudança climática. A explicação é que o arroz de ciclo tardio é cultivado no sul da China, onde as temperaturas ultrapassam a temperatura ótima da cultura e por isso a duração do ciclo aumenta (WANG et al., 2017). Na Austrália, o trigo de primavera terá antecipação no florescimento e o trigo de inverno terá atraso no florescimento devido a redução do número de dias de temperatura baixa para o processo de vernalização. Tanto o trigo de inverno como o de primavera terão maior risco de estresse por calor devido as altas temperaturas (WANG et al., 2015b).

Para as culturas ornamentais não foram encontrados estudos envolvendo mudança climática. Porém estudos em ambiente controlado demonstraram que o aumento da temperatura pode resultar no encurtamento do ciclo de diversas culturas como *Antirrhinum majus* L. (MUNIR et al., 2015), *Brunonia australis* e *Calandrinia* sp. (CAVE et al., 2013). A

redução do ciclo das culturas devido ao aumento da temperatura pode levar à redução do número de flores, tamanho das flores e quantidade de biomassa (PRAMUK; RUNKLE, 2005; MOCCALDI; RUNKLE, 2007; VAID; RUNKLE; FRANTZ, 2014). Na cultura do gladiolo, cultivado a céu aberto, temperaturas acima de 34°C podem ocasionar danos na haste floral como queimadura das sépalas e pétalas, além do murchamento da espiga que pode resultar em entortamento e redução da qualidade do produto (SCHWAB et al., 2015b; UHLMANN et al., 2017).

2.4. MODELAGEM DAS CULTURAS AGRÍCOLAS

Modelos agrícolas são uma simplificação da realidade e quando bem calibrados permitem sua utilização para auxiliar no manejo das culturas agrícolas, bem como, avaliar o efeito das mudanças climáticas sobre as culturas (do RIO et al., 2016; BECKER et al., 2020b), estudos de previsão de safra (da SILVA et al., 2016; MORELL et al., 2016) e a determinação da melhor data de plantio (ANDARZIAN et al., 2015; BECKER et al., 2020a). Modelos utilizam dados de temperatura, radiação solar, fotoperíodo e precipitação (LENTZ, 1998) como dados de entrada para simular o desenvolvimento e crescimento das plantas e, por isso, são muito importantes em estudos que se deseja verificar a influência das condições climáticas nas culturas possibilitando economia de tempo e recursos (MARIN et al., 2006; OTENG-DARKO et al., 2013).

Apesar dos desafios da modelagem de espécies ornamentais, como a grande diversidade de espécies e genótipos, heterogeneidade dos sistemas de cultivo e a importância de considerar a qualidade dos produtos nos modelos (GARY et al., 1998), são encontrados trabalhos de modelagem com as culturas de sálvia (*Salvia splendens* F.) e calêndula (*Tagetes patula* L.), para prever os efeitos da temperatura e regime integral de luz diária no crescimento e florescimento (ciclo da cultura, massa seca e número de flores) em diferentes ambientes comerciais (MOCCALDI; RUNKLE, 2007); do *Limonium* (*Limonium sinuatum* x *Limonium perezii*), para simular o tempo para o florescimento da cultura em função do fotoperíodo. Os autores afirmam que o modelo pode auxiliar produtores a agendar a data de plantio e predizer o tempo de florescimento baseado em dados históricos de luz diária (CHEN; FUNNELL; MORGAN, 2010).

Para simular melhor a produtividade das culturas agrícolas, principalmente de culturas cultivadas sem irrigação suplementar, modelos de balanço hídrico do solo tem sido

frequentemente acoplados aos modelos de crescimento e desenvolvimento das culturas agrícolas com o objetivo de fornecer a condição hídrica no solo para a penalização do crescimento vegetal em caso de déficit hídrico (AMIR; SINCLAIR, 1991; ALBERTO et al., 2006; TIRONI et al., 2017). Há preferência pela utilização de modelos mecanísticos simplificados (AMIR; SINCLAIR, 1991, THORNTHWAITE; MATHER, 1955), que descrevem processos (modelos baseados em processos ou process-based models) e requerem um número menor de variáveis de entrada, facilitando o seu uso junto com modelos agrícolas. Também podem ser utilizados os modelos mais complexos, que permitem um entendimento mais detalhado do funcionamento do balanço hídrico do solo, como o modelo de Ritchie (1998). Por serem culturas comumente produzidas em ambiente protegido e irrigadas, diferente do gladiolo que é cultivado a céu aberto, não foram encontrados estudos de modelagem considerando o efeito de déficit hídrico para culturas ornamentais.

Para a realização de previsão de safra, os modelos são uma ferramenta de fácil utilização que permitem o monitoramento e a previsão da produção de culturas como o arroz no Rio Grande do Sul (da SILVA et al., 2016), milho nos Estados Unidos, região do Corn-Belt (MORELL et al., 2016) e, para trigo, milho, colza, girassol, batata e beterraba na Europa (VELDE; NISINI, 2019). As previsões de produção agrícola e as estimativas de produção agrícola são necessárias para fornecer aos tomadores de decisão de políticas agrícolas informações oportunas para uma rápida tomada de decisão durante a estação de crescimento. As estimativas da produção agrícola também são úteis em relação ao comércio, políticas de desenvolvimento e assistência humanitária ligadas à segurança alimentar.

O método de previsão de safra desenvolvido para o arroz no RS, utiliza o modelo SimulArroz (ROSA et al., 2015) para predizer a produção de arroz a partir de dados meteorológicos previstos pelo modelo climático regional RegCM4 (GIORGIO et al., 2012). A previsão de safra na Europa é realizada com o WOFOST, um modelo biofísico, dinâmico, com desempenho em uma variedade de condições meteorológicas, de solo e de manejo. O WOFOST simula o crescimento da cultura através da diferença entre os assimilados produzidos pela fotossíntese e consumidos pela respiração. O rendimento potencial é determinado pelos fatores de definição de CO₂, temperatura, radiação solar e características da cultura. No momento da previsão, o WOFOST é executado com os dados meteorológicos interpolados e observados, que são estendidos pela previsão de 10 dias do ECMWF (www.ecmwf.int). Os resultados do modelo são agregados ao nível nacional e usados como preditores decadais na análise estatística (VELDE; NISINI, 2019).

Já a metodologia desenvolvida para predizer a produção de milho no Corn-Belt, utiliza dados meteorológicos históricos para simular as diferentes possibilidades de produção naquele ano, em função de anos anteriores e, informa qual é a probabilidade de ocorrer produtividade acima ou abaixo da média histórica (MORELL et al., 2016). Todas essas metodologias tem por objetivo prever a produtividade das culturas. No caso de plantas ornamentais como o gladiólo, o principal objetivo é prever a data de ocorrência do ponto de colheita, afim de auxiliar antecipadamente na tomada de decisão do produtor.

2.4.1. O modelo PhenoGlad

O modelo PhenoGlad (UHLMANN et al., 2017) é um modelo dinâmico baseado em processos, que simula a data de ocorrência dos principais estágios de desenvolvimento da cultura do gladiólo. Foi previamente calibrado e validado com diferentes cultivares, datas de plantio, anos e locais de experimentos realizados no Rio Grande do Sul e em Santa Catarina (UHLMANN et al., 2017). No PhenoGlad, a fenologia do gladiola é simulada sem limitação de água e, considera três fases principais de desenvolvimento baseado na escala de desenvolvimento de Schwab et al. (2015a): fase de germinação, fase vegetativa e fase reprodutiva. Começando no plantio, o estágio de desenvolvimento (DVS) é calculado acumulando os valores diários da taxa de desenvolvimento, usando a temperatura média diária do ar, com a abordagem não-linear de Wang e Engel (1998). A função não linear de resposta à temperatura é usada para penalizar o desenvolvimento quando a temperatura diária do ar está abaixo ou acima da temperatura ideal. O modelo PhenoGlad simula o desenvolvimento de diferentes cultivares ou, de modo geral, de quatro diferentes ciclos de desenvolvimento: Precoce, Intermediário I, Intermediário II e Tardio. Cada ciclo de desenvolvimento possui uma taxa máxima diária de desenvolvimento que representa um grupo de cultivares pertencentes a ciclo. As temperaturas cardinais: mínima (Tb), ótima (Topt) e máxima (TB) na fase de germinação são Tb = 5 °C, Topt = 25 °C e TB = 35 °C. Na fase vegetativa, as temperaturas cardinais são Tb = 2 °C, Topt = 27 °C e TB = 45 °C e na fase reprodutiva, as temperaturas cardinais são Tb = 6 °C, Topt = 25 °C e TB = 42 °C. Os dados de entrada necessários para rodar o PhenoGlad incluem temperaturas mínimas e máximas diárias do ar, data de plantio ou emergência e, cultivar ou ciclo de desenvolvimento (Precoce, Intermediário I, Intermediário II e Tarde). A temperatura do ar é o único fator que controla o desenvolvimento do gladiólo no PhenoGlad e, o modelo foi calibrado sob condição potencial (sem limitação da água) (UHLMANN et al., 2017).

O modelo PhenoGlad também simula a ocorrência de danos nas hastes florais, causados por temperaturas baixas ou altas. Quando a temperatura mínima diária (T_{min}) é inferior a -2 °C durante pelo menos quatro dias seguidos, da emergência ao estágio R5, a cultura é morta por geada. Se a temperatura mínima for menor ou igual a -2 °C por um dia ou se $-2^{\circ}\text{C} < T_{min} < 3^{\circ}\text{C}$ durante 4 dias seguidos durante a fase reprodutiva, a haste floral é morta pela geada. A lesão por calor no PhenoGlad é considerada quando a temperatura máxima é maior ou igual a 34 °C por três dias consecutivos durante a fase reprodutiva, causando queimaduras graves nas sépalas. Se a temperatura máxima for superior a 48 °C, a temperatura letal superior é atingida e a cultura é morta pelo calor.

2.5. DÉFICIT HÍDRICO NA CULTURA DO GLADÍOLO

O desenvolvimento do gladiolo é afetado pela umidade do solo, sendo este o fator mais limitante à obtenção de hastes florais de boa qualidade (SEVERINO, 2007). No momento do plantio dos cormos, a umidade do solo deve estar adequada para proporcionar uma emergência rápida e uniforme das plântulas e facilitar o desenvolvimento inicial das raízes. Durante a emissão da terceira à sétima folha, o fornecimento regular de água é fundamental (SEVERINO, 2007), pois nesses momentos está ocorrendo a formação da espiga no interior da planta e a emissão da espiga para fora do cartucho da planta (SCHWAB et al., 2015a).

Diversos estudos demonstram que a deficiência hídrica provoca formação de hastes florais de menor comprimento e número de floretes, além de provocar queimadura na ponta das espigas, sendo o principal fator que afeta os parâmetros quantitativos de qualidade das hastes florais (PEREIRA et al., 2009). Menores níveis de irrigação resultaram em hastes florais de comprimento reduzido, com menos floretes e menor diâmetro de flores, num estudo conduzido em Mato Grosso – Brasil (PORTO et al., 2014). Na Antália – Turquia, em gladiólos cultivados em estufa, o tratamento irrigado com 50% da quantidade evaporada no tanque classe A resultou em menor comprimento e diâmetro de hastes florais, comprimento da espiga e número de floretes (BASTUG et al., 2006). Os autores ainda verificaram redução no conteúdo de água do solo próximo ao período de emissão da espiga, indicando aumento do uso da água nessa fase do desenvolvimento.

A deficiência hídrica também afeta o acúmulo de massa seca na planta. O cormo e a inflorescência são compartimentos da planta de gladiolo, e competem pelos fotoassimilados produzidos durante a fotossíntese. A deficiência hídrica causa redução na massa seca total da

planta, além de modificar a partição, direcionando menor porcentagem de assimilados para a haste floral e maior porcentagem para os cormos (ROBINSON et al., 1983), aumentando a massa seca de raízes (PEREIRA et al., 2016b). A maior produção de raízes é um mecanismo de defesa ao déficit hídrico que tem o objetivo de explorar um volume maior de solo em busca de água (SOUZA et al., 2014). Outros estudos que avaliaram a qualidade das hastes florais comparando a condição irrigada com a não irrigada também encontraram redução da massa seca da haste quando produzida com menor reposição de água no solo (PORTO et al., 2014; MAZZINI-GUEDES et al., 2017).

Estudo realizado por Shillo e Halevy (1976), em que a irrigação foi interrompida durante 22 dias em diferentes estágios de desenvolvimento da cultura, demonstrou que os períodos de desenvolvimento mais sensíveis são do plantio à emergência, e de 4 a 6 folhas (pouco antes da emissão da espiga), resultando em não florescimento das plantas. Em Israel, as plantas normalmente não florescem quando plantadas no final do verão devido às altas temperaturas, acompanhadas de deficiência hídrica (SHILLO; HALEVY, 1976). O estágio mais sensível à condição de alta temperatura e baixa umidade do ar foi entre o aparecimento da 5^a e 7^a folha (logo antes da emissão da espiga), resultando em maior redução da porcentagem de florescimento, tamanho de hastes florais e de espiga, e número de floretes por espiga (SHILLO; HALEVY, 1976). Esses resultados indicam que o efeito prejudicial da alta temperatura não é direto, uma vez que só causa efeitos negativos na planta quando acompanhado de ar seco, em função da alta demanda hídrica da atmosfera nessa condição.

Em outro estudo, onde se avaliou a frequência de irrigação em diferentes fases do desenvolvimento da cultura: vegetativa, espigamento e florescimento, as plantas apresentaram menor comprimento de hastes florais e número de floretes quando submetidas à deficiência hídrica, no período de espigamento (PEREIRA et al., 2009). Nesse mesmo estudo, foi observado que em algumas plantas não houve formação de haste floral no tratamento de menor frequência de irrigação (irrigação quando a tensão de água no solo era de 60 kPa).

O efeito da deficiência hídrica na duração do ciclo da cultura apresenta algumas divergências. Alguns autores afirmam que a deficiência hídrica causa antecipação do florescimento (BARBOSA et al., 2011; PAIVA et al., 2012) enquanto outros afirmam que a emissão de folhas é mais lenta, resultando em maior duração da fase plantio-colheita (SHILLO; HALEVY, 1976; PORTO et al., 2014; PEREIRA et al., 2016a). Plantas em estágio de V2-V3 foram submetidas, durante 15 dias, a três condições de temperatura e umidade do ar (SHILLO; HALEVY, 1976). Os autores verificaram que, no final do período do tratamento, as plantas que cresceram em ar quente e seco apresentavam entre 3 e 4 folhas, enquanto as

que cresceram em ar quente e úmido (menor demanda hídrica da atmosfera) tinham 4 a 5 folhas. Também foi observado que irrigações mais frequentes (aplicadas quando a tensão de água no solo era de 15 kPa), em um Latossolo Vermelho distroférrico, anteciparam a abertura das inflorescências que ocorreu próximo dos 65 dias após o plantio (PEREIRA et al., 2009). Resultado semelhante foi encontrado por Porto et al, (2014) em que as plantas atingiram o ponto de colheita aos 71 dias após o plantio no tratamento de 50% de reposição de água, e aos 62 dias no tratamento de 125% de reposição de água.

2.5.1. Resposta das plantas ao déficit hídrico

O estresse nas plantas por déficit hídrico ocorre quando a taxa de transpiração excede a taxa de absorção de água pelas raízes (MARENCO; LOPES, 2005), e pode ser provocada por um déficit na zona radicular ou por excessiva demanda evaporativa da atmosfera (SHILLO; HALEVY, 1976). Em condição de baixo suprimento hídrico, ocorre redução da umidade do solo e diminuição da disponibilidade de água para as plantas, devido a maior força de retenção da água no solo. Diante do desafio de sobreviver nessas condições, as plantas desenvolveram mecanismos de tolerância ao déficit hídrico.

As principais linhas de defesa das plantas ao déficit hídrico no solo são a inibição da expansão foliar, a expansão do sistema radicular, o fechamento estomático e a aceleração da senescência e abscisão das folhas (TAIZ; ZEIGER, 2017). A expansão foliar é o primeiro processo a ser afetado pela redução do conteúdo de água no solo (LAGO et al., 2011; KELLING et al., 2015), pois o déficit hídrico reduz o conteúdo de água na planta e a pressão de turgor nas células, que é responsável pela expansão foliar (TAIZ; ZEIGER, 2017; PEREIRA et al., 2016b). Quanto menor a área foliar, menor a transpiração, conseguindo assim conservar água no solo por mais tempo para sua sobrevivência.

Com o aumento do período de deficiência hídrica poderá ocorrer expansão ou aprofundamento do sistema radicular, a fim de explorar um volume maior de solo em busca de água (SOUZA et al., 2014). O aprofundamento das raízes no solo pode ser considerado a segunda linha de defesa das plantas ao déficit hídrico (TAIZ; ZEIGER, 2017), porém quando as plantas expostas ao déficit hídrico estão na fase de frutificação, os fotoassimilados são destinados para os frutos, e não para o crescimento das raízes.

O fechamento estomático é considerado a terceira linha de defesa das plantas ao déficit hídrico, sendo o mecanismo mais importante quando o déficit ocorre de maneira mais rápida ou em plantas que já atingiram sua área foliar máxima (TAIZ; ZEIGER, 2017).

Quando as raízes sentem a redução de água no solo, um sinal químico é emitido, através da produção de ácido abscísico, que desencadeia processos metabólicos nas células-guarda envolvendo a saída de solutos e, consequentemente, de água, acarretando o fechamento dos estômatos. Esse processo regula a perda de água pelas plantas em condições de déficit hídrico no solo (TAIZ; ZEIGER, 2017).

Em situação de déficit hídrico severo, a planta pode reduzir sua área foliar através da aceleração da senescência e da abscisão foliar (SANTOS; CARLESSO, 1998; PINHEIRO et al., 2014). Essa abscisão foliar ocorre devido ao aumento da síntese de etileno na planta (TAIZ; ZEIGER, 2017). Essa estratégia de sobrevivência da planta ocorre em situações de prolongada restrição hídrica, em que o objetivo é reduzir a área foliar transpirante e economizar água no solo.

2.5.2. Disponibilidade de água no solo

O conteúdo de água na planta varia com a disponibilidade hídrica no solo e na atmosfera e com as taxas de transpiração da planta, sendo que, o teor de água na planta diminui quando as taxas de transpiração excedem as de absorção de água do solo (MARENCO; LOPES, 2005). Como todos os processos que ocorrem na planta estão associados à disponibilidade de água, uma redução nessa disponibilidade afeta o crescimento e desenvolvimento das culturas agrícolas, influenciando na produtividade de culturas de grãos (ALBERTO et al., 2006) e na qualidade de produtos da floricultura (PORTO et al., 2014).

O solo é considerado um sistema trifásico composto por uma fase sólida, constituída por partículas minerais (areia, silte e argila) e orgânicas, formando um sistema poroso. A parte porosa do solo é composta de uma fase líquida, cujo solvente principal é a água, e uma fase gasosa, o ar do solo que ocupa o restante do espaço poroso. A quantidade de água armazenada no solo pode ser expressa por diferentes índices como: a quantidade total de água armazenada (QTA), a capacidade de armazenamento de água disponível (CAD), a fração de água disponível (FAD) e a fração de água transpirável no solo (FATS) e, por meio destes, pode-se determinar a ocorrência do déficit hídrico no solo (MARTINS et al., 2008). A QTA no perfil de um solo é definida como a quantidade de água que um solo pode armazenar, e é calculada multiplicando o valor de umidade da capacidade de campo (CC) pela profundidade da camada (CARLESSO; ZIMMERMAN, 2000), sendo que a CC é a quantidade de água que um solo pode reter após a ocorrência da drenagem natural do perfil, muitas vezes utilizada como o limite superior de disponibilidade de água para as plantas.

A CAD é a diferença do conteúdo volumétrico de água entre o limite superior e o limite inferior de disponibilidade de água para as plantas, considerando cada camada do perfil de solo explorado pelo sistema radicular das plantas. O limite superior de água disponível para as plantas é definido como o conteúdo de água no solo observado 24 horas após a drenagem do perfil, e o limite inferior de água disponível é o conteúdo de água no solo quando as plantas se apresentarem completamente senescidas (CARLESSO; ZIMMERMAM, 2000). Já a FAD é a razão entre o conteúdo volumétrico atual de água no solo explorado pelo sistema radicular e a quantidade potencial de água no solo. Apesar de apresentarem como desvantagem o fato de que nem toda água disponível é extraída pela cultura, tanto a CAD quanto a FAD são os indicadores mais utilizados do déficit hídrico e também do momento de irrigar as plantas (CARLESSO, 1995).

O conceito de FATS assume que o conteúdo de água no solo utilizado pela planta para a transpiração varia entre o conteúdo de água na capacidade de campo, quando a transpiração é máxima, e o conteúdo de água no solo quando a transpiração da planta é igual a 10% da transpiração máxima (SINCLAIR; LUDLOW, 1986). A FATS é utilizada para determinar a resposta das plantas ao déficit hídrico durante o período de redução de umidade no solo, e o conteúdo de água crítico para o qual a planta fecha os estômatos e reduz seu crescimento. Dentro dos conceitos citados, a FATS parece ser o melhor indicador da quantidade real de água no solo que pode ser extraída pelas plantas para a transpiração (SANTOS; CARLESSO, 1998) e tem sido utilizada para avaliar a resposta das plantas à redução de água disponível para a transpiração em diversas culturas como mandioca (LAGO et al., 2011; PINHEIRO et al., 2014), batata (LAGO et al., 2012; SOUZA et al., 2014), mudas de eucalipto (MARTINS et al., 2008), videiras (RAMOS; MARTÍNEZ-CASASNOVAS, 2014) e, inclusive para culturas ornamentais como o crisântemo (KELLING et al., 2015) e campanula (*Campanula medium*) (MAO et al., 2014).

2.4.2.1 Déficit hídrico representado pela FATS

A fração de água transpirável no solo (FATS) (SINCLAIR; LUDLOW, 1986) é um índice bastante utilizado para avaliar o efeito da deficiência hídrica do solo na transpiração, no crescimento foliar e para detectar o início do fechamento estomático. Os autores caracterizam três estágios de hidratação das plantas associados à redução de umidade do solo. O estágio I ocorre quando a planta não tem deficiência hídrica e, a condutância estomática e transpiração são máximas, ou seja, a transpiração não é limitada pelo conteúdo de água no

solo sendo influenciada somente pela demanda hídrica da atmosfera. O estágio II ocorre quando a água disponível no solo diminui e, para manter seu balanço hídrico e turgescência celular, há diminuição da condutância estomática e da transpiração. No estágio III, os estômatos fecham e a perda de água se dá somente devido à condutância epidérmica.

Para a determinação da FATS, são considerados os estágios I e II (SINCLAIR; LUDLOW, 1986; MUCHOW; SINCLAIR, 1991), considerando que a variação da transpiração com a FATS segue uma resposta que tem duas fases. Na primeira fase, a transpiração é máxima em uma faixa de valores de FATS que varia de 1 (solo na capacidade de campo) até um valor quando começa a ocorrer redução da transpiração das plantas devido ao início do fechamento estomático que é chamada de FATS crítica. Na segunda fase, a transpiração reduz proporcionalmente à redução da FATS até zero.

A FATS crítica representa a capacidade do genótipo em responder ao déficit hídrico no solo para manter a turgescência celular, sendo um parâmetro para identificar genótipos mais tolerantes ao déficit hídrico (JYOSTNA DEVI et al., 2009). É usada em modelos de simulação de culturas acoplados a modelos de balanço hídrico para simular o efeito do déficit no crescimento e na produtividade das culturas (AMIR; SINCLAIR, 1991; MUCHOW; SINCLAIR, 1991; ALBERTO et al., 2006; TIRONI et al., 2017) e para manejo da irrigação (KELLING et al., 2015).

O modelo descrito por Amir e Sinclair, que simula o crescimento e produtividade de trigo, foi estendido para a condição de limitação de água (AMIR; SINCLAIR, 1991). Nessa condição o desenvolvimento da área foliar foi retardado como uma função do teor relativo de água do solo, sendo que a FATS foi usada para descrever a resposta do crescimento foliar ao teor de água no solo. A diminuição da troca de gases nas folhas, associada ao fechamento estomático, também foi expressa como uma função da FATS. Nesse caso, a eficiência do uso de radiação (RUE) calculada para a condição sem estresse, foi inibida como uma função logística da FATS.

Para simular a produtividade de mandioca em condição de déficit hídrico, dois modelos de balanço hídrico, de Thornthwaite e Mather e de Ritchie, foram acoplados ao modelo Simanihot (TIRONI et al., 2017), que simula o crescimento e desenvolvimento da cultura em condição potencial. O balanço hídrico é calculado para se obter o conteúdo de água diário do solo e então calcular a FATS dividindo-se a quantidade de água atual do solo pela quantidade de água potencial do solo. O valor diário da FATS é o parâmetro da equação logística que relaciona a FATS com o crescimento foliar relativo diário. Quando a FATS atinge o valor da FATS crítica, o crescimento foliar passa a ser afetado.

Simulando a produtividade das culturas do trigo, soja e milho para Santa Maria, em condição de restrição hídrica no solo, a FATS foi relacionada com o fenômeno ENOS para avaliar seu efeito no rendimento anual de grãos (ALBERTO et al., 2006). Foi encontrado que as menores produtividades de soja e milho ocorrem em anos neutros, que estão associados à baixa disponibilidade hídrica no solo. Anos de La Niña são os mais favoráveis ao rendimento de grãos de trigo por não haver excesso de precipitação, e anos de El Niño são os mais favoráveis para o rendimento de grãos de soja e milho devido a maior disponibilidade hídrica no solo. Isso indica que quanto mais realísticos os modelos, melhor eles representam as interações entre a planta e o ambiente, possibilitando a realização de estudos como o realizado por Alberto et al. (2006).

A FATS também foi utilizada para descrever a transpiração e o crescimento foliar de quatro cultivares de crisântemo, Cherie White, Bronze Repin, Yoapple Valley e Calabria (KELLING et al., 2015). Os autores encontraram que as duas primeiras cultivares apresentaram valores de FATS crítica para a transpiração maiores do que às demais, indicando um mecanismo de controle estomático mais eficiente e, consequentemente, maior tolerância à deficiência hídrica. Os valores de FATS crítica para o crescimento foliar foram maiores do que os valores encontrados para transpiração, demonstrando que o crescimento foliar reduz antes de o mecanismo de fechamento estomático ser ativado, devido à redução do turgor nas células. Os autores ainda afirmam que a FATS poderia ser utilizada como instrumento no manejo da irrigação do crisântemo e para obtenção de genótipos tolerantes à deficiência hídrica.

Apesar de o entendimento das respostas de transpiração e crescimento foliar das plantas em função da FATS ter diversas finalidades e, ter sido determinada para diversas culturas, inclusive para espécies florícolas, não foram encontrados na literatura estudos sobre a resposta da cultura do gladiolo em função da FATS.

3. ARTIGO 1

Climate risk zoning for gladiolus under climate change scenarios⁽¹⁾

Abstract – 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 Rio Grande do Sul state considering damage due to low and high temperature. 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. Planting dates were considered recommended when the occurrence of 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 the most affected and 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 damages 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: rising temperature, heat injuries, floral stem quality, planting date

⁽¹⁾ Artigo científico formatado nas normas da Revista Brasileira de Engenharia Agrícola e Ambiental

Zoneamento de risco climático para gladiolo em cenários de mudança climática

Resumo – O objetivo desse estudo foi desenvolver um zoneamento de risco climático para a cultura do gladiolo 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 diárias (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. As datas de plantio foram consideradas recomendadas quando a ocorrência de danos na cultura por altas ou baixas temperaturas ocorreu 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, já que haverá uma ampliação do período recomendado para plantio nas épocas do ano que atualmente sofrem danos por baixas temperaturas. Para atender a demanda de gladiolo 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: aumento da temperatura, danos por calor, qualidade das hastes florais, data de plantio

INTRODUCTION

Gladiolus (*Gladiolus x grandiflorus* Hort.) is one of the most important bulb flower crops worldwide (Thakur et al., 2015). Because it is an easy-to-produce crop that requires low initial cost and can be cultivated in the open field, gladiolus has become an important cut flower for small farmers in Brazil, who sell 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 Rio Grande do Sul State is important for meeting the demand of the state that currently imports about 90% of cut flowers (Ibraflor, 2019).

Ornamental plants, especially those grown in open field 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 may cause injuries on floral stem due to heat stress and frost, killing plants or reducing flower quality (Uhlmann et al., 2017; Schwab et al., 2018).

The latest report of the Intergovernmental Panel on Climate Change (IPCC) indicates an average global temperature increase of 0.85°C over the period from 1880 to 2012, with the largest increase in the 90's (IPCC, 2013). Long term 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 damages 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 Rio Grande do Sul state considering damage due to low and high temperature.

MATERIAL AND METHODS

The recommended and non-recommended periods for planting gladiolus in the Rio Grande do Sul State (RS) was 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 optimist, intermediate and pessimist 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 81km of resolution with the RegCM4 (Regional Climate Model, version 4). The projection of an increase in temperature and CO₂ 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 scenarios).

The current climate risk zoning in RS 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). We chose to use these data because of low density of meteorological stations across the State.

The PhenoGlad model (Uhlmann et al., 2017), a dynamic process-based on 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 include 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 (T_{min}) is lower than -2°C during at least three days in a row from emergence to the R5 stage, then the crop is killed by frost. If the minimum temperature is lower than or equal to -2°C during one day or if $-2^{\circ}\text{C} < T_{min} < 3^{\circ}\text{C}$ during 4 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 counties of the Rio Grande do Sul State were grouped into 23 homogeneous regions (Figure 1), and each region was represented by a meteorological data grid point. The PhenoGlad model (Uhlmann et al., 2017) 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 for the 23 regions of the state. The recommended planting dates was considered when the PhenoGlad model identified the occurrence of high and low temperature damages in less than 10% of the evaluated years. For example, for a given planting date, if the model indicated the occurrence of high or low temperature damages in 10% or more of the years of meteorological data, this planting date was considered inappropriate for planting gladiolus. 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. The results were presented on maps using the QGIS software and the future climate risk zoning was compared with the current climatic risk zoning for the crop.

RESULTS AND DISCUSSION

The recommended periods for planting gladiolus throughout the year in six 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 in Figure 2. These six regions of the State have the greatest climate contrast. The recommended period for planting gladiolus in the current zoning (black lines on Figure 2) is much larger than compared to 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 in the Uruguaiana region, minimum temperatures are lower in the current zoning (Figure 3A) and maximum temperatures are much higher in the baseline period than in the current zoning (Figure 3B). This indicates that, for the baseline period, a shorter period throughout the year is recommended for planting due to the higher occurrence of damages 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 (Figure 3A and 3B). 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 damages in the gladiolus crop by high temperatures.

With increasing air temperature there is a tendency to change the recommended planting period as we look at a more pessimistic scenario. 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. 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 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 finalized before the planting of Early cultivars.

It is also noted that there will be a 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 (Lopez-Marin et al., 2011) and its effect on gladiolus culture 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 in the months that

previously occurred damages due to low temperatures in the crop (Figure 2C). Only in scenarios 4.5 and 8.5, these regions will suffer more from high temperatures, so no plantings between June and December are recommended for both developmental cycles in scenario 8.5. Similar results were obtained for rice in the Rio Grande do Sul State, which had better conditions for cultivation in the South region due to the reduction of damages 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 (do Rio et al., 2015; Wang et al., 2015a; Wang et al., 2015b). Most ornamental crops, unlike gladiolus, are grown in greenhouses, where the air temperature is modified (Moccaldi & Runkle, 2007), so studies of 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 and All Souls' Day has been previously studied (Becker et al., 2020). In order to meet the demand for floral stems on All Souls' Day, planting should be carried out later than is currently climate, due to the shortening of the crop development cycle, and also a higher occurrence of damage due to high temperatures. In a similar way, our study shows that plantings in September, aiming to harvest in 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., 2020) since flowering occurs between April and May. In the zoning presented in this study, we consider the 10%

level that is more judicious, therefore, planting for Mothers' Day is recommended only in the Rio Grande, Bom Jesus, and Bagé region. For the Uruguaiana region, the cultivation is more restricted, mainly in scenarios of greater heating, like the RCP8.5. In Iraí it is still possible to produce gladiolus for this peak of consumption 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 the climate change scenarios RCP2.6, RCP4.5 and RCP8.5 are presented in Figures 4, 5 and 6. In the RCP2.6 scenario, Early and Intermediate II cultivars can be planted throughout 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 damages (<10%).

In the RCP4.5 scenario, 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 RCP8.5 scenario, the same condition is also 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, it is recommended the gladiolus planting in the entire Rio Grande do Sul State only between February and May. It is noteworthy a large number of regions not recommended for planting gladiolus in August and September, a time that aims to meet the demand for flower stems for the All Souls' Day.

In the Rio Grande do Sul State, the cultivated area with floriculture products is 1360 ha and consumption *per capita* is R\$ 38.29 or US\$ 9.57 (Ibraflor, 2018). However, about 90% of the cut flowers consumed in the State are imported from other Brazilian regions, being the gladiolus an alternative to supply this 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 since they will have an increase in the recommended period for planting in the months that previously occurred crop damages due to low temperatures.

4. 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.

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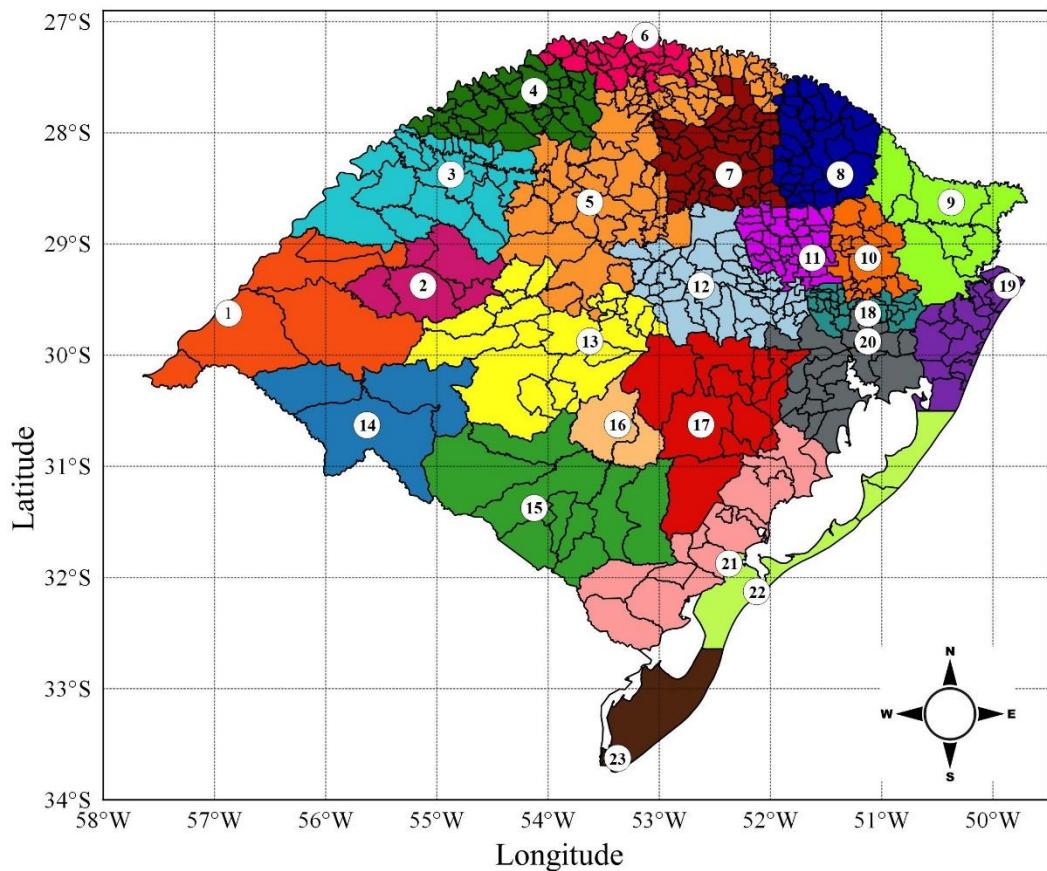


Figure 1. Location of the 23 homogeneous regions distributed in the Rio Grande do Sul State used in this study to determine the climate risk zoning of gladiolus in climate change scenarios. (1) represents region of Uruguiana, (2) São Francisco de Assis, (3) São Luiz Gonzaga, (4) Santa Rosa, (5) Cruz 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.

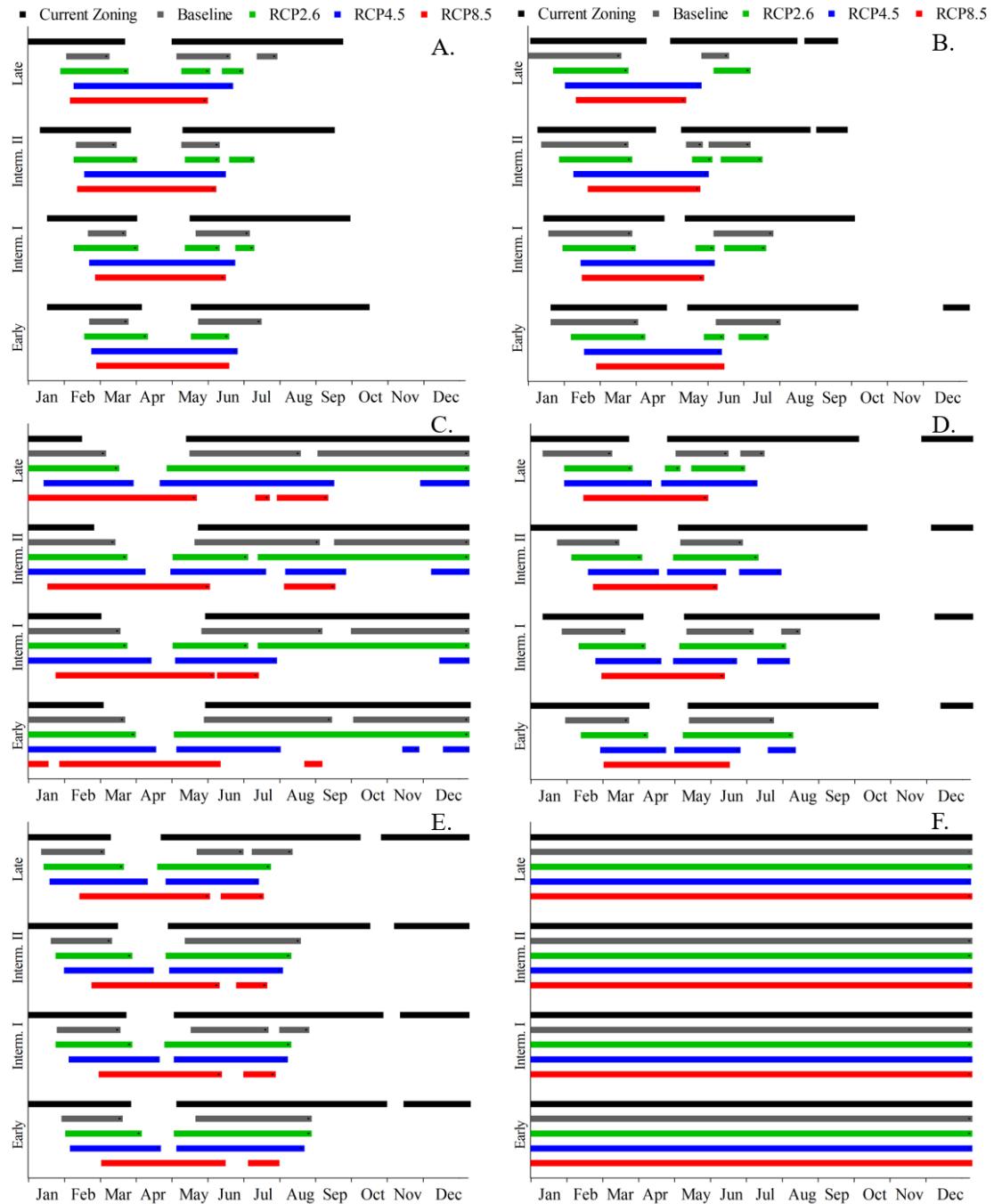


Figure 2. Recommended (solid lines) and non-recommended (gaps within the solid lines) planting periods in (A) Uruguaiana region, (B) Iraí region, (C) Bom Jesus region, (D) Santa Maria region, (E) Bagé region and Rio Grande region (F) for Early, Intermediate I, Intermediate II and Late gladiolus under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

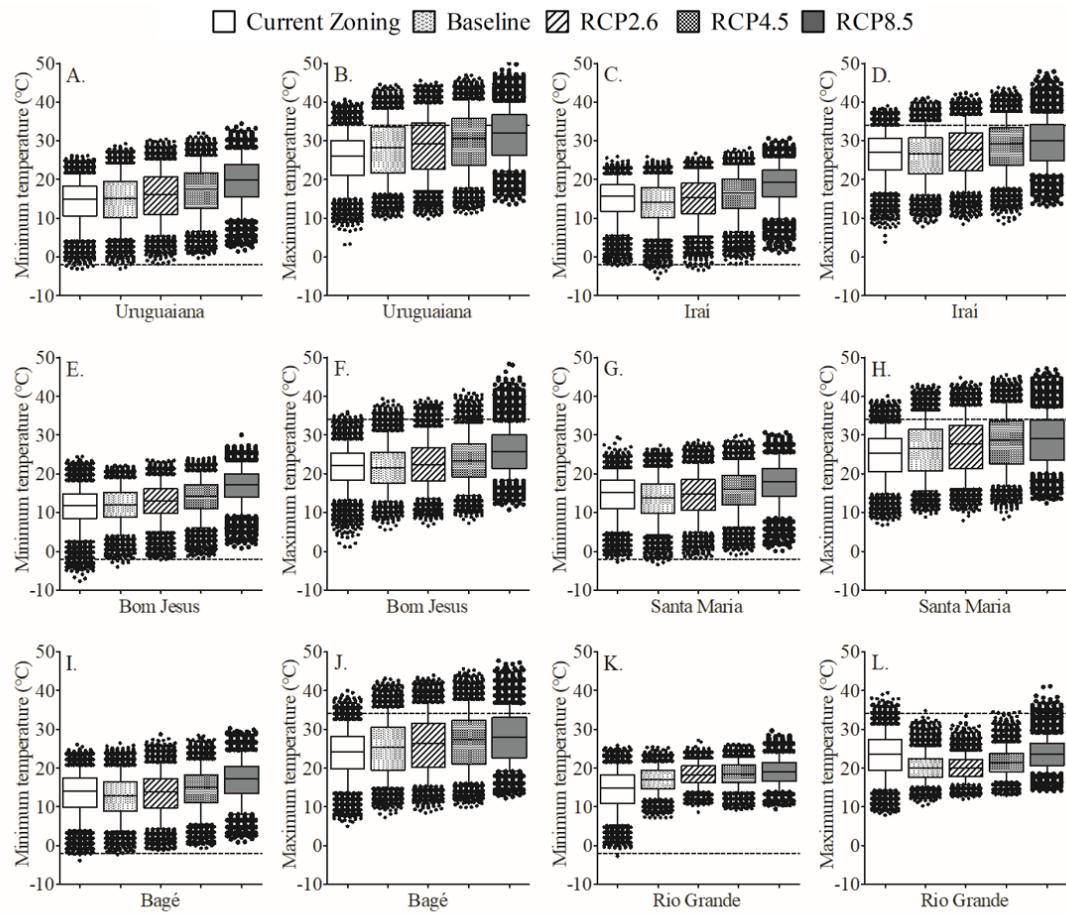


Figure 3. Minimum and maximum air temperatures during the current zoning (1980 to 2013), during the baseline period (1970 a 2005) and for three climate change scenarios RCP2.6, RCP4.5 and RCP8.5 (2070 to 2098) in six regions of the Rio Grande do Sul State: (A.) and (B.) Uruguaiana, (C.) and (D.) Iraí, (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 bellow 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.

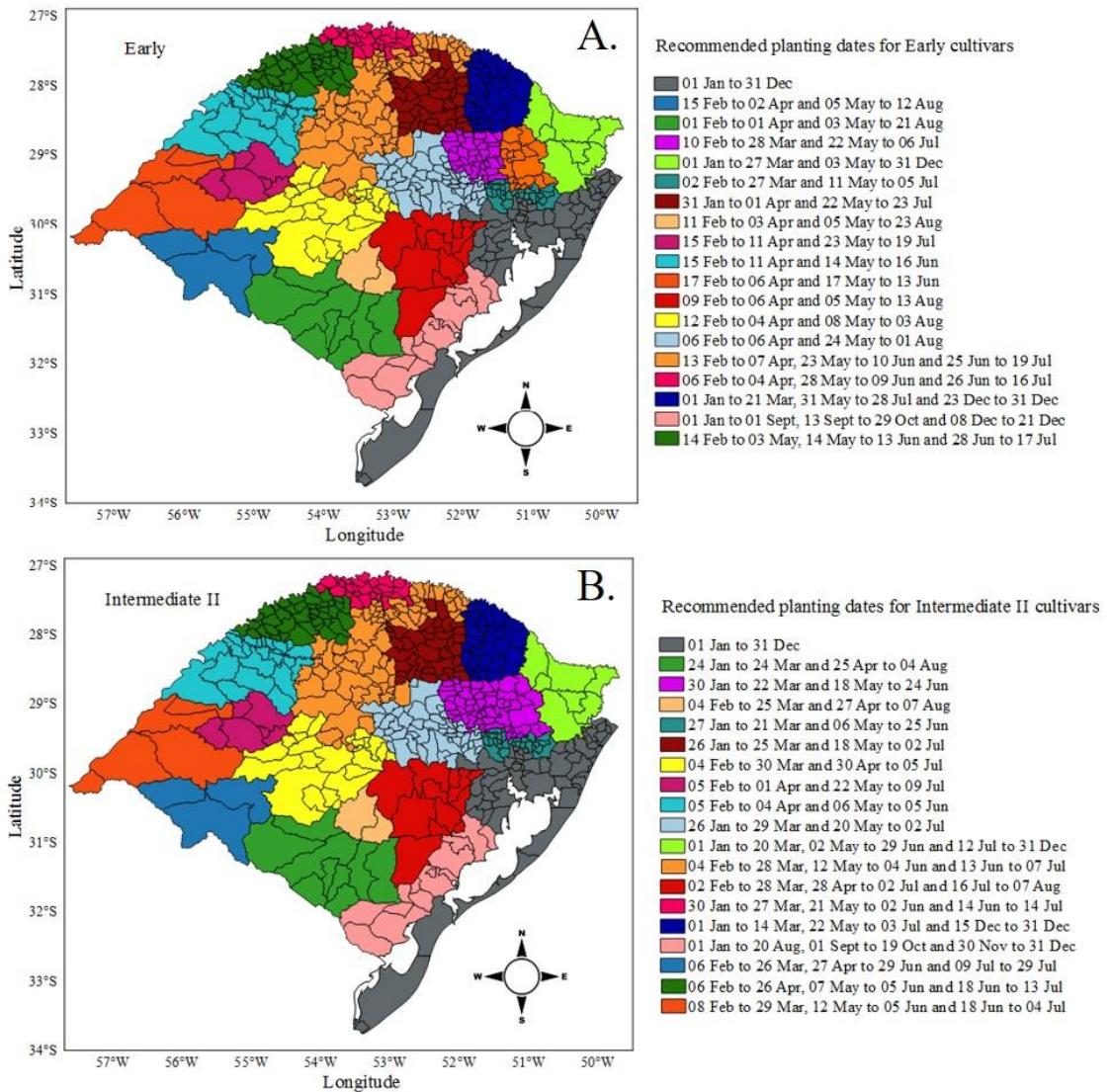


Figure 4. Climate risk zoning in the RCP2.6 climate change scenario for Early (A.) and Intermediate II (B.) gladiolus cultivars in the Rio Grande do Sul State.

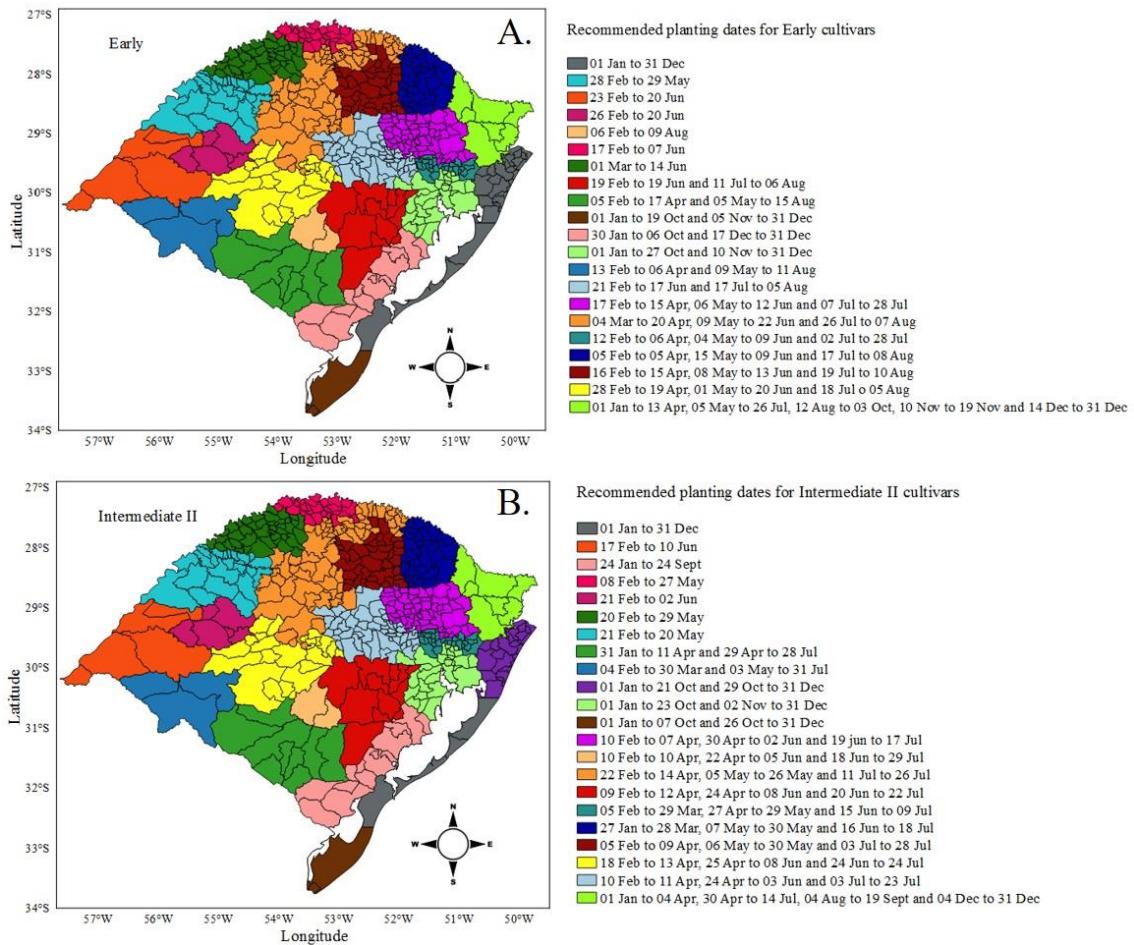


Figure 5. Climate risk zoning in RCP4.5 climate change scenario for Early (A.) and Intermediate II (B.) gladiolus cultivars in the Rio Grande do Sul State.

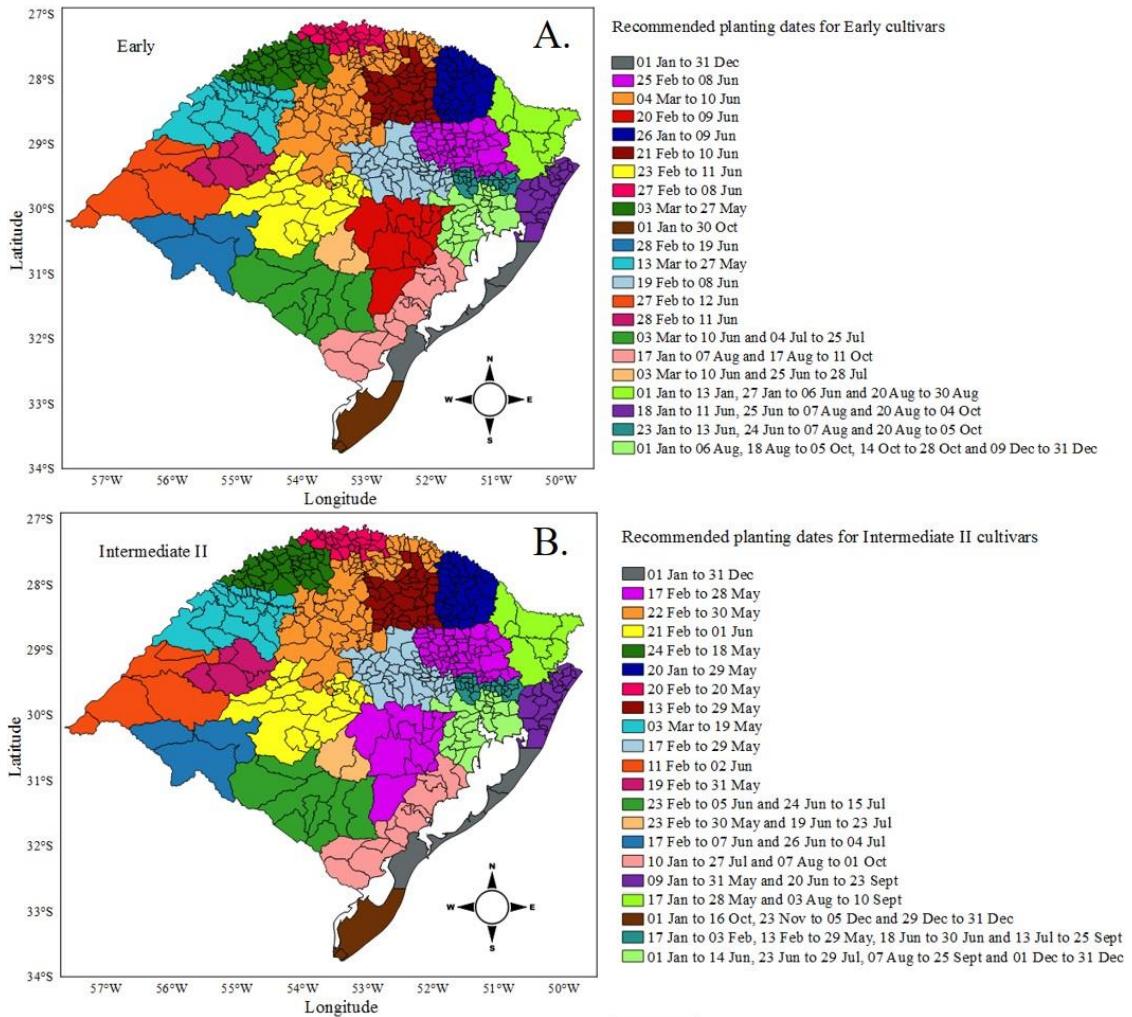


Figure 6. Climate risk zoning in the RCP8.5 climate change scenario for Early (A.) and Intermediate II (B.) gladiolus cultivars in the Rio Grande do Sul State.

4. ARTIGO 2

Harvest forecast: an approach applied to gladiolus

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HARVEST FORECAST: AN APPROACH APPLIED TO GLADIOLUS

Abstract. Knowing in advance the probable flowering date of the gladiolus allows farmers to plan for alternatives to mitigate the negative effects of environment in delaying or anticipating harvest. The objective of this study was to develop an approach for forecasting the date of gladiolus harvest. The approach was evaluated in Rio Grande do Sul (RS) and Santa Catarina (SC) States, Southern Brazil. Commercial farms of gladiola were accompanied in several counties from 2016 to 2018. The PhenoGlad model was used for predicting the harvest date of the flower stems once every 15 days. The PhenoGlad model uses current weather data to simulate crop development until the forecast date. After that, the model uses historical weather data to predict all possible scenarios of crop development. The higher probability period of occurrence of the harvest date (50%) was provided to farmers. The PhenoGlad model showed good performance among planting dates, years and locations. In the first three forecasts in RS, the RMSE varied from about 7 to 4.5 days. In SC, the RMSE varied from 5.5 to 3.4 days. These errors are acceptable from a practical viewpoint, because it is a forecast of harvest date performed about 45 days before harvest. With the approach, farmers can be informed about the progress of the development of the gladiolus and on the chances that the harvesting point will occur at the desired moment.

Keywords: cut flower; planning harvest; PhenoGlad; ornamental plants; developmental stages.

Introduction

Gladiolus (*Gladiolus x grandiflorus* Hort.) is one of the most popular bulbous cut flowers worldwide (Thakur et al., 2015). The major producing countries are the United States, Netherlands, Italy, France, Bulgaria, India, and Israel (Vasanthakumar et al., 2015). In central México gladiola represents 80% of the cut flowers produced (Gómez-Pérez et al., 2018) and in Brazil, it is one of the top ten cut flowers with major market holidays on All Souls' Day and Mother's Day (Junqueira and Peetz, 2017). Gladiolus is cultivated in Brazil in open field and is an excellent alternative for small farmers and local flower production (Uhlmann et al., 2019).

Farmers plant gladiolus, as well as many other flower crops, aiming to have flower stems ready for specific holidays and special dates based on zoning or self-experience. Once planting is performed, in-season climate variability can play an important role in defining the timing of harvest point, leading to have flower stems before or after the target date of commercialization. If we are able to know in advance the likely day of flowering, farmers can be advised to look for alternatives to mitigate the negative effects of delaying or anticipating the harvest. While approaches for forecasting yield of crop grains have been developed (Morel et al., 2016), a reliable approach for forecasting gladiolus harvest point is not available, which constituted the rationale for this study.

Crop yield forecast systems have evolved from empirical approaches that relied on field experience or on simple statistical relationships to more process-based approaches using crop models such as to predict maize yields in the U.S. Corn Belt (Morell et al., 2016), to predict rice yield in Brazil (da Silva et al., 2016), and to predict wheat, maize, rapeseed, sunflower, potato and suger beet in Europe (Velde and Nisini, 2019). PhenoGlad model is a dynamic process-based crop model (Uhlmann et al., 2017) that simulates the developmental stages of gladiolus. The PhenoGlad model was previously used in different studies (Becker et

al., 2020; 2021) and is suitable for using in an approach for forecasting gladiolus harvest. The objective of this study was to develop an approach for forecasting the date of gladiolus harvest.

Materials and methods

The study region

This study was performed in the Rio Grande do Sul (RS) and Santa Catarina (SC) States, Southern Brazil (Figure 1), which are states of high demand for cut flowers and import about 90% of their flower consumption (Ibraflor, 2018). Furthermore, about 83% of rural properties in Rio Grande do Sul and about 89% in SC are smaller than 50 ha (IBGE, 2017), and the production of cut flowers, such as gladiolus, is an excellent alternative for additional income in these small properties (Uhlmann et al., 2019). According to Köppen's climate classification system, the RS and SC States have regions with humid subtropical climate without a dry season and hot (Cfa) and temperate (Cfb) summer (Alvares et al., 2013).

Commercial farms of gladiola were accompanied in the counties of Santa Maria, Santiago, Cachoeira do Sul, Itaara, São João do Polêsine e Dilermando de Aguiar in the Rio Grande do Sul State (Table 1), and in Curitibanos, Concórdia and Rio do Sul in Santa Catarina State (Table 2), during three years, from 2016 to 2018. The farmers intended to sell the flower stems on specific holidays in Brazil such as Mother's Day (second Sunday of May), All Souls' Day (02 November) and Valentine's Day (12 June).

The cultivars used by farmers were Gold Field (Late cycle), White Goddess, Black Velvet, Jester, Red Beauty, Rose Supreme, Fidelio, Green Star (Intermediate II cycle), Peter Pears and Amsterdam (Intermediate I cycle), Rose Friendship and White Friendship (Early cycle), which represent a wide range of colors and maturation groups (MG). Weekly visits were held at the farms to keep track on the development of the plants. The emergence date of each cultivar in each location was defined as the date when 50% of individual plants had

emerged. The date of occurrence of the R2 stage (blooming) was observed on 12 to 20 tagged plants per cultivar according to the phenological scale of gladiola by Schwab et al. (2015). The observed R2 stage for each cultivar was considered when 50% of observed plants were at the stage. Management practices during the growing season followed the technical recommendations. Irrigation was performed by farmers as needed, but they did not measure the amount of irrigated water.

The PhenoGlad model

The model used in this study was PhenoGlad, a dynamic process-based gladiola phenology model previously calibrated and validated with different cultivars, planting dates, years and locations from experiments conducted in two states in Southern Brazil, RS and SC States (Uhlmann et al., 2017). In PhenoGlad, gladiola phenology is simulated without water limitations and considering three main phases based on the developmental scale by Schwab et al. (2015): sprouting phase (S stages), vegetative phase (V stages), and reproductive phase (R stages). Starting at planting, the developmental stage (DVS) is calculated by accumulating the daily developmental rate values, using daily mean air temperature, with the nonlinear approach from Wang and Engel (1998). A nonlinear temperature response function is used to penalize the development of the crop when the daily air temperature is below or above the optimum temperature. The PhenoGlad model simulates the development of selected cultivars or, in the general mode, of four different MG: Early, Intermediate I, Intermediate II and Late. Each MG has a maximum daily developmental rate that represents a group of cultivars.

The cardinal temperatures, minimum (T_b), optimum (T_{opt}) and maximum (T_B), in the sprouting phase are T_b = 5°C, T_{opt} = 25°C, and T_B = 35°C. In the vegetative phase the cardinal temperatures are T_b = 2°C, T_{opt} = 27°C and T_B = 45°C and in the reproductive phase, cardinal temperatures are T_b = 6°C, T_{opt} = 25°C and T_B = 42°C. Input data required

to run the PhenoGlad include daily minimum and maximum air temperatures, planting or emergence date and cultivar or MG (Early, Intermediate I, Intermediate II and Late). Air temperature is the only factor that controls gladiola development in PhenoGlad and the model was calibrated under potential condition (without water limitation) (Uhlmann et al., 2017).

Harvest forecast approach for gladiola

The harvest forecast approach for gladiola was based on the approach used for corn (Morel et al., 2016) and rice (da Silva et al., 2016). It consists in predicting the harvest date of the flower stems so that the farmer may know in advance whether he/she will have flowers to meet market demand for the target date. Harvest forecast was run once every 15 days, for each cultivar, for each commercial farm. The PhenoGlad model was run with inputs from the farm, such as the planting date or emergence date observed, the cultivar or MG, and historical minimum and maximum air temperature of 55 years for the counties in RS State and of 38 years for the counties in SC. Daily weather data were obtained from the nearest automatic weather stations of the Brazilian National Weather Service (INMET). In each new forecast run, the PhenoGlad model also used weather data from the current season to update the forecast.

Figure 2 illustrates how the harvest forecast approach is performed. The PhenoGlad model uses current in-season weather data to simulate crop development until the forecast date (solid green line in Figure 2a). After that, the model uses historical weather data to predict all possible scenarios of crop development as a function of the meteorological conditions of each year (colored lines in Figure 2a). Therefore, each year of historical weather data results in a harvest date (R2 stage (Schwab et al., 2015)), resulting in a range of possible final harvest date. The higher probability period of occurrence of the harvest date was

provided to farmers, eliminating the first and last quartile that represents the earliest and the latest harvesting (Figure 2b).

To understand the evolution of forecasting throughout gladiola development, for each forecast launched, the predicted range of harvest point date was detailed by calculating the mode, the earliest harvesting, the latest harvesting, the first quartile, and the third quartile. The last forecast was run when the meteorological data measured were enough to simulate the entire crop development. As a result, single date of the R2 stage (harvest date) simulated by the model was obtained. The harvest date simulated was compared to the observed date of R2 stage in commercial farms. Model performance in simulating the harvest date was evaluated with the statistics RMSE, BIAS index (Wallach, 2006), index of agreement (dw) (Willmott, 1981), correlation coefficient (r) and systematic (MSEs) and unsystematic (MSEns) errors (Willmott, 1981). Low RMSE, zero BIAS, one dw and r, and low systematic and high unsystematic error are characteristics of a good model. The performance of the approach for the first three forecasts was also evaluated using these statistics, in order to quantify the accuracy of the forecast still at the beginning of the crop development.

Results

In order to represent the evolution of the harvest forecast during the crop development, we use as an example two distinct growing seasons: aiming to produce floral stems for Mother's Day 2017 (Jester cultivar) and for All Souls' Day 2016 (cultivar White Goddess) in RS (Figure 3). It is noted that for the Mothers' Day growing season, which occurs during February, March and April (Fig. 3a), the expected range of R2 stage occurrence is lower than for the All Souls' Day growing season (Fig. 3b), which occurs during July, August, September and October, mainly if we look at the range between the first and third quartiles.

As the forecast was launched later in the growing season, the range narrows, and the forecast indicates a short period of R2 stage. In these two cases, the information given to the farmer at the third forecast, for example, was that there would be a 50% chance of the floral stems of the Jester cultivar would be ready for harvest between 10 May and 11 May, and stems of the White Goddess cultivar among 22 October and 25 October.

Forecasted versus observed days after planting (DAP) of harvest date (R2 stage) for all the cultivars of gladiolus in RS and SC States, aiming floral stems harvest on All Souls' Day, Mother's Day and Valentine's Day are in Figure 4. The forecasted R2 stage was close to the simulated R2 in the last forecast run, when meteorological data of current season were enough to simulate the entire crop development. Aiming harvesting flower stems on All Souls' Day, the RMSE was 5.51 days for the locations in RS state and 4.67 days for the locations in SC state.

The forecast for harvesting flower stems on Mother's Day had a lower RMSE (4.48 days in RS State and 3.54 days in SC). For the gladiolus cultivation aimed harvesting on Valentine's Day in SC, the RMSE was 3.71 days. The performance of the harvest forecasting approach in the first three forecasts during the growing season in RS and SC is in Figure 5. For harvesting on All Souls' Day in RS (Fig. 5a), the RMSE varied from 6.99 days, in the third forecast, to 7.21 days in the first forecast.

For harvesting on Mother's Day in RS (Fig. 5b), the RMSE in the first three forecasts was lower than for harvesting on All Souls' Day. The RMSE varied from 4.37 days, in the third forecast, to 4.71 days, in the second forecast. For harvesting on All Souls' Day in SC (Fig. 5c), the RMSE varied from 5.38 days, in the third forecast, to 5.98 days, in the first forecast. For harvesting on Mother's Day in SC (Fig. 5d), the RMSE was only 3.14 days, in the second forecast, 3.4 days, in the third forecast and, 3.79 days in the first forecast. For harvesting on Valentine's Day (Fig. 5e), the RMSE was 5.39 days, 4.73 days and 4.80 days in first three forecasts, respectively.

Discussion

The different cultivars, planting dates and locations (Tables 1 and 2) constitute a robust dataset to test the practical application of the harvest forecast approach for gladiola. The greater range of the harvest forecast observed in the All Souls' Day compared to the Mother's Day (Figure 3b) is related to the greater interannual variability of the air temperature during the Spring compared to the Fall (Becker et al., 2020). During the Mother's Day growing season (Fig. 3a), this variability is lower because the different years of meteorological data simulate much more similar responses regarding the date of R2 stage occurrence (harvest date) and, therefore, the first predictions have a lower range, mainly between the first and third quartiles. In the last forecast, when we already had current season meteorological data sufficient to simulate the entire development of the crop, the forecast points to a single date of R2 stage, considered by the PhenoGlad model as the date when 50% of the gladiola plants came in harvesting (Uhlmann et al., 2017).

The black dotted line in Figure 3 is the average observed date at which the evaluated plants reached the harvest point in the farm. However, this is only a simplified way of representing the date of the harvesting point in the gladiola, because in reality, a gladiola field has plants blooming during about two weeks. In order to better understand how the flowering of a gladiolus crop occurs, we monitored the flowering of different gladiola cultivars in Santa Maria, RS, on a daily basis and noticed that there is a flowering peak after the flowering of the earlier plants and after the flowering peak, there are later plants to bloom (Figure 6). The important thing is for the farmer to know if this blooming peak will occur near the date the consumer needs the floral stems ready for a party decoration, for example, or if it will occur a few days before the target date. In this case, he will need to have a cold chamber for storing the flower stems and delaying the opening of the florets until the day of delivering the flower stems to the consumer (Schwab et al., 2014). If the harvest forecast predicts the flowering time before a target marketable day, the farmer still can cold store the

spikes (5 to 8°C) for up to 15 days, slowing down the progress of flowering open so that spikes are marketable at the target day (Uhlmann et al., 2017).

For the cultivar Jester, 262 corms of gladiolus were planted on 22 November 2017 (Fig. 6a) and the plants were grown with two stems per bulb, that is, each planted corm was able to produce two flower stems, resulting in a greater number of stems harvested and in a greater variability between plants. Therefore, the harvest period was higher than when plants were grown with a single stem per bulb, totaling about 40 days (Fig. 6a). Based on this information, the 50% probability range (Fig. 3b), considered by the forecast is a good range to indicate to farmers a likely period that they will have gladiolus for harvest, since we disregard the earliest and the latest harvesting of the crop.

The PhenoGlad model showed good performance for the cultivars among planting dates, years and locations. The PhenoGlad has greater error in simulating the harvesting date of the flower stems produced for All Souls' Day than for Mother's Day and Valentine's Day. The RMSE in the prediction of R2 stage varied from 3.54 days to Mother's Day in SC (Fig. 4b) to 5.51 days to All Souls' Day in RS (Fig. 4a), which is similar to the RMSE for others crops, such as 4.3 to 10.9 days for rice (Streck et al., 2011), 2.7 to 4.8 days for maize (Streck et al., 2009) and 5 to 6 days for winter wheat (Streck et al., 2003). For practical applications, an error of five days for simulating the R2 stage of gladiola is acceptable (Becker et al., 2021).

We observed that there are some random events that can interfere in PhenoGlad model accuracy, but they do not greatly reduce the model performance. For example, the accuracy of the PhenoGlad model in simulating the R2 stage is lower when the model is run from planting compared to when the model is run from emergence date (Uhlmann et al, 2017). It occurs because in some growing seasons, we were unable to collect the emergency date of the plants and, therefore, the harvest forecast was run from the planting date. So, if we had run all the forecasts from the emergency date, it is possible that the RMSE would have been even smaller. Another factor that can affect the performance of the model in simulating the development of the crop is the low density of

meteorological stations and low quality of the meteorological data collected (Grassini et al., 2015; Xavier et al., 2016). To get around this, we used data from a weather station that is often not so close to the farm and may not fully represent the environmental conditions in which the plants are exposed (Morell et al., 2016).

In order to be able to plan and deliver the flower stems at the target date, farmers need to know in advance if the flower stems will reach the harvest point on the target date. For harvesting gladiola on All Souls' Day in RS, the RMSE to simulate the R2 stage was about 7 days in the first three forecasts (Fig. 5a), about 1.5 days greater than the final error of the forecast (Fig. 4a). In SC, the RMSE was about 5.5 days for the first forecasts (Fig. 5c), about 1 day greater than the error of the final forecast (Fig. 4a). As the duration of the gladiolus development cycle at this time of year ranges from 96 to 118 days (RS) and from 87 to 120 days (SC), a 7 day error for RS and 5.5 days for SC is acceptable, as it refers to an information generated about 50 to 70 days before harvesting the flower stems, allowing the grower to plan strategies for storing stems.

For harvesting on Mother's Day, the RMSE to simulate the R2 stage was about 4.5 days in RS (Fig. 5b) and 3.4 days in SC (Fig. 5d) in the first three forecasts. These errors are low, because it is a forecast of harvest date of the floral stems performed about 45 days before harvest, and the crop, at this time of year, presents a development cycle ranging from 80 to 96 days (RS) and from 85 to 93 days (SC), depending on the cultivar. For harvesting on Valentine's Day in SC, that includes the months of March, April, and May, the error was about 5 days in the first predictions (Fig. 5e), about 1.3 days greater than the error of the final forecast (Fig. 4c). At the same time, the developmental cycle of gladiola varies from 95 to 109 days, so a 5 days error is acceptable for this methodology that aims to inform the farmer in advance about the probable harvest period of the flower stems. This information has practical and applied results for gladiola farmers who have focused on producing floral stems for decorating events and other commemorative dates.

The yield forecasts of maize for the U.S. Corn Belt is released at the CropWatch web site (<https://cropwatch.unl.edu/>) every three weeks. These yield forecasts allow adjusting yield goals for the current growing season in comparison to normal years and can support management decisions such as timing and amounts of fertilization and irrigation, or application of pesticides during the grain-filling period (Morell et al., 2016). For ornamental crops, like gladiola, the forecast approach presented here can inform the farmer about the progress of the development of the gladiolus in his farm and on the chances that the harvesting point will occur at the desired target, or if some climatic variability, such as heatwaves, will cause the flowering to be anticipated. In this case, the farmer can plan to store the flower stems in a cold chamber to delay the opening of the florets (Schwab et al., 2014).

Conclusions

A forecast approach for the date of gladiolus harvest was proposed and evaluated. The approach is an important tool for ornamental plant growers who need to attend specific times of demand for flowers, which require flowering to occur in a predetermined period. The approach provides the farmer to know about two months in advance how likely the flower stems of gladiolus will be ready for the target date. If the forecast indicates that the flower stems will be ready before the target date, the farmer can plan to store them in a cold chamber. The approach can be extended to other regions of the world and to other ornamental crops in order to assist producers in the decision-making process for a more efficient production planning.

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Author Contributions

Conceptualization: Becker, C.C.; Streck, N.A.; Uhlmann, L.O.; Schwab, N.T. Data acquisition: Becker, C.C.; Uhlmann, L.O.; Tomiozzo, R.; Balest, D.S.; Bosco, L.C.; Bonatto, M.; Souza, A.G. Data Analysis: Becker, C.C.; Uhlmann, L.O.; Balest, D.S.; Tomiozzo, R.; Bonatto, M. Design of methodology: Becker, C.C.; Streck, N.A.; Uhlmann, L.O.; Tomiozzo, R.; Balest, D.S.; Schwab, N.T.; Bosco, L.C.; Bonatto, M.; Souza, A.G. Writing and Editing: Becker, C.C.; Streck, N.A.; Uhlmann, L.O.; Tomiozzo, R.; Balest, D.S.; Schwab, N.T.; Bosco, L.C.; Bonatto, M.; Souza, A.G.

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Table 1. Locations, number of cultivars, year of cultivation, planting dates, and absolute minimum (Min), maximum (Max) and Mean air temperatures during the gladiola developmental cycle in commercial farms in Rio Grande do Sul State used in the study.

Location	Number of cultivars	Year	Planting date	Temperature (°C)		
			(dd/mm)	Min	Max	Mean
All Souls' Day						
Santa Maria	5	2016	21/07 a 04/08	1.3	31.5	16.4
Santa Maria	4	2017	17/07 a 29/07	0.7	33.3	17.0
Itaara	3	2018	16/07 a 30/07	-0.3	32.3	17.9
Cachoeira do Sul	1	2018	18/07	1.0	35.1	17.1
São João do Polêsine	4	2018	19/07 a 02/08	1.0	35.1	17.1
Mother's Day						
Santa Maria	5	2017	12/02 a 24/02	5.4	34.3	19.8
Cachoeira do Sul	4	2018	15/02	10.7	36.6	23.6
Dilermando de Aguiar	3	2018	14/02	10.3	36.6	23.5
Santiago	4	2018	19/02	10.9	33.7	22.3
Santa Maria	5	2018	16/02 a 19/02	10.2	36.6	23.5

Table 2. Locations, number of cultivars, year of cultivation, planting dates and absolute minimum (Min), maximum (Max) and Mean air temperatures during the gladiola developmental in commercial farms in Santa Catarina State used in the study.

Location	Number of cultivars	Year	Planting date (dd/mm)	Temperature (°C)		
				Min	Max	Mean
All Souls' Day						
Curitibanos	5	2016	20/06 a 22/07	-1.1	31.2	15.1
Curitibanos	4	2017	28/06 a 24/07	-1.3	31.2	15.0
Concórdia	5	2017	14/07 a 09/08	3.6	35.4	19.9
Rio do Sul	5	2017	07/07 a 04/08	3.4	31.9	17.7
Mother's Day						
Curitibanos	5	2017	09/02 a 22/02	0.1	30.2	14.3
Curitibanos	4	2018	12/02	10.8	29.8	20.1
Concórdia	4	2018	15/02	10.9	33.3	22.1
Rio do Sul	4	2018	19/02	12.3	34.3	23.3
Valentine's Day						
Curitibanos	5	2017	02/03 a 15/03	-0.3	27.0	13.4
Curitibanos	4	2018	03/03	1.3	29.8	15.6
Concórdia	3	2018	08/03	2.3	33.3	17.8
Rio do Sul	4	2018	09/03	6.0	31.7	18.9

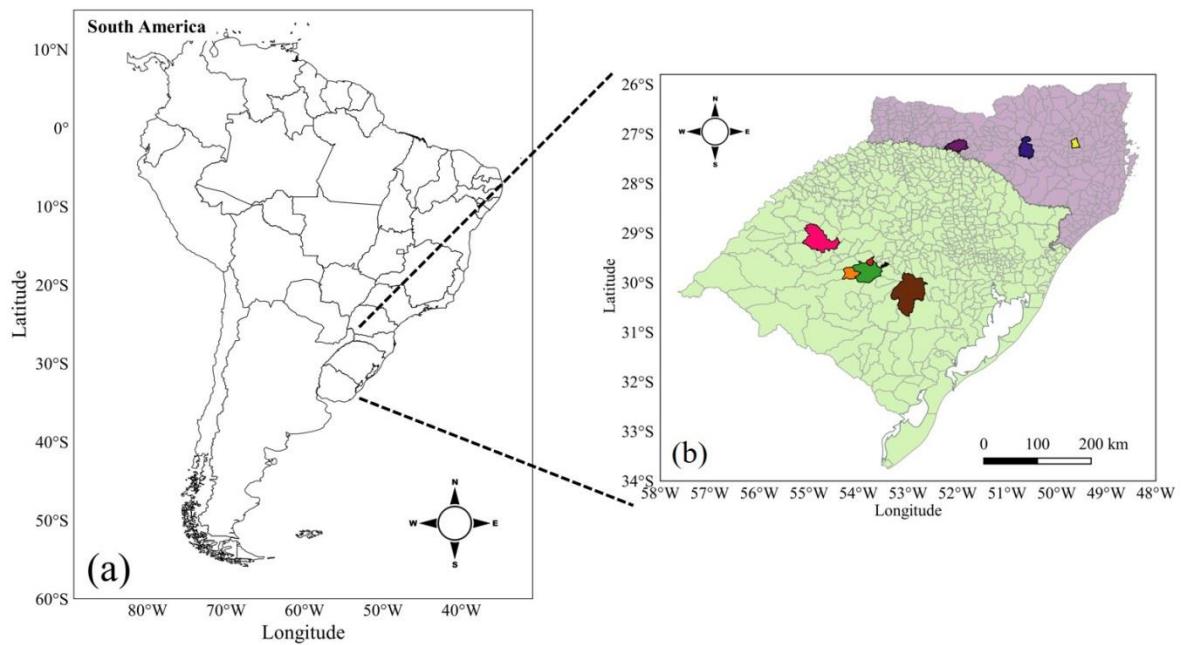


Fig. 1. Maps of South America and Brazil (a), and Rio Grande do Sul and Santa Catarina States (b) with the locations where the harvest forecast approach was applied: Santa Maria (green), Santiago (pink), Cachoeira do Sul (brown), Itaara (red), São João do Polêsine (black), Dilermando de Aguiar (orange), Cutitibanos (blue), Concórdia (purple) and Rio do Sul (yellow).

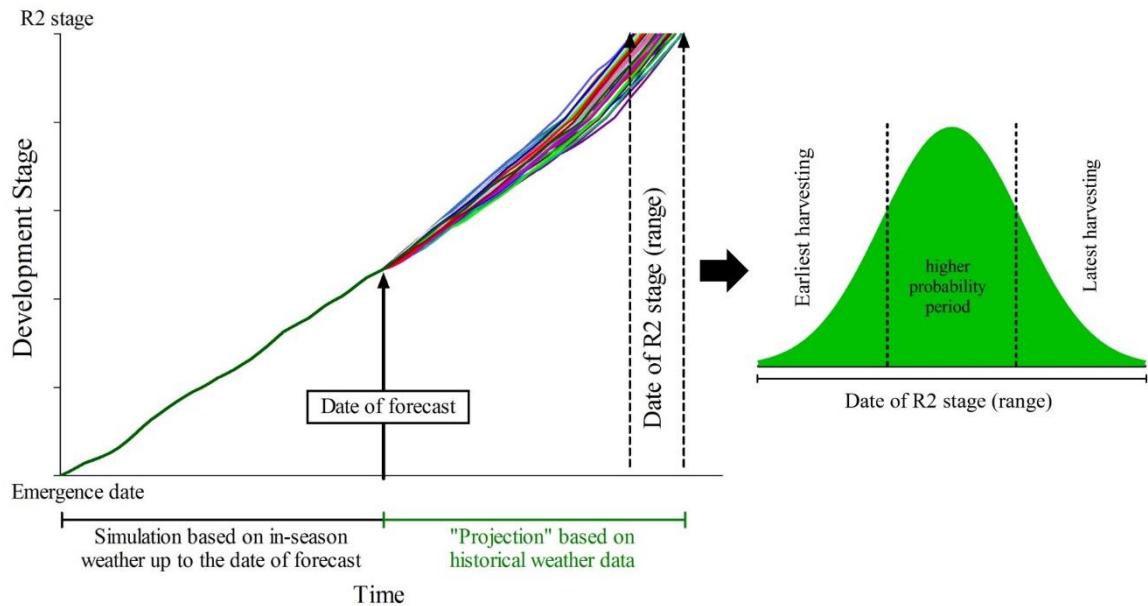


Fig. 2. Graphical demonstration showing how the harvest forecasts were performed with the PhenoGlad model (left) and, the distribution of possible end-of-season harvest point (R2 stage) (right) with the higher probability period represented by the central dates that have 50% of the probability.

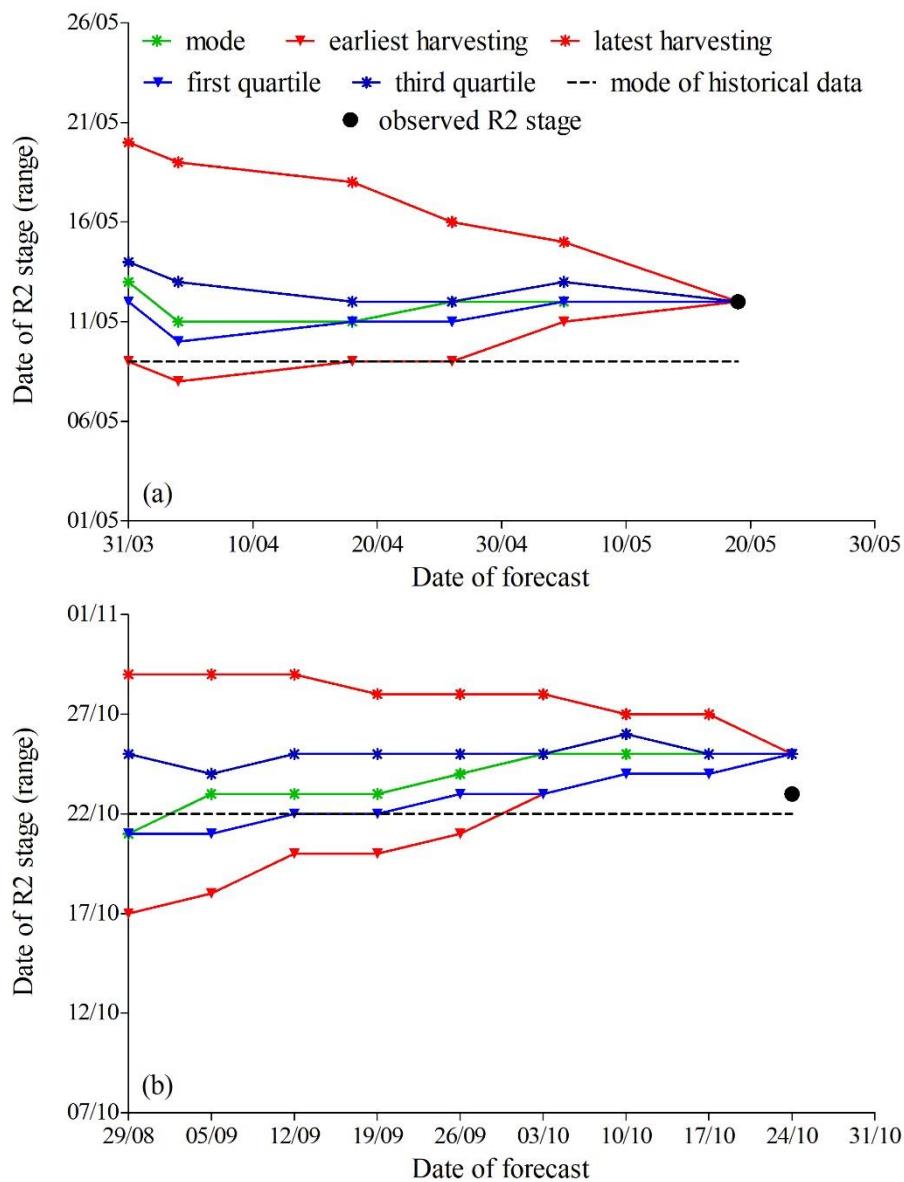


Fig. 3. Evolution of the harvest forecast for gladiola in two distinct growing seasons in Rio Grande do Sul State: for Mother's Day 2017 (a; Jester cultivar) and for All Souls' Day 2016 (b; cultivar White Goddess).

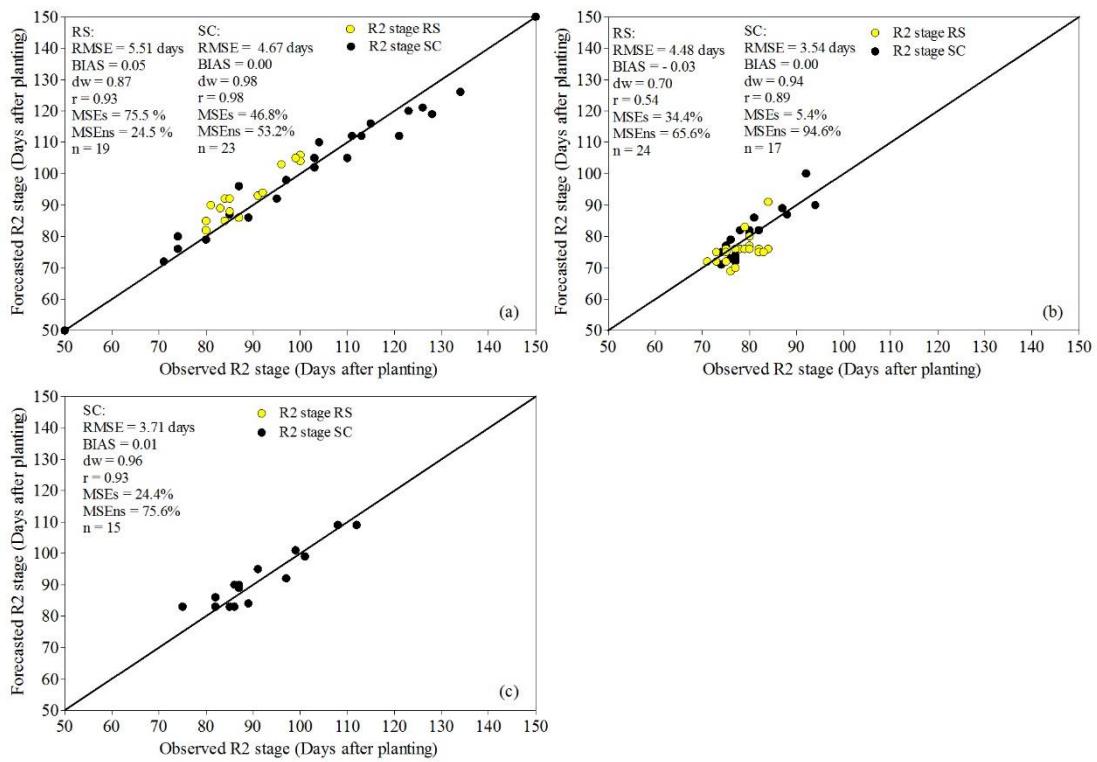


Fig. 4. The forecasted versus observed harvest date (R2 stage) for gladiola on All Souls' Day (a), on Mother's Day (b) and on Valentine's Day (c) in six locations in Rio Grande do Sul State and three locations in Santa Catarina State. Data of all planting dates and cultivars are pooled. The solid line is the 1:1 line. RMSE = root mean square error, BIAS = BIAS index, dw = index of agreement, r = correlation coefficient, MSEs = percentage of systematic means square error, MSEns = percentage of unsystematic mean square error, n = number of observations.

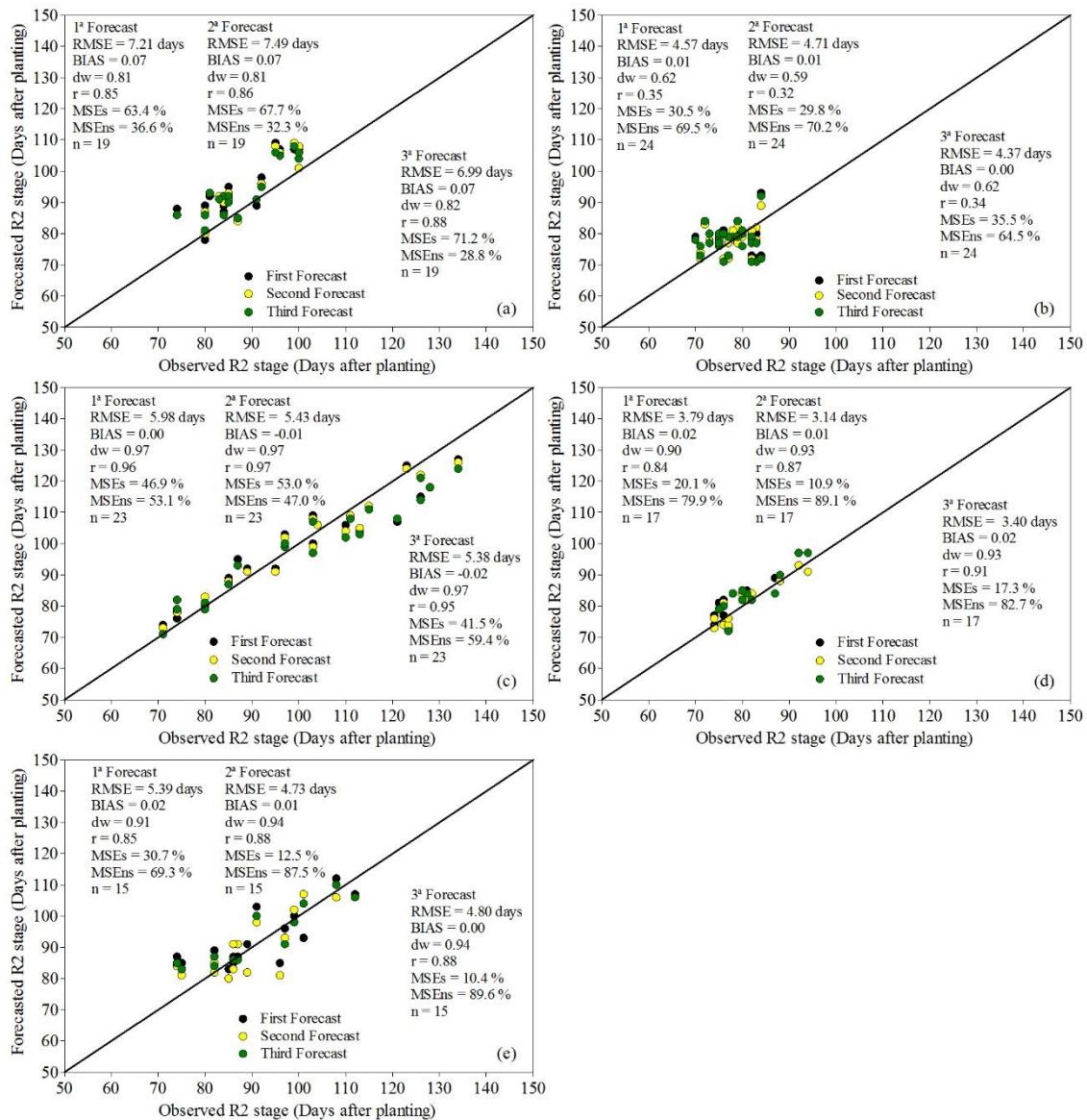


Fig. 5. The forecasted versus observed harvest date (R2 stage) in the first three forecasts of the growing season for gladiola on All Souls' Day (a) and on Mother's Day (b) in Rio Grande do Sul State and, on All Souls' Day (c), on Mother's Day (d) and on Valentine's Day (e) in Santa Catarina State. Data of all planting dates and cultivars are pooled. The solid line is the 1:1 line. RMSE = root mean square error, BIAS = BIAS index, dw = index of agreement, r = correlation coefficient, MSEs = percentage of systematic means square error, MSEns = percentage of unsystematic mean square error, n = number of observations.

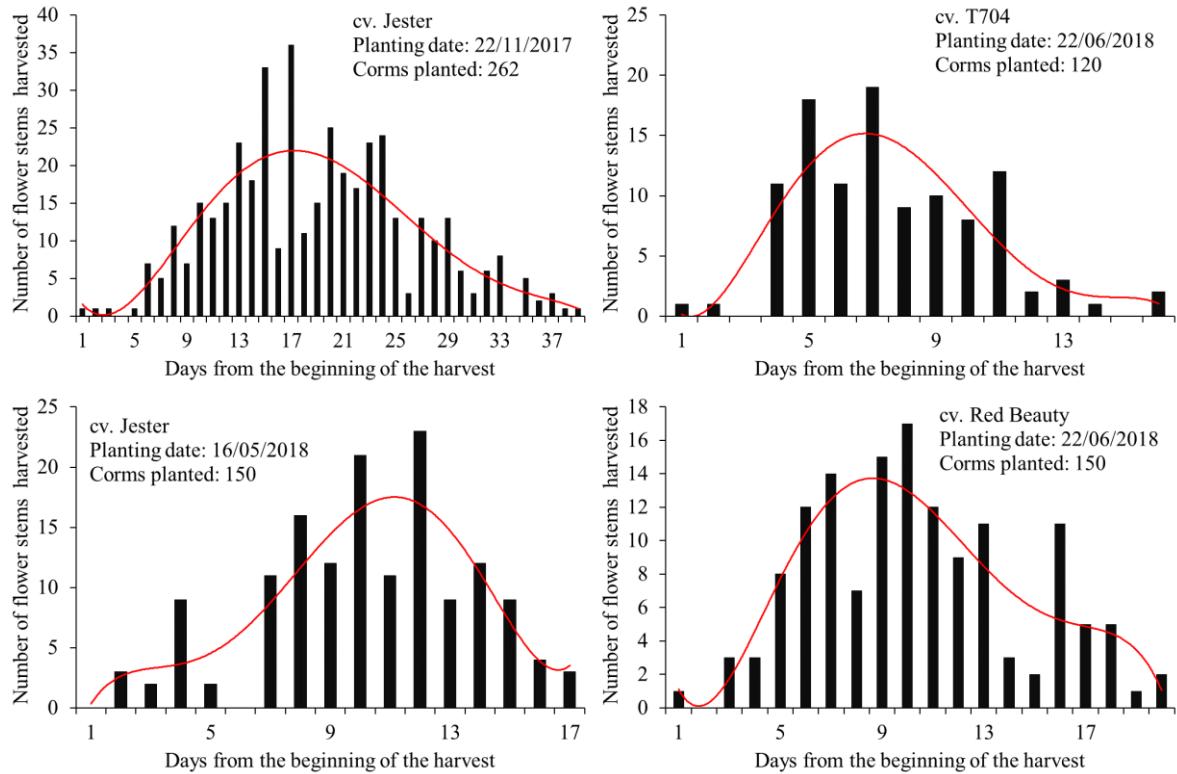


Fig. 6. Distribution of flowering in gladiola (R2 stage) for cultivars Jester (planting dates: 22/11/2017 and 16/05/2018 – dd/mm/yyyy), T704 (planting date: 22/06/2018) and Red Beauty (planting date: 06/22/2018) in Rio Grande do Sul State. The flower stems that were in the R2 stage were harvested and counted daily. The cultivar Jester planted on 22/11/2017 was conducted with two plants per planted corm. In the other cultivars, the sprouts were cut, keeping only one plant per planted corm.

5. ARTIGO 3

How does water deficit affect gladiolus growth and development?⁽³⁾

Abstract – The growing demand for gladiolus, especially in peaks of consumption, requires efficient schedule production and good quality of the marketed product. The objective of this study was understand how water deficit affects the growth and development of gladiolus and, consequently, the quality of the floral stems produced. Two field experiments were conducted with four gladiolus cultivars submitted to two irrigation treatments: irrigated and not-irrigated. The phenological development was observed daily in 20 marked plants. At harvest point, the quantitative parameters of the floral stem were also measured and ten plants were collected to determine the dry mass of the compartments. The duration of the gladiolus development cycle was longer in the not-irrigated treatment, resulting in greater error when compared to the Phenoglad model. Water deficit also affects the quality of the flower produced, due to reduced plant growth, however, does not affect dry mass partition. Therefore, the supplementary irrigation on gladiolus is essential for producing quality floral stems and easily scheduled for peak consumption.

Key words: irrigation; schedule production; floral stem quality; *Gladiolus x grandiflorus* Hort.

(3) Artigo científico formatado nas normas da Revista Engenharia Agrícola.

Como o déficit hídrico afeta o crescimento e desenvolvimento gladiólo?

Resumo – A crescente demanda por gladiólos, especialmente em picos de consumo, requer um agendamento eficiente da produção e a qualidade do produto comercializado. O objetivo deste estudo foi compreender como o déficit hídrico afeta o crescimento e o desenvolvimento de gladiólo e, consequentemente, a qualidade das hastes florais produzidas. Foram realizados dois experimentos de campo com quatro cultivares de gladiólo submetidas a dois tratamentos de irrigação: irrigado e não irrigado. A fenologia foi observada diariamente em 20 plantas marcadas. No ponto de colheita, os parâmetros quantitativos de qualidade das hastes florais também foram medidos e dez plantas foram coletadas para determinar a massa seca dos compartimentos. A duração do ciclo de desenvolvimento do gladiólo foi maior no tratamento não irrigado, resultando em maior erro quando comparado ao modelo Phenoglad. O déficit hídrico também afeta a qualidade da flor produzida devido ao menor crescimento das plantas, no entanto, não afeta a partição da massa seca. Portanto, a irrigação suplementar no gladiólo é essencial para a produção de hastes florais de qualidade e para facilitar o agendamento para os picos de consumo.

Palavras-chave: irrigação; agendamento da produção; qualidade das hastes florais; *Gladiolus x grandiflorus* Hort.

INTRODUCTION

Water deficit is a limiting factor for the growth and development of agricultural crops (Teixeira et al., 2019). Under conditions of reduced soil water availability, plants close the stomata, reducing carbon dioxide input and reducing the photosynthetic process (Pinheiro et al., 2014; Souza et al., 2014). As a result, crop yield is reduced and, in the case of ornamental crops, there is a reduction in the quality of the floral stems, which are the final crop product (Porto et al., 2014; Pereira et al., 2016b).

The gladiolus (*Gladiolus x grandiflorus* Hort.) is one of the ornamental crops most important worldwide, mainly as a cut flower (Thakur et al., 2015). Because it is an easy to produce crop that requires low initial cost and is cultivated in the field, gladiola has become an important cut flower for small farmers in Brazil (Uhlmann et al., 2019). Due to the ease of cultivation and the rusticity of the gladiolus plant, farmers do not pay due attention to the water needs of the crop. However, the growing demand for this flower, especially in peak consumption, requires efficient production planning and good quality of the marketed product. (Schwab et al., 2015b; Becker et al., 2019a; Becker et al., 2019b).

Scheduling of gladiolus production can be accomplished using historical data and crop development models to simulate the best planting date of corms (Becker et al., 2019a). But in water deficit condition is the developmental cycle of gladiolus unchanged? With the lower water content available in the soil, plant growth can also be altered (Kelling et al., 2015; Lago et al., 2012; Pinheiro et al., 2014), however studies already carried out are intended for field crops indicating reduced yields (Alberto et al., 2006; Teixeira et al., 2019). Unlike field crops, ornamental plants have two crucial aspects that determine farmer success: efficiency in scheduling production and maintaining the quality of floral stems. Therefore, the objective of this study was understanding how water deficit affects the growth and development of gladiolus and, consequently, the quality of the floral stems produced.

MATERIAL AND METHODS

Two field experiments were conducted with four gladiolus cultivars: Rose Friendship (Early development cycle), Rose Supreme (Intermediate II development cycle), Peter Pears (Intermediate I development cycle) and Jester (Intermediate II cycle development), in Santa Maria/RS. The planting of the corms was carried out on 22/11/2017 and on 01/12/2018. Planting at this time was intended to expose the plants to the condition of high evaporative demand from the atmosphere.

The experiments were conducted in beds 22 m long and 1 m wide. The gladiolus corms were planted in two paired rows in the longitudinal direction of the flowerbed, 0.4 m apart. The corms were spaced by 0.2 m in the row, totaling 220 plants per flowerbed. Each flowerbed contained one cultivar and, half of the flowerbed was irrigated and the other half not irrigated. The plants were kept irrigated until the emergence was completed (04/12/2017 and 12/12/2018) and from then on only the irrigated treatment plants received drip irrigation.

For irrigation management, a daily water balance was calculated. Readily available water in the soil (RAW) was considered to be 80% of the total available water (TAW) for the root depth of 25 cm, and was allowed to be consumed 20% of the RAW (10 mm) for irrigation. The maximum crop evapotranspiration (ETc), was calculated as: $ET_c = ET_{ref} \times K_c$, where ET_{ref} is the reference evapotranspiration by the Penman-Monteith method and K_c is the crop coefficient. The K_c was 0.7 for sprouting phase and 1.0 for reproductive phase (Allen et al., 1998). Throughout the gladiola vegetative phase, K_c values were calculated by linear interpolation. When the accumulated ET_c reached the value of 10 mm, irrigation was performed. Supplemental irrigation was performed by dripping through drip hoses placed on the plant line.

During the conduction of the experiments, the emergence of the plants was monitored and evaluations of the phenological development were performed daily in 20 marked plants,

according to the scale of Schwab et al. (2015a). When the plants reached the harvest point (stage R2), the quantitative parameters of the floral stem (Schwab et al., 2015b) were also measured: total plant length, floral stem length and diameter of the floral stem just below the first floret of the spike. Ten plants were collected to determine the dry mass of the plant compartments. The collected material was separated and placed in a chamber at 60°C until reaching a constant mass. The three main organs of the gladiolus plant (leaves, new-corm and floral stem) were considered to determine the percentage of dry mass for this organ. Statistical analysis was performed considering each experiment separately. The average of total dry mass, floral stem dry mass, floral stem lenght, spike lenght, floral stem diameter, number of florets and dry mass in percentage were submitted to two - way ANOVA analysis to evaluate the effect of the sources of variation (cultivars and water regime). In cases where the cultivars x water regime interaction was significant, the analysis was unfolded within each factor. When the cultivars x water regime was not significant, the average was compared. Tukey test was performed at 5% probability for comparison of means.

RESULTS AND DISCUSSION

Figure 1A shows the weather conditions during crop development in experiment 1. The maximum air temperature ranged from 18.2°C to 38.6°C, the minimum temperature ranged from 9.2°C to 22.8°C. Precipitation was characterized by an average of 20 mm of rain showers, interspersed with periods of 10 days without precipitation, which allowed a water deficiency condition for plants that were not irrigated. From 52 to 66 days after planting there was an accumulated precipitation of 123.2 mm, but at that time the plants were already at the end of the cycle (very close to the harvest point). In experiment 2 (Figure 1B), the maximum air temperature ranged from 22.0°C to 38.6°C and the minimum temperature ranged from 10.0°C to 24.8°C. Right after emergence of the crop, good rainfall occurred, totaling 155 mm,

and after that there were dry periods interspersed with rainy periods. The irrigated and non-irrigated treatments in experiment 1 had differences in soil water content throughout the development cycle and, it was only at the end of the crop development that the soil moisture became similar between the water regimes (Figure 1C). In experiment 2 the differences in water content occurred only from 22 to 32 DAP and from 58 to 72 DAP (Figure 1D). Throughout the experiments, the soil water content ranged from $0.304 \text{ cm}^3/\text{cm}^3$ to $0.135 \text{ cm}^3/\text{cm}^3$ in experiment 1, and from $0.351 \text{ cm}^3/\text{cm}^3$ to $0.100 \text{ cm}^3/\text{cm}^3$ in experiment 2.

Water deficit affected the development cycle length of all cultivars that were not irrigated (Figure 2). The duration of the vegetative phase was 45, 56 and 57 days for the irrigated treatment and 52, 60 and 64 days for the non-irrigated treatment for Rose Friendship, Peter Pears and Jester, respectively, grown in Experiment 1. Consequently, the cycle length from planting to harvest point (R2) was 62, 72 and 73 days for irrigated treatment and 68, 77 and 83 days for non-irrigated treatment. In experiment 2, the vegetative phase was 59 and 61 days for irrigated treatment and 63 and 66 days for non-irrigated treatment for Rose Supreme and Jester, respectively. The cycle duration up to stage R2 was 77 and 80 days in the irrigated and 83 and 87 days in the non-irrigated.

This prolongation of the crop development cycle occurs mainly due to the longer duration of the vegetative phase, which is what drives the total cycle length (Streck et al., 2012). Similar result occurred when plants in V2-V3 stage were subjected, for 15 days, to three temperature and humidity conditions. Plants that grew in hot and dry air had between 3 and 4 leaves, while those that grew in hot and humid air had 4 to 5 leaves at the end of the period (Shillo & Halevy, 1976). With the reduction of water content in the plant, there is stomata closure, reduced perspiration and increased temperature in cells, slowing down development, whose response occurs as a function of air temperature levels (Uhlmann et al., 2017). Study by Pereira et al. (2016a) testing different water contents in gladiolus production

also found that lower water content delays flowering of flower stems because leaf emission is slower.

Information such as this is important to assist the farmer in production planning. The PhenoGlad model (Uhlmann et al., 2017) was used to simulate the date of harvest of the floral stems of each cultivar in the potential condition (without water limitation) from the planting date (Figure 2). For cultivar Jester, in experiment 1, the farmer would expect to harvest the flower stems on 03/02/2018, based on the PhenoGlad model. If he used irrigation he would actually harvest on 03/02/2018 but if he did not use irrigation he would harvest only on 13/02/2018. A 10-day delay in harvesting the flower stems, making it impossible for this farmer to guarantee the highest prices when selling the product on the date of highest market demand (Becker et al., 2019a; Uhlmann et al., 2019). It is visible the practical impact that not using irrigation has on the planning of the production of floral stems or, the impact that not accounting for water deficit factor in the models, has simulated the development of the crop. Knowing the effect of water deficit on crop cycle duration is extremely important for improving agricultural models, which are increasingly being used to schedule production (Becker et al., 2019a; Becker et al., 2019b).

In addition to altering the development of gladiolus, water deficit also affects the quality of the flower produced, due to reduced plant growth. Because there was no interaction between cultivars and water regimes, Figure 3 shows the mean of total dry mass of the plant (without considering the old corm's mass), the dry mass of the floral stem, floral stem length, floral stem diameter, number of florets and spike lenght observed in experiment 1 and experiment 2 for irrigated and non irrigated treatments. In Figure 4, these variables were compared between cultivars. In experiment 1 (Figure 3A-3E), all variables analyzed showed a reduction in quality when they did not receive supplementary irrigation. In experiment 2 (Figure 3F-3J), only the variable floral stem length presented difference between irrigated and

non irrigated treatments. These results demonstrate that the water deficit in experiment 2 was less severe. For floral stem length (Figure 4C) and number of florets (Figure 4E) in experiment 1 there was no difference between cultivars. The Jester cultivar showed the best results for total dry mass (Figure 4A) and floral stem dry mass (Figure 4B). In experiment 2 (Figure 4F-4J) the Rose Supreme cultivar presented the best results for total dry mass (Figure 4F), floral stem diameter (Figure 4I) and spike length (Figure 4J). These results indicate that cultivars Jester and Rose Supreme present the best quality of the floral stems.

Figure 5 shows the spike length observed in experiment 1 and the number of florets observed in experiment 2. Because the cultivar x water regime interaction was significant for these variables the analysis was unfolded within each factor. In experiment 1, both cultivars presented bigger stem length in irrigated treatment (Figure 5A). The cultivar Rose Friendship presented the bigger stem length in irrigated treatment and, Jester and Rose Friendship presented the best results on non irrigated treatment. The number of florets is the variable least affected by water deficit and cultivar. There was no difference between water regime or between cultivars for the same irrigation treatment.

These results demonstrate the importance of irrigation in gladiolus plants to obtain quality floral stems: larger in full size and spike and, with a greater number of florets, which will guarantee the longest vase life of the floral stem (Schwab et al., 2014; Uhlmann et al., 2019). Several studies have evaluated the effect of irrigation management on gladiolus crop growth and report similar results. There is a reduction in the dry mass of the floral stem when produced with less soil water replacement (Porto et al., 2014; Mazzini-Guedes et al., 2017), and lower levels of irrigation result in reduced floral stems with fewer florets and smaller flower diameter (Bastug et al., 2006; Porto et al., 2014).

For chrysanthemum, irrigation management is also important for productivity and final product quality (Farias et al., 2012; Kelling et al., 2015). This is because under

conditions of reduced soil water availability, plants close the stomata, decreasing carbon dioxide input and reducing the photosynthetic process (Pinheiro et al., 2014; Souza et al., 2014). In addition, leaf expansion is reduced and as a result, crop yields decrease (Alberto et al., 2006) or in the case of ornamental plants, there is a reduction in flower quality (Bastug et al., 2016; Porto et al., 2014).

Understanding the dynamics of dry mass partitioning between plant organs is also important, as crop models that simulate mass production in the crop consider partitioning at each stage of the plant to grow mass (Tironi et al., 2017). The three main organs of the gladiolus plant (leaves, new-corm and floral stem) were considered to determine the percentage of dry mass for this organ at stage R2 (Table 1). Note that the difference exists only when comparing the cultivars. However, when taking into account irrigated and non-irrigated treatments, there is no favored organ during partitioning. According to this information, we can state that water deficiency reduces the absolute dry mass of plants, but does not affect dry mass partition, indicating that the plant reduces its total size but no organ is favored if water deficiency occurs.

CONCLUSIONS

Water deficit increases the duration of the vegetative phase of gladiolus and, consequently, the duration of the total cycle, making it difficult to schedule production. The total dry mass and floral stem dry mass is reduced under water deficit, however the dry mass partition between the plant organs is not altered. The quality of the floral stems produced is reduced under water deficit conditions, being essential the supplementary irrigation to guarantee a high value of the marketed product.

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Table 1. Dry mass of leaves, dry mass of new-corm and dry mass of floral stem for Rose Friendship, Peter Pears and Jester cultivars during experiment 1 (PL=22/11/2017) and Rose Supreme and Jester cultivars during experiment 2 (PL = 01/12/2018), in the irrigated and not irrigated water regimes.

Cultivar	Water regime		Mean	Cultivar	Water regime		Mean		
	Irrigated	Not Irrigated			Irrigated	Not Irrigated			
Experiment 1				Experiment 2					
Dry mass of leaves (%)									
Rose F.	47.1	46.8	46.9B	Rose S.	57.2	57.2	57.2A		
Peter P.	53.3	53.7	53.5A	Jester	52.5	49.5	52.0B		
Jester	52.8	53.9	53.2A	Mean	54.9a	55.8a			
Mean	51.3a	51.0a							
CV (%)			4.8	CV (%)			7.8		
Dry mass of new-corm (%)									
Rose F.	4.0	3.8	3.9C	Rose S.	16.2A	14.2A	15.3		
Peter P.	10.1	10.1	10.1A	Jester	8.6B	18.3A	10.2		
Jester	5.2	6.0	5.6B	Mean	12.6	14.9			
Mean	6.3a	6.4a							
CV (%)			23.0	CV (%)			31.0		
Dry mass of floral stem (%)									
Rose F.	47.6	47.9	47.8A	Rose S.	26.0	28.1	26.9B		
Peter P.	35.1	34.3	34.7C	Jester	37.8	31.2	36.7A		
Jester	40.6	39.0	40.0B	Mean	31.6a	28.7a			
Mean	41.0a	41.1a							
CV (%)			6.8	CV (%)			16.1		

* Capital letters compare the cultivars within the treatment and lowercase letters compare the effect of the treatment on the same cultivar. Bars not followed by the same letter differ by Tukey's test at 5% significance level.

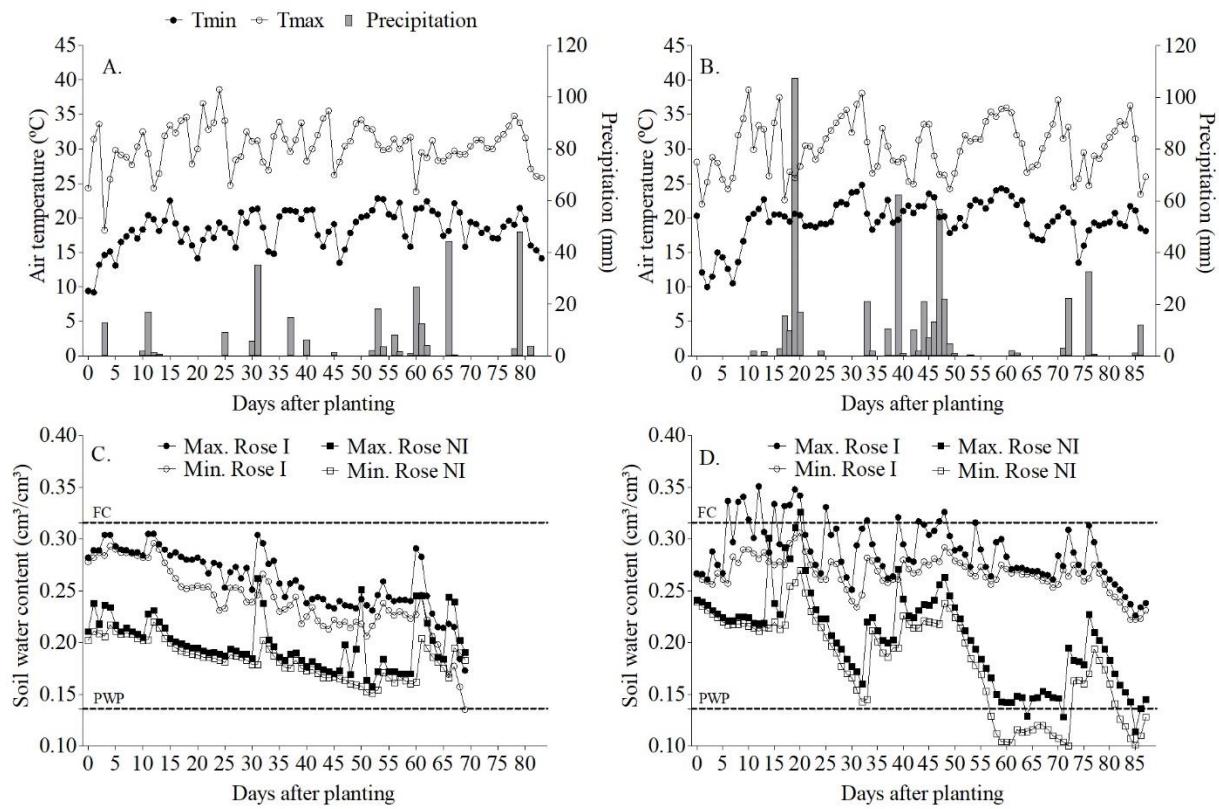


Figure 1. Minimum (Tmin) and maximum air temperature (Tmax), precipitation (mm) and soil water content during experiment 1 (PL = 22/11/2017) (A, C) and experiment 2 (PL = 01/12/2018) (B, D).

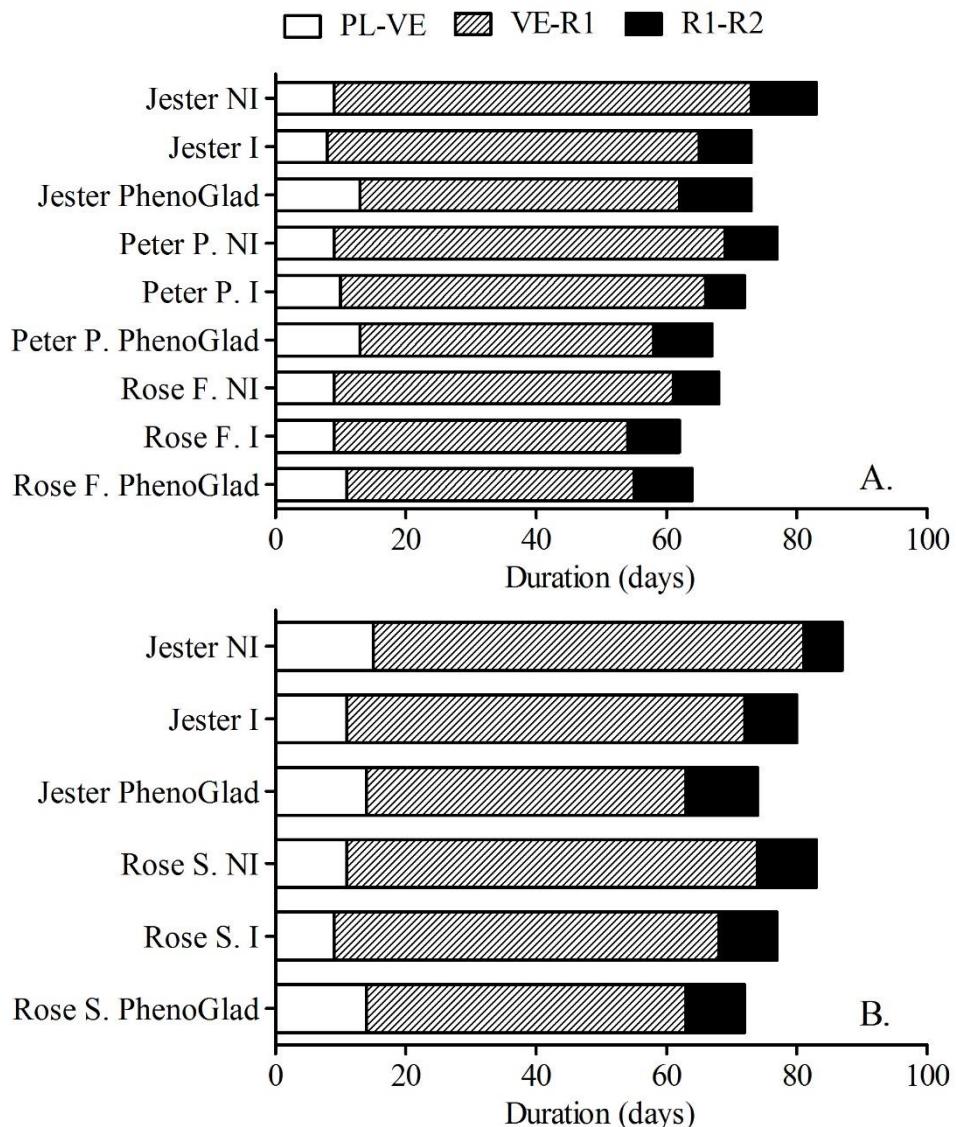


Figure 2. Duration (days) of sprouting (PL-VE), vegetative (VE-R1) and reproductive (R1-R2) phases of the cultivars Jester, Peter Pears and Rose Friendship in experiment 1 (PL = 22/11/2017) and, of the cultivars Jester and Rose Supreme in experiment 2 (PL = 01/12/2018) for the irrigated (I) and non-irrigated (NI) treatments and, simulated by the PhenoGlad model.

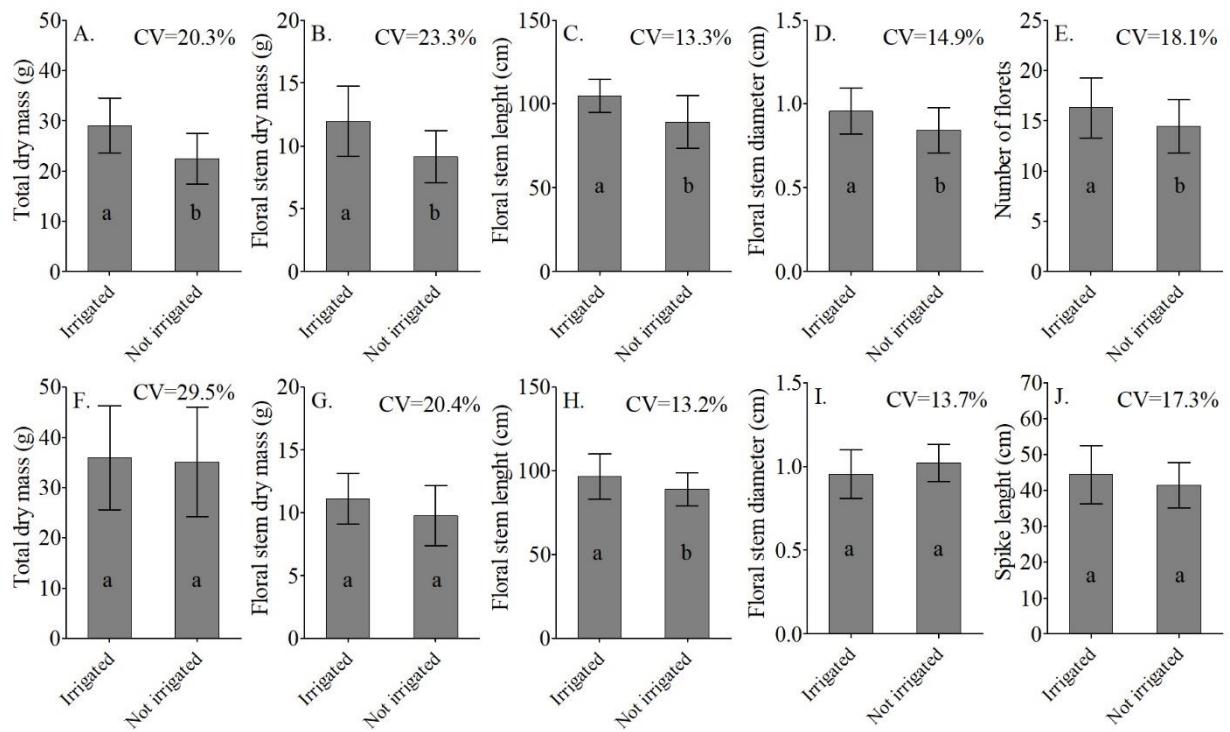


Figure 3. Total dry mass (A, F), floral stem dry mass (B,G), floral stem length (cm) (C, H), floral stem diameter (D, I), number of florets (E) and floral stem dry mass (J) for irrigated and not irrigated treatments during experiment 1 (PL = 22/11/2017) (panels from A to E) and experiment 2 (PL = 01/12/2018) (panels from F to J). *Bars not followed by the same letter differ by Tukey's test at 5% significance level.

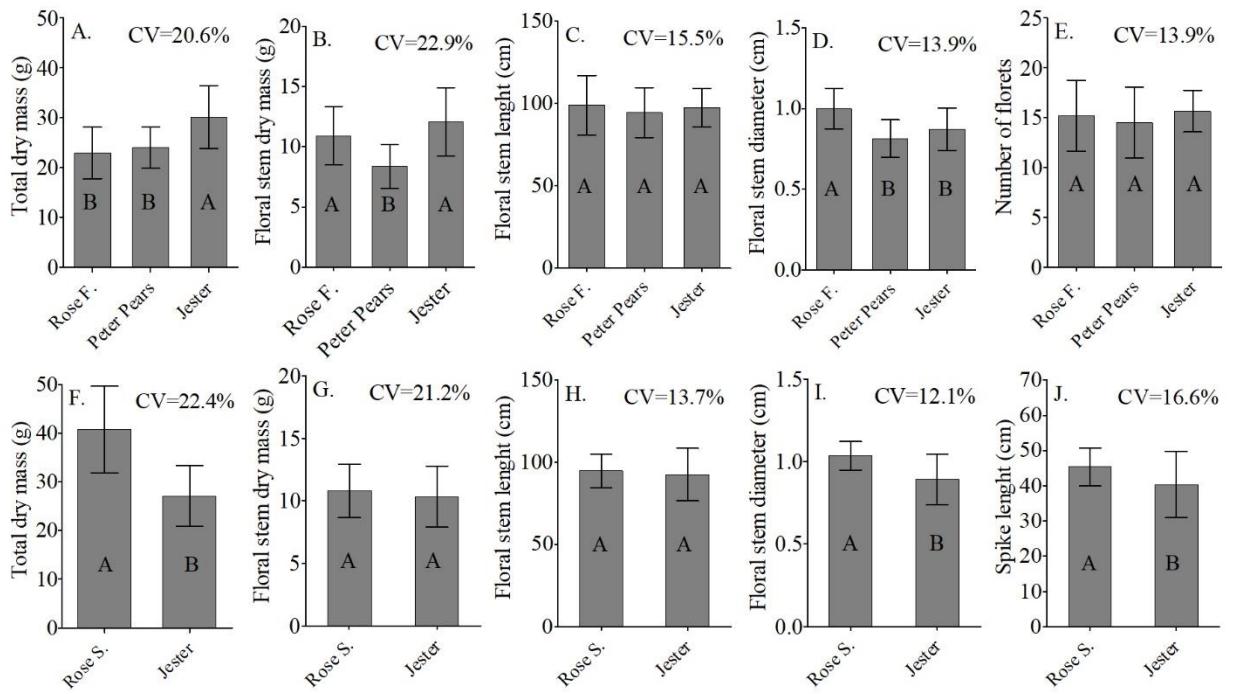


Figure 4. Total dry mass (A, F), floral stem dry mass (B,G), floral stem length (cm) (C, H), floral stem diameter (D, L), number of florets (E) and floral stem dry mass (J) for Rose Friendship, Peter Pears and Jester during experiment 1 (PL = 22/11/2017) (panels from A to E) and for Rose Supreme and Jester during experiment 2 (PL = 01/12/2018) (panels from F to J). *Bars not followed by the same letter differ by Tukey's test at 5% significance level.

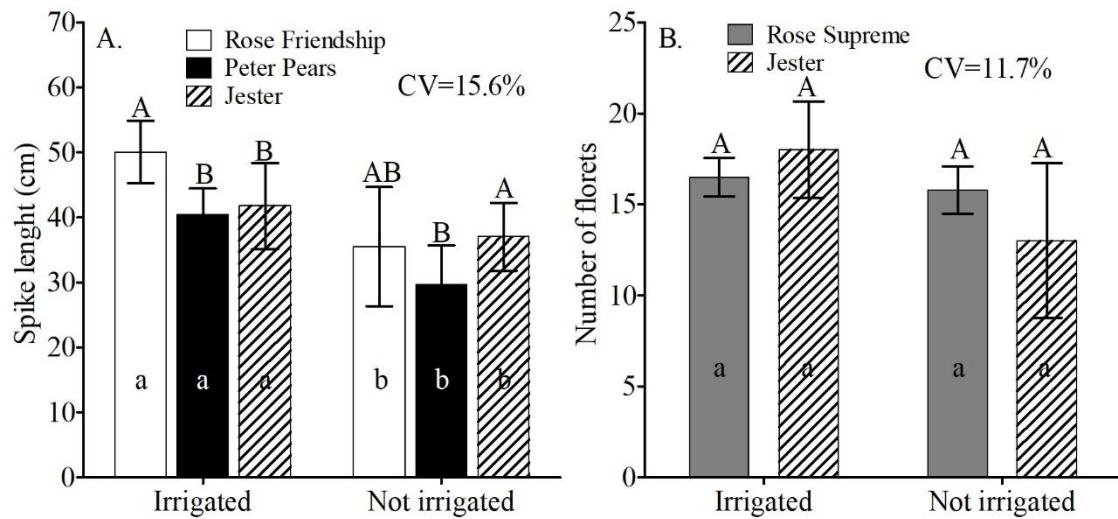


Figure 5. Spike lenght (A) for Rose Friendship, Peter Pears and Jester during experiment 1 (PL = 22/11/2017) and number of florets for Rose Supreme and Jester during experiment 2 (PL = 01/12/2018) in the irrigated and not irrigated treatments. * Capital letters compare the cultivars within the treatment and lowercase letters compare the effect of the treatment on the same cultivar. Bars not followed by the same letter differ by Tukey's test at 5% significance level.

6. ARTIGO 4

Transpiration and leaf growth of gladiolus in response to soil water deficit

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Abstract

Aims The objective of this study was to evaluate the response of transpiration and leaf growth in a drying soil represented by the fraction of transpirable soil water (FTSW) for cultivars of gladiolus in different developmental stages.

Methods Three experiments were carried out in pots, with four gladiolus cultivars in different developmental stages and two water regimes: without water deficit and with water deficit. The FTSW, transpiration and leaf growth were measured on a daily basis, during the period of soil drying. Evaluation of plant development (phenology) were performed daily and, at harvest point, the quantitative parameters of the floral stems were measured.

Results FTSW was an efficient method to evaluate gladiolus response to water deficit. The threshold FTSW for transpiration is higher when water deficit in the soil occurred during the reproductive phase. When water deficit occurred during the vegetative phase, flower stem quality recovered after rehydration while when water deficit occurred during the reproductive phase flower stem quality was reduced even after rehydration

Conclusion The cultivars cultivars Rose Friendship and Amsterdam are more tolerant to water deficit by maintaining leaf emission, leaf growth and quality of flower stems even under water deficit.

Keywords *Gladiolus x grandiflorus* Hort.; FTSW; flower quality; irrigation; scheduling flowering.

Introduction

Water deficit is a limiting factor for the growth and development of agricultural crops (Teixeira et al. 2019). The fraction of transpirable soil water (FTSW) approach has been widely used for the evaluation of plant response to water deficit (Lago et al. 2012; Souza et al. 2014; Pinheiro et al. 2014; Kelling et al. 2015) and to penalize crop growth and development due to water deficit in crop models (Amir and Sinclair, 1991; Muchow; Sinclair, 1991; Alberto et al. 2006; Tironi et al. 2017). The threshold FTSW indicates the timing of stomatal closure in response to soil water deficit (Ray and Sinclair 1997; Sinclair and Ludlow 1986) and the degree of tolerance to water deficit. The FTSW threshold has been determined for many annual agricultural crops (Devi et al. 2009; Gholipoor et al. 2012; Sinclair and Ludlow 1986), for some forest crops such as *Eucalyptus grandis* and *Eucalyptus saligna* (Martins et al.

2008), and for some ornamental crops like chrysanthemum (*Dendranthema grandiflorum*) (Kelling et al. 2015) and campanula (*Campanula medium*) (Mao et al. 2014).

Ornamental crops have responses to water deficit that directly affect the quality of the final product (Porto et al. 2014; Pereira et al. 2016b) and the production scheduling that aims to meet specific market moments (Becker et al. 2020), especially when it comes to field-grown crops, such as gladiolus. Gladiolus is one of the most popular bulbous cut flowers worldwide (Thakur et al. 2015) and an important crop for small farmers in Brazil because it is easily grown in open field (Uhlmann et al. 2019). Gladiolus occurs naturally mainly in the Mediterranean and Southern Africa regions, where there are more than 100 wild species of Gladiolus (Tombolato et al. 2005; Riaz et al. 2010), and are grown in many tropical, subtropical and temperate regions worldwide (Ahmad et al. 2011). The marketable flower is a spike with large and beautiful florets with different colors, and the plant is propagated through corms and has thick leaves with waxy cuticle, characteristics that give it rusticity in the production environment because they reduce water loss through transpiration (Machado et al. 2015).

The response of gladiolus to water deficit using the FTSW approach is still unknown. Because of the growing demand for gladiolus flower stems and the increasing growth of gladiolus as an alternative source of income for farmers, an important step is to identify the most water-tolerant cultivars. Therefore, the objective of this study was to evaluate the response of transpiration and leaf growth in a drying soil represented by the FTSW for cultivars of gladiolus in different developmental stages.

Materials and methods

Three pot experiments (Experiment 1 – E1, Experiment 2 – E2 and Experiment 3 – E3) were conducted in Santa Maria, RS, Brazil ($29^{\circ}43' S$; $53^{\circ}43' W$; 95 m a.s.l.) during 2017, 2018 and 2019. The experiments were conducted in 8 L (24-cm diameter \times 23-cm tall) plastic pots, under a structure covered with 200 μm low density polyethylene to prevent precipitation on plants. Planting started on 13 July 2017 for Jester Gold cultivar and on 04 Aug 2017 for Amsterdam (E1), on 15 Dec 2017 for Rose Friendship and White Goddess (E2) and, on 29 Nov 2018 and 26 Dec 2018 for Amsterdam (E3). The cultivars used in this study are among the most produced by gladiolus farmers and differ in duration of developmental cycles, from early (Rose Friendship) to late (Jester Gold). Different planting dates were used in E1 in order to have plants of the different cultivars with the same number of leaves at the beginning

of the experiment and, in E3 to have plants of the Amsterdam cultivar in the vegetative phase (late planting), “named Amsterdam V” and in the reproductive phase (early planting), named “Amsterdam R”, at the onset of the water deficit.

The experimental design was a completely randomized, with two water regimes: without water deficit (T1) and with water deficit (T2), and ten replicates (one pot with one plant). The pots were painted white to reduce absorption of solar radiation by the outer walls, filled with A horizon soil samples of a Hapludalf soil, and placed on a 70 cm high bench. The correction of soil nutrients and acidity was made according to soil analysis and local recommendations for gladiolus. One corm was planted per pot and the first sprout that emerged on the soil surface was regarded as the main plant, while the other sprouts were eliminated as soon as they emerged to standardize one stem (plant) per pot. All pots were maintained in a well-watered condition until the start of the imposition of the water deficit (Sinclair and Ludlow 1986; Souza et al. 2014).

From a total of 40 pots planted with each cultivar, 20 pots per cultivar (to reduce plant variability) were selected for the experiment, ten of them were used as control (T1), in which there was no water deficit, and ten pots in which water deficit was applied (T2). The experiment followed the protocol originally described by Sinclair and Ludlow (1986) and that has been widely used in other studies (Devi et al. 2009; Gholipoor et al. 2012; Kelling et al. 2015). Prior to the application of water deficit, all pots were saturated with water (Sinclair and Ludlow 1986) and allowed to drain for 24 h (Lago et al. 2012), when soil was assumed to be at field capacity. On completing the 24 h after saturation, all pots were covered with a white opaque plastic film, and the initial weight of each pot was determined. This day was the onset of the imposition of the water deficit (02 Oct 2017 in E1, 11 Jan 2018 in E2 and 02 Feb 2019 in E3).

Thereafter, the water deficit was applied in the T2 pots, which were not irrigated until the ending of water deficit, when transpiration of the plants in T2 was 10 % or lower as compared with plants in T1 (Sinclair and Ludlow 1986; Muchow and Sinclair 1991). When the imposition of the water deficit ended before the plants reached the R2 stage, the plants were rehydrated until they reached the harvest point, in order to quantify the parameters of the floral stems. Water deficit was applied when plants had seven leaves in E1, four leaves in E2 and, four and ten leaves in E3. Every day, starting at 4 p.m., all pots were weighed on an electronic scale with a capacity of 50 kg and an accuracy of 5 g. After the weighing, each pot in T1 was irrigated with the amount of water that had been transpired by the plant since the

previous day, as determined by the difference between the weight of the pot on that specific day and the initial weight (Sinclair and Ludlow 1986; Muchow and Sinclair 1991).

Daily minimum and maximum air temperatures were measured during the three experiments inside a shelter located in the middle of the experiment. Incoming solar radiation under the structure during the three experiments was estimated from solar radiation measured at a weather station located approximately 300 m from the covered structure multiplied by a factor of 0.8. This factor was determined according to the measurements taken inside and outside the structure, using the LCi-SD Portable Photosynthesis System.

The relative transpiration (TR) was calculated by the equation (Sinclair and Ludlow 1986):

$$TR = \frac{MT2_j - MT2_{j-1}}{[\sum(MT1_j - MT1_{j-1})]/n} \quad \text{Eq. 1}$$

where MT2 is the mass of each pot in T2 (g per pot), MT1 the mass of each pot T1 (g per pot), 'j' refers to the day of measurement, and 'n' represents the number of replicates (plants) in T1. The experiments finished when all plants in T2 presented $TR \leq 0.1$ (10%), as recommended by the original protocol, assuming that below this rate of transpiration the stomata are closed and the water loss is only due to the epidermal conductance (Sinclair and Ludlow 1986; Muchow and Sinclair 1991). The final mass was the weight of the pot when $TR \leq 0.1$. After the end of each experiment, the FTSW for each T2 pot was calculated, each day, by the equation (Sinclair and Ludlow 1986):

$$FTSW = \frac{MT2_j - MT2_{end}}{MT2_{initial} - MT2_{end}} \quad \text{Eq. 2}$$

where MT2 is the mass of each pot in T2 (g per pot), 'j' refers to the day, 'initial' indicates MT2 on the starting day of the application of water deficit (beginning of the experiment) and 'end' indicates MT2 on the last day of the experiment.

Leaf area (LA) was determined daily throughout the experiment by measuring the longest length (L) and the largest width (W) of each leaf on the plant. The LA of each leaf was calculated multiplying the length and width by a shape factor: $LA = 0.664 * L * W$ (Schwab et al. 2014). The LA of all leaves was summed for each plant on each day and the daily relative leaf growth (LGR) for each gladiolus was calculated by:

$$LGR = \frac{LAT2_j - LAT2_{j-1}}{[\sum(LAT1_j - LAT1_{j-1})]/n} \quad \text{Eq. 3}$$

where LAT2 is the leaf area of all leaves measured on each plant in T2 (cm^2 per plant), LAT1 is the leaf area of all leaves measured on each plant in T1 (cm^2 per plant), 'j' refers to the day of measurement and 'n' represents the number of replications (plants) in T1.

The variables transpiration and leaf growth were subjected to two normalizations as recommended (Sinclair and Ludlow 1986; Ray and Sinclair 1997). The first normalization was the application of equations 1 and 3 to TR and LGR, respectively, so that TR and LGR varied from zero to one and enabled large daily environmental variations during the experimental periods to be minimized. The second normalization aimed to reduce variations between plants caused mainly by differences in plant size. For the second normalization, TR and LGR of individual plants were divided by the mean of TR and LGR before water stress developed in the soil for each plant, resulting in the NTR and NLGR variables.

The NTR and NLGR data (after the second normalization) were fitted to the logistic-type equation $Y = 1/\{1 + \exp[-a(X - b)]\}$ (Sinclair and Ludlow 1986; Ray and Sinclair 1997), where Y is the dependent variable (NTR and NLGR), X is FTSW and "a" and "b" are empirical coefficients estimated by nonlinear regression analysis. As an indicator of tolerance to soil water deficit, the value of the threshold FTSW for NTR and NLGR was estimated as the value of FTSW when the NTR or NLGR from the logistic equation equaled 0.95 (Lago et al. 2012), through the equation (Pinheiro et al. 2014):

$$FATSc = b - \ln(0,0526)/a \quad \text{Eq. 4}$$

Evaluations of the plant development (phenology) were performed daily, according to the scale of Schwab et al. (2015a). When the plants reached the harvest point (R2 stage), the following variables of the floral stems quality (Schwab et al. 2015b) were also measured: floral stem length, spike length, floral stem diameter, and number of florets per spike. The initial and final number of leaves and leaf area were counted. These variables and FTSW threshold for NTR and NLGR were analyzed according to a 2×2 factorial scheme with each plant being a replicate, A factors were the cultivars (2 levels) and B factors were the soil water regimes (two levels = without deficit and with deficit). These data were subjected to

analysis of variance (ANOVA) and means were compared by the Tukey test at 5 % probability of type I error.

Results

The minimum air temperature ranged from 7.4°C to 20.2°C during E1, from 15.2°C to 23.0°C during E2, and from 13.6°C to 22.0°C during E3 (Figure 1a) while maximum air temperature ranged from 19.5°C to 34.6°C during E1, from 24.5°C to 34.2°C during E2, and from 22.5°C to 40.0°C during E3. The minimum daily solar radiation inside the structure during experiments E1, E2 and E3 was 1.8, 2.8 and 3.2 MJ/m²/day, and the maximum was 24.6, 24.7 and 28.4 MJ/m²/day, respectively (Figure 1b). The vapor pressure deficit (VPD) ranged from 0.37 to 33 hPa in E1, from 2.6 to 22 hPa during E2, and from 1.9 to 36.3 hPa during E3 (Figure 1c).

Statistical analysis indicated no significant effect of cultivar x water regime interaction for the variables initial and final leaf number and, initial and final leaf area for experiments E1 and E3 (Table 1). Only the final leaf area in E2 showed significant interaction, so the analysis was split into the factors. The initial number of leaves in E1 was about seven leaves and there was no statistical difference between cultivars and between water regimes (Table 1). However, due to its larger leaves, characteristic of the cultivar Amsterdam, its initial leaf area was larger than leaf area of the cultivar Jester Gold. In E1, final number of leaves, determined at the end of the imposition of the water deficit, showed no difference between water regimes, only between cultivars. Final leaf area was larger for the cultivar Amsterdam. Final leaf area in T1 did not differ from T2.

The E2 began when plants had about four leaves (Table 1). The initial leaf area showed no statistical difference between water regimes in E2, only between cultivars. At the end of the imposition of the water deficit, T1 plants had about 8 leaves while T2 plants had about 6.5 leaves. The E3 was conducted with the cultivar Amsterdam at different times: the gladiolus plants were submitted to water deficit at V4 stage (four leaves - Amsterdam V) and V10 stage (ten leaves - Amsterdam R). There was no statistical difference between water regimes for initial leaf area. As observed in E2, T1 plants had about 8 leaves at the end of the imposition of the water deficit, while T2 plants had only 6 leaves. The final leaf area also presented statistical difference, being smaller in T2 (with water deficit).

The response of NTR to FTSW for the gladiolus cultivars in the three experiments is shown in Figure 2. The threshold FTSW for NTR varied from 0.355 in Amsterdam V (Figure

2e) to 0.732 in Jester Gold (Figure 2a). The threshold FTSW for NTR was high in the E1 for cultivar Jester Gold (Figure 2a) when atmospheric demand (VPD) was lower and the cultivar was in the reproductive phase. The threshold FTSW for NTR was low in the E3 for “Amsterdam V” (Figure 2e) when the atmospheric demand (VPD) was higher and the cultivar was in the vegetative phase.

The response of NLGR to FTSW for the three gladiolus cultivars in experiments E2 and E3 is shown in Figure 3. For cultivars whose imposition of water deficit occurred near the reproductive phase, it was not possible to calculate the LGR because plants already had defined final leaf number and maximum plant leaf area. The threshold FTSW ranged from 0.464 (Figure 3a) to 0.587 (Figure 3b) and was higher for White Goddess than for Rose Friendship in E2. The threshold FTSW for Amsterdam in E3 was 0.583 (Figure 3c), similar to threshold FTSW for White Goddess in E2.

The variables of floral stems quality for the three experiments are shown in Figure 4. In E1, the floral stem length was high in Amsterdam than Jester Gold (Figure 3a) and both cultivars had high floral stem length in T1 (without water deficit) than T2 (with water deficit). The spike length showed statistical difference between the water regimes for both cultivars (Figure 3d), but there was no difference among cultivars within the same water regime. The floral stem diameter was larger for Amsterdam in both water regimes, but only showed differences between water regimes for Amsterdam (Figure 3g). The number of florets per spike was higher at T1 than T2 (Figure 3j). In T1, the cultivar Amsterdam presented higher number of florets than Jester Gold and in T2 there was no difference among cultivars.

The floral stem length, in E2, was similar in Rose Friendship and White Goddess (Figure 3b) and only cultivar White Goddess showed differences between water regimes, with T2 resulting in shorter floral stem length. The spike length was similar to Rose Friendship and White Goddess (Figure 3b) and only White Goddess cultivar showed differences between water regimes. The spike length (Figure 3e) and floral stem diameter (Figure 3f) had similar results and, presented similar values to Rose Friendship and White Goddess and, only cultivar White Goddess presented difference between the water regimes. The number of florets (Figure 3k) was not quantified for Rose Friendship and was lower for T2 in White Goddess cultivar.

In E3, there was no statistical difference between the water regimes for both cultivars in floral stem length, spike length, floral stem diameter and number of florets per spike (Figure 3c, 3f, 3i, 3l). There was no statistical difference between cultivars in T1 for both variables

(Figure 3c, 3f, 3i, 3l). In T2 there was statistical difference among cultivars only for floral stem diameter (Figure 3i).

Discussion

The experiments carried out at different planting dates allowed the gladiolus plants to be exposed to different weather conditions (Figure 1). In E1, the temperature was milder and, the solar radiation and VPD levels were lower. At E3, the temperatures were higher and the atmospheric water demand was also higher (high radiation and VPD). The number of days when the evaporative demand of the atmosphere was high (VPD at 15 h greater than 15 hPa) was higher in E3 ($15/24 = 62.5\%$), followed by E2 ($12/24 = 50\%$) and last on E1 ($15/42 = 35.7\%$).

Statistical analysis indicated no significant effect of cultivar x water regime interaction for the initial and final leaf number and initial and final leaf area for experiments E1 and E3 (Table 1), indicating that the response of the cultivars was the same in two water regimes in each experiment. The no difference in initial leaf number and leaf area between the water regimes for the three experiments indicates that the plants selected for the experiment presented uniformity of development stage and leaf area.

Water deficit has been a major factor causing yield losses in agricultural crops worldwide (do Rio et al. 2016; Teixeira et al. 2019). While the effects of water deficit has been widely studied on grain crops, its effects on ornamental crops has been less studied, mainly when FTSW is used as indicator of water amount in the soil.

Cell expansion is the first process affected by water deficit in the soil, and therefore, reduction in leaf area growth is a primary response of plants to soil water shortage (Lago et al. 2011; Kelling et al. 2015). In E1, there was no statistical difference between water regimes for final leaf number and leaf area (Table 1) because the leaf area of the plants was already practically defined on starting of water deficit, since the plants were very close to the R1 stage (Table 2), which occurs concomitantly with the emission of the flag leaf (Schwab et al. 2015a). The onset of water deficit in E2 occurred in V4 (four leaves), in order to follow the evolution of plant leaf area along the water deficit and to quantify relative leaf growth, which was not possible during E1, since the plants had leaf numbers very close to the final leaf number. The difference in initial leaf area between cultivars, in E1 and E2, is due to the characteristics of Amsterdam and White Goddess cultivars, which have larger leaves than Jester Gold and Rose Friendship cultivars, respectively.

When we compare the final number of leaves and the final leaf area between water regimes, the effect of water deficit on growth and development of gladiolus is clear (Table 1). If the deficit occurs during the vegetative phase (E2 and E3), leaf emission occurs more slowly and the leaf area is reduced. The effect on leaf emission occurs mainly by the increase of the temperature inside the leaves due to the stomatal closure (Taiz e Zaiger 2017; Uhlmann et al. 2017). The different gladiolus cultivars show differences in growth and development responses as a function of water deficit. Note that the cultivar Rose Friendship had one leaf less and about 149 cm² less on T2, while the Amsterdam (V) and White Goddess cultivars had 2 leaves less and about 180 cm² and 267 cm² less on T2, respectively (Table 1). These results indicate that the cultivar Rose Friendship seems to feel less intensely the negative effects of lack of water and may be an alternative for farmers who do not use irrigation. If water deficit occurs during the reproductive phase (as for Jester Gold and Amsterdam in E1), the difference between T1 and T2 is only 0.5 leaves and about 62 cm² of leaf area (Table 1).

The impacts of the slower leaf emission have practical implications in cropscheduling, as farmers need to plant corms at the right time for flower stems to bloom near peaks of consumption (Uhlmann et al. 2019; Becker et al. 2020). As shown in Table 2, any delay in gladiolus leaf emission has a direct impact on the flowering date of the flower stems (Streck et al. 2012). Harvest point (R2 stage) at T2 occurred about 6 days after T1 for Rose Friendship, about 10 days after T1 for White Goddess, and about 5 days after T1 for Amsterdam (V) (Tabela 2). The effect of water deficit on gladiolus cycle duration has been reported in previous studies (Shillo and Halevy 1976; Porto et al. 2014; Pereira et al. 2016a). In grain crops such as maize the response is similar (Storck et al. 2009).

The reduction in leaf area under water deficit results from a decrease in leaf cell turgor, that leads to the activation of the stomatal closure mechanism, thus causing a reduction in leaf cell division and expansion and, consequently, reducing leaf growth (Taiz and Zeiger 2017). In addition to reducing the rate of leaf appearance, many crops reduce plant transpiration by increasing leaf senescence (Taiz and Zeiger 2017; Pinheiro et al. 2014; Mao et al. 2014). Gladiolus, however, showed no leaf senescence in the three experiments, only minor burns on the leaves tip. This response is a consequence of gladiolus been originated from South Africa, where the climate is Mediterranean, and therefore adapted to hot and dry summers (Machado et al. 2015).

The highest threshold FTSW for NTR in Jester Gold (Figure 2a) is hypothesized to be due to two factors: lower atmospheric demand in E1 (Kelling et al. 2015) and plants being close to the reproductive phase when crop water demand is higher (Shillo and Halevy 1976;

Bastug et al. 2006). The beginning of the water deficit in E1 occurred on 03 Oct 2017 and, just one day later, the Jester Gold cultivar plants reached the R1 stage (Table 2). Because plants were at a critical developmenta phase, the onset of stomatal closure occurred earlier (FTSW threshold = 0.732) and, therefore, the experiment lasted about 42 days, similar to occurred for crisântemo (Kelling et al. 2015). On the other hand, cultivar Amsterdam reached the stage R1 about 13 days after the onset of the imposition of the water deficit (Table 2), when part of the soil water had already been consumed, justifying the FTSW threshold value of 0.516 (Figure 2b).

When the water deficit was imposed during the vegetative phase (V4), the FTSW threshold was 0.486 for Rose Friendship and 0.533 for White Goddess. These values were higher than for Amsterdam (V) on E3 (0.355), probably due to higher atmospheric demand during E3. The cultivar Amsterdam (R) obtained a FTSW threshold value (0.649) similar to Jester Gold on E1 (Figure 2f), confirming that the onset of gladiolus stomatal closure varies as a function of developmental stage.

Studies with 5-leaf stage maize plants showed FTSW threshold values for TR from 0.31 to 0.38 depending on evaporative demand of the atmosphere (Muchow and Sinclair 1991; Ray et al. 2002), whereas when the water deficit was imposed close to tasseling stage, this value ranged from 0.64 to 0.73 (Langner 2018). Cherie White and Calabria chrysanthemum cultivars presented FTSW threshold for NTR of 0.62 and 0.48 under high atmospheric demand and values of 0.65 and 0.54 under low atmospheric demand (Kelling et al. 2015), similar to that observed for Amsterdam (E1) and Amsterdam V (E3) and different from that observed for potatoes (Lago et al. 2012; Souza et al. 2014). Our results suggest that when gladiolus cultivars are in the reproductive phase, they have a “conservative” strategy, where plants react to drought stress by reducing leaf expansion and closing their stomata when FTSW is still relatively high and. On the other hand, when gladiolus plants are in the vegetative phase, they have a “productive” strategy, whereby the crop keeps expanding and transpiring as much as possible despite increasing drought (Casadebaig et al. 2008).

As FTSW decreases, the NTR varied around the maximum value, and after reaching an FTSW threshold, the NTR started to decrease due to stomatal closure (Sinclair and Ludlow 1986), one of the key defense plants use to protect themselves from soil water deficit in the short term (Taiz and Zeiger 2017). Variability of the data was lower in the range of FTSW values between zero and 0.4 (Figure 2), indicating that the response of NTR to FTSW in the range that causes stomata closure is well defined. Therefore, the approach of using the threshold FTSW as an indicator for tolerance to water shortage is appropriate.

The data variability of response of NLGR to FTSW is greater than that shown in Figure 2 for NTR. In previous studies with other crops, the leaf growth response to FTSW also had greater variability than the relative transpiration (Muchow and Sinclair 1991; Lago et al. 2011). The variability of the data is high, especially in the FTSW range between 0.5 and 1.0, a common feature in experiments using the FTSW approach with other crops (Sinclair and Ludlow 1986; Ray and Sinclair 1997; Martins et al., 2008). Besides the variability in the data, the logistic equation described well the NTR response to the FTSW for the different cultivars and experiments (Figure 3). The NLGR began to decrease after NTR (at a lower FTSW) for Rose Friendship and, before NTR (at a higher FTSW), for White Goddess (Figure 3b) and Amsterdam (Figure 3c) cultivars. This anticipation of the reduction in leaf growth compared to the reduction in transpiration in a drying soil indicates a passive hydraulic response of gladiolus leaves to water deficit and agree with previous studies where leaf growth reduction occurs before stomatal closure is activated in sunflower, cassava, chrysanthemum and millet (Casadebaig et al., 2008; Lago et al. 2011; Kelling et al. 2015; Esmaeilzade-Moridani et al. 2015).

About 13 days after the onset of water deficit on E1, Jester Gold reached the R2 stage (Table 2) and, about 22 days, the Amsterdam reached the R2 stage. So, after this day, the soil was much drier at T2 than at T1, justifying the lower values of floral stem length, spike length, floral stem diameter and number of florets in the water deficit treatment (Figure 4a, d, g, j). Regardless of the water regime, cultivar Amsterdam has a larger floral stem length and number of florets than Jester Gold (Figure 4a, j). Therefore, if the consumer wants to assemble larger pots with longer-lasting floral stems (Schwab et al. 2014), the Amsterdam cultivar is an excellent option.

The cultivars Rose Friendship and White Goddess (E2) and, Amsterdam (V) (E3) reached the harvest point about 12, 20 and 15 days after the end of the experiment, respectively (Table 2). After rehydration, cultivars Rose Friendship and Amsterdam (V) were able to recover from water deficit and, consequently, the quality of the floral stems produced. The ability to recover from water stress after rehydration was identified in cassava, which presented an increase in leaf number, height and leaf area similar to the water regime without deficit (Pinheiro et al. 2014). Even with rehydration, the cultivar White Goddess did not recover the quality of the floral stems, being a cultivar not indicated for farmers that do not use irrigation. The cultivar Amsterdam (R) also showed no difference in the floral quality variables between the water regimes, possibly because it reached the harvesting point only 4

days after the beginning of the water deficit imposition, when the soil in T2 was not dry enough for affect the quality of the floral stems.

More tolerant cultivars to soil water deficit are those with higher threshold FTSW (Kelling et al. 2015) because they have a more efficient stomatal control mechanism. In millet, assumed as a water-resistant crop in arid, semi-arid and marginal lands, a quick response to soil water at high thresholds FTSW was reported (Esmaeilzade-Moridani et al. 2015). For gladiolus, the highest FTSW occurred when the water deficit was imposed in the reproductive phase and, in this case, the quality of the floral stems was lower. In contrast, the FTSW threshold was lower when the deficit occurred during the vegetative phase and the quality of the floral stem was not affected as after the water deficit the plants were rehydrated.

As a practical result from this study to gladiolus farmers, the cultivar Rose Friendship seems to be the most tolerant to water deficit, as it initiates the reduction in NTR with low FTSW threshold (0.464), while maintaining leaf emission similar to irrigated plants and, after rehydration, keeps the quality of the floral stems.

In addition to helping in identifying water-deficit tolerant cultivars, the response curves of transpiration and leaf growth versus FTSW (Figures 2 and 3) also have a practical applications in crop simulation models (Esmaeilzade-Moridani et al. 2015). The PhenoGlad model (Uhlmann et al. 2017) is a dynamic process-based model that simulates phenology of irrigated gladiolus. The next step, now possible, is to take into account the effect of water deficit on transpiration and incorporate this effect into the model for improving the prediction of development of gladiolus and helping farmers to select cultivars that can maintain the quality of flower stems under some water deficit.

In conclusion, the FTSW threshold for NTR in gladiolus varies depending on the developmental stage at which the water deficit is applied, being higher when it occurs during the reproductive phase and lower when it occurs during the vegetative phase. When the deficit occurs near the reproductive phase, floral stems have lower quality whereas if the water deficit occurs during the vegetative phase, the quality of the floral stems can be recovered after rehydration. Water deficit reduces leaf appearance rate in gladiolus, delaying the harvesting point of the flower stems. The cultivars Rose Friendship and Amsterdam showed to be more tolerant to water deficit by maintaining leaf emission, leaf growth and quality of flower stems even under water deficit.

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Table 1 Initial and final number of leaves and leaf area for gladiolus cultivars Jester Gold, Amsterdam, Rose Friendship, White Goddess and Amsterdam in the vegetative (V) and reproductive stage (R) grown without water deficit (T1) and with water deficit (T2), in three experiments (E1=water deficit started on 03/10/2017, E2=12/01/2018 and E3=03/02/2019).

Cultivar	Water regime		Mean	Water regime		Mean		
	T1	T2		T1	T2			
E(V7)								
Initial leaf number				Final leaf number				
Jester Gold	7.4	7.0	7.2A*	9.0	8.2	8.6B		
Amsterdam	7.0	6.9	6.95A	9.6	9.4	9.5A		
Média	7.2a	6.95a		9.3a	8.8a			
Initial leaf area (cm ²)				Final leaf area (cm ²)				
Jester Gold	737.1	671.3	704.2B	800.2	721.1	762.7B		
Amsterdam	796.5	792.1	794.3A	1086.8	1025.4	1056.1A		
Média	766.8a	731.7a		943.5a	881.3a			
E(V4)								
Initial leaf number				Final leaf number				
Rose Friendship	3.6	3.9	3.75A	8.0	6.9	7.4A		
White Goddess	4.0	4.0	4.0A	7.9	6.1	6.9A		
Média	3.8a	3.95a		7.9a	6.5b			
Initial leaf area (cm ²)				Final leaf area (cm ²)				
Rose Friendship	67.3	74.6	71.0B	481.1aA	332.2bA	398.4		
White Goddess	88.5	105.0	96.8A	580.5aA	313.1bA	438.9		
Média	77.9a	89.8a		530.8	323.2			
E(VeR)								
Initial leaf number				Final leaf number				
Amsterdam (V)	4.3	3.9	4.1B	8.4a	6.4b	7.4		
Amsterdam (R)	9.7	9.5	9.6A	-	-			
Média	7.3a	6.8a						
Initial leaf area (cm ²)				Final leaf area (cm ²)				
Amsterdam (V)	210.9	221.6	216.6B	623.9a	444.1b	534.0		
Amsterdam (R)	723.3	694.5	708.9A	-	-			
Média	495.6a	470.5a						

* Means not followed by the same lowercase letters in rows and uppercase letters in columns are differ (Tukey test. p < 0.05).

Table 2 Starting of water deficit (dd/mm/yy), ending of experiment and date of occurrence of R1 and R2 stages for cultivars Jester Gold, Amsterdam, Rose Friendship, White Goddess and Amsterdam in the vegetative (V) and reproductive (R) stages grown in water regimes without water deficit (T1) and with water deficit (T2), in three experiments (E1, E2 and E3).

Experiment	Cultivars	Starting of water deficit	Ending of water deficit	Duration (days)	R1 stage	R2 stage
E1	Jester Gold	03/10/17	13/11/17	42	04/10/17(T1)	16/10/17 (T1)
	Amsterdam		28/10/17		05/10/17(T2)	17/10/17 (T2)
	Rose Friendship	12/01/18	04/02/18	24	16/10/17(T1)	25/10/17 (T1)
	White Goddess				17/10/17(T2)	26/10/17 (T2)
E2	Amsterdam (V)	03/02/19	26/02/19	24	07/02/18(T1)	16/02/18 (T1)
	Amsterdam (R)				13/02/18(T2)	22/02/18 (T2)
	Amsterdam (V)	03/02/19	26/02/19	24	17/02/18(T1)	25/02/18 (T1)
					26/02/18(T2)	07/03/18 (T2)
E3	Amsterdam (V)	03/02/19	26/02/19	24	01/03/19(T1)	10/03/19 (T1)
					05/03/19(T2)	15/03/19 (T2)
	Amsterdam (R)	03/02/19	26/02/19	24	30/01/19(T1)	07/02/19 (T1)
					29/01/19(T2)	07/02/19 (T2)

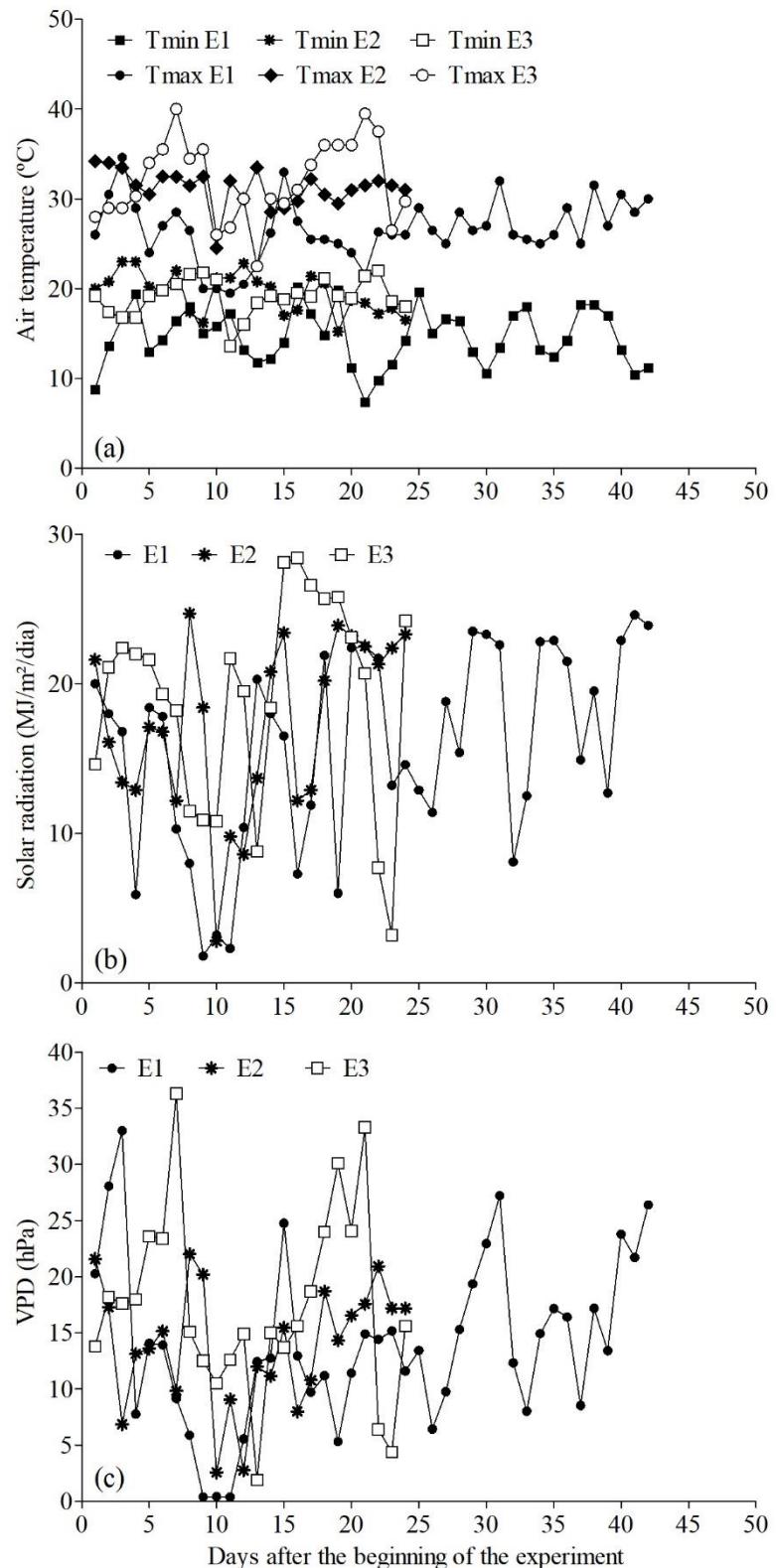


Fig. 1 Daily minimum (Tmin) and maximum (Tmax) air temperature (a), daily solar radiation under the covered structure (b) and daily air vapor pressure deficit (VPD) at 3 p. m. (c) during the three experiments (E1, E2 and E3). Each experiment began the day after soil in the pots was water saturated.

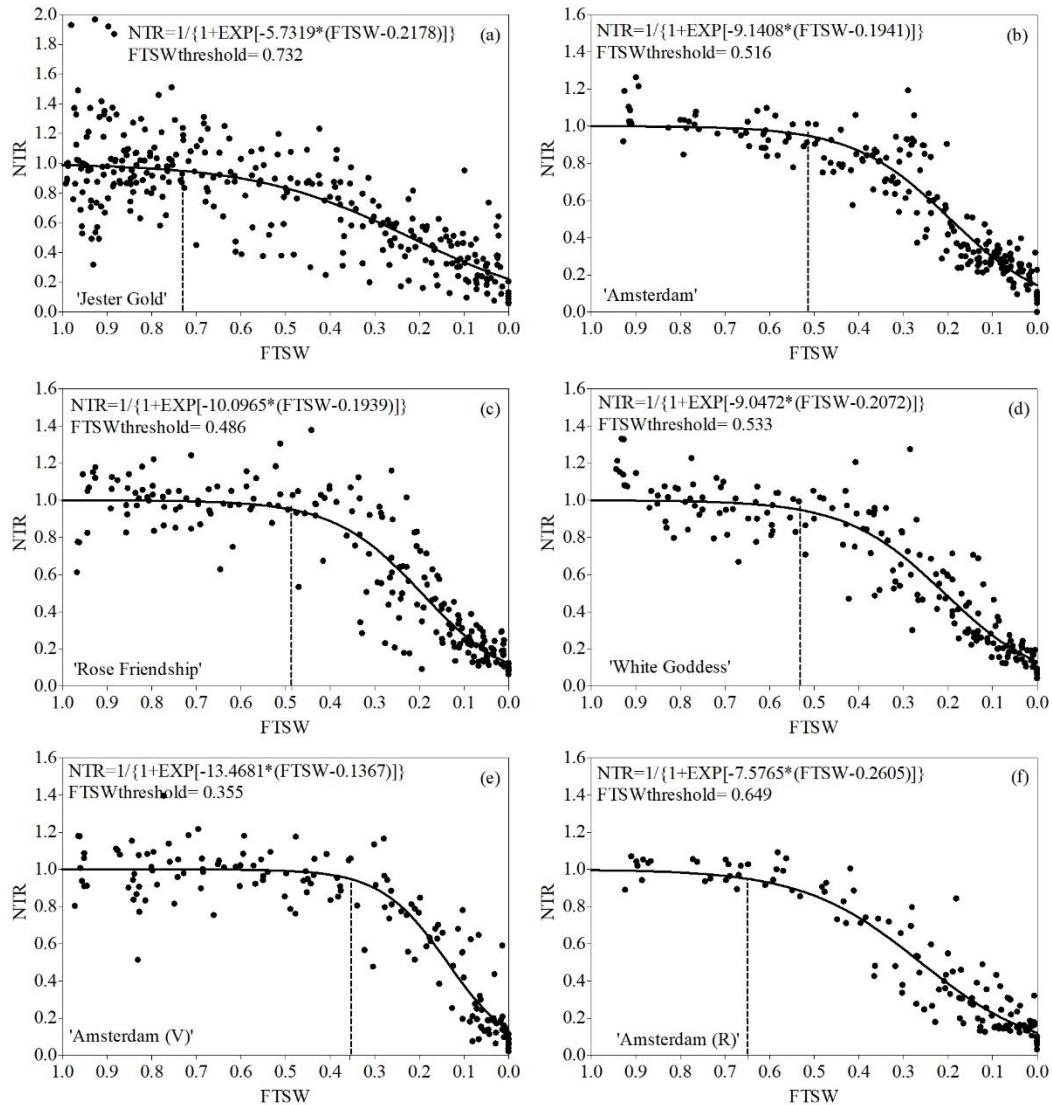


Fig. 2 Normalized relative transpiration (NTR) as a function of fraction of transpirable soil water (FTSW) for gladiolus cultivars Jester Gold (a), Amsterdam (b), Rose Friendship (c), White Goddess (d) and Amsterdam in the vegetative (V) (e) and reproductive stage (R) (f) grown in three experiments: E1=water deficit started on 03/10/2017 (a, b), E2=12/01/2018 (c, d) and E3=03/02/2019 (e, f)). Threshold FTSW: fraction of transpirable soil water when the NTR starts to decrease due to stomatal closure.

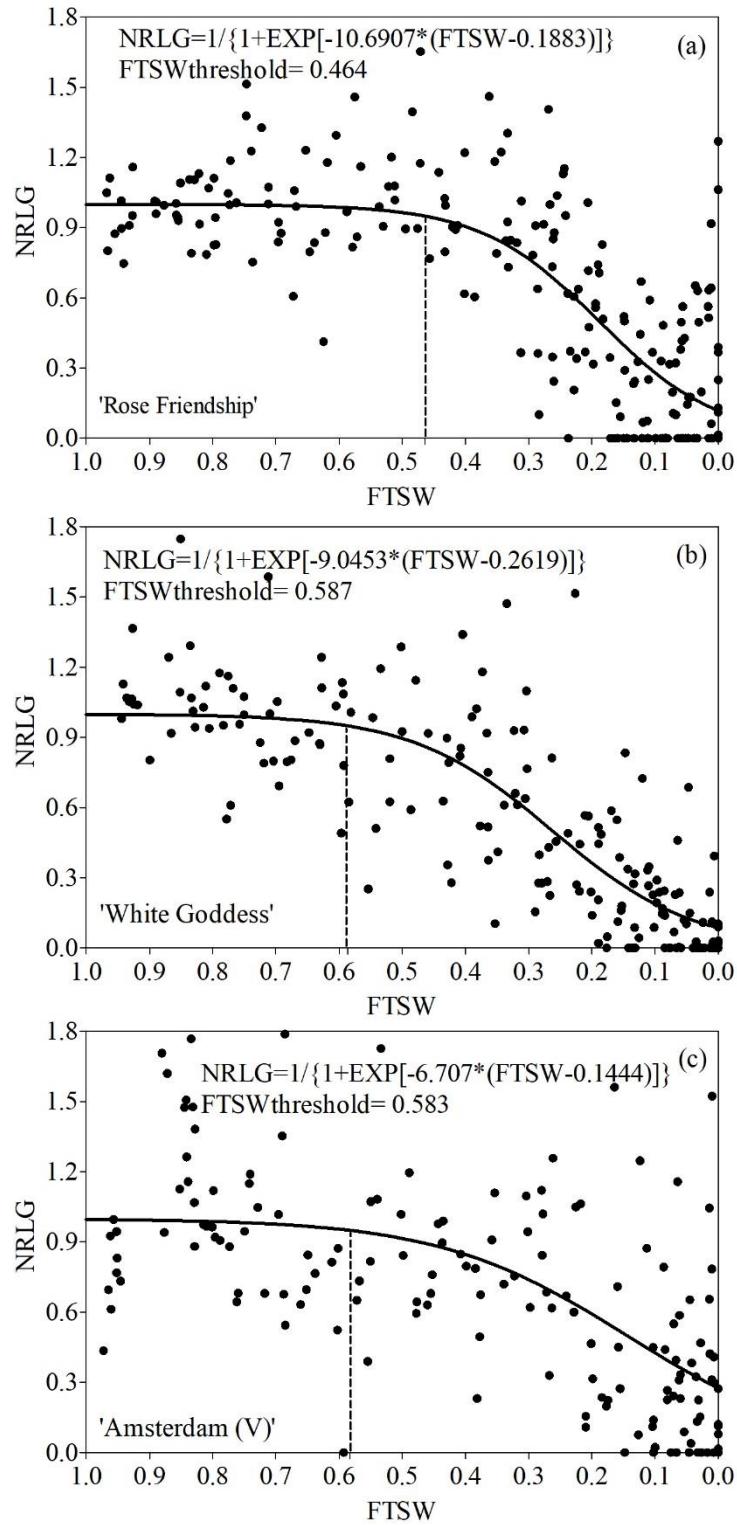


Fig. 3 Normalized relative leaf growth (NLGR) as a function of fraction of transpirable soil water (FTSW) for gladiolus cultivars: Rose Friendship (a), White Goddess (b) and Amsterdam in the vegetative stage (V) (c) grown in experiments: E2=12/01/2018 (a, b) and E3=03/02/2019 (c)). Threshold FTSW: fraction of transpirable soil water when the NLGR starts to decrease due to water deficit.

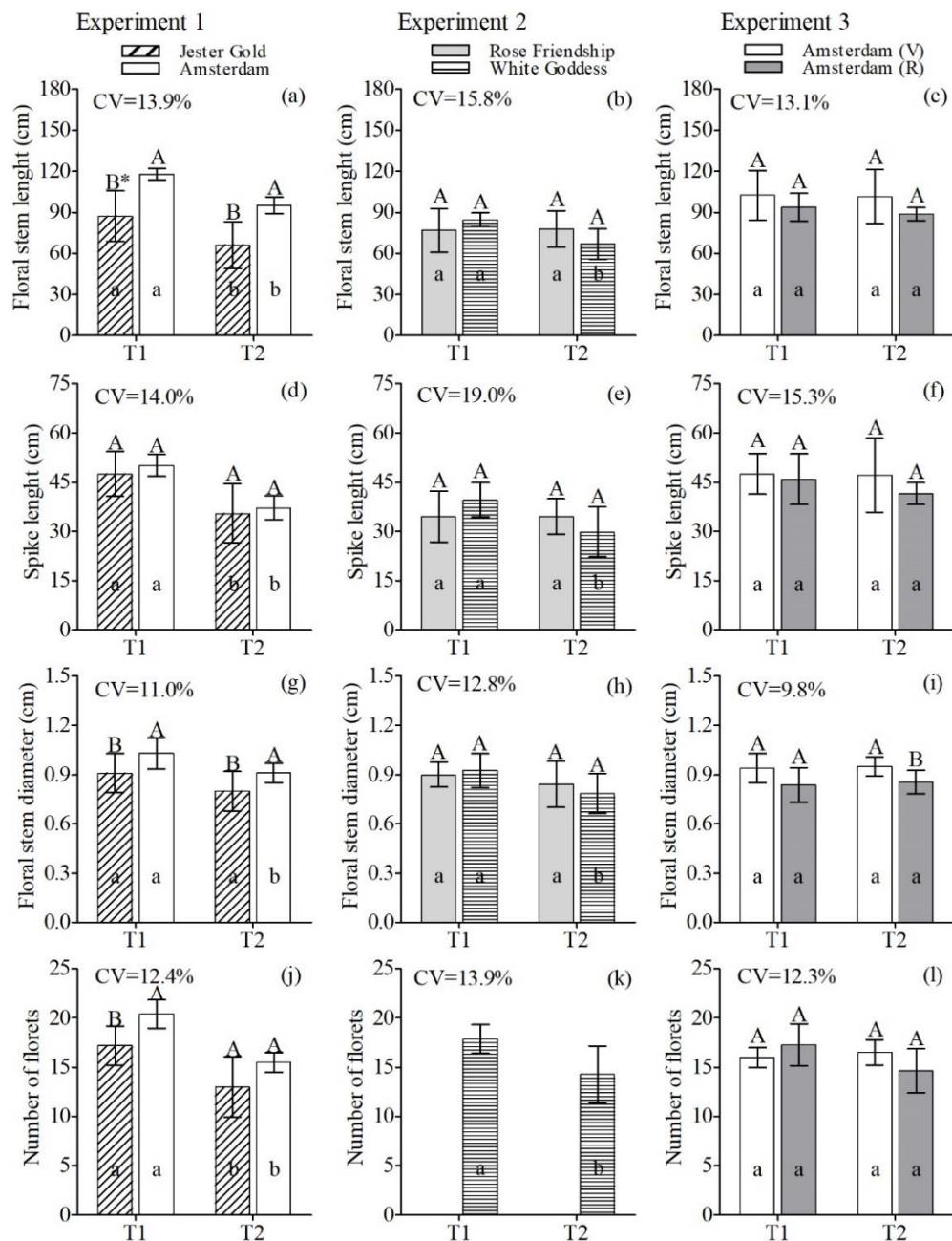


Fig. 4 Variables of gladiolus flower stems quality: floral stem length (a, b, c), spike length (d, e, f), floral stem diameter (g, h, i) and number of florets per spike (j, k, l) for cultivars Jester Gold, Amsterdam, Rose Friendship, White Goddess and Amsterdam grown in treatments without water deficit (T1) and with water deficit (T2), in three experiments (E1=water deficit started on 03/10/2017 (a, d, g, j), E2=12/01/2018 (b, e, h, k) and E3=03/02/2019 (c, f, I, l)). V (vegetative) and R (reproductive) stands for the developmental phase when water deficit was imposed. * Uppercase letters compare the cultivars within the treatment and lowercase letters compare the effect of the treatment on the same cultivar. Bars not followed by the same letter are differ (Tukey test. $p < 0.05$). CV= coefficient of variation.

7. DISCUSSÃO GERAL

O modelo PhenoGlad constitui-se de uma ferramenta importante para auxiliar em estudos relacionados à cultura do gladiolo, necessitando de pouco tempo se comparado a experimentos de campo. Nesta tese, a utilização do modelo PhenoGlad permitiu a realização do zoneamento de risco climático para gladiolo em cenários de mudança climática. Regiões mais quentes como Uruguaiana e Iraí apresentam o menor período recomendado para plantio ao longo do ano nos três cenários climáticos e, os 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, já que haverá uma ampliação do período recomendado para plantio nas épocas do ano que atualmente causam danos por baixas temperaturas. Para atender a demanda de gladiolo 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.

Com o modelo PhenoGlad também foi possível aplicar à cultura do gladiolo, a metodologia de previsão de safra desenvolvida para a cultura do milho nos EUA. A partir desta metodologia, o produtor pode acompanhar a evolução do desenvolvimento da cultura com base nos dados meteorológicos de anos anteriores. Conhecendo a probabilidade de as hastes florais ficarem prontas antes ou depois da data comemorativa, o produtor pode executar um planejamento de modo que se as hastes ficarem prontas mais cedo, ele poderá armazená-las em câmara fria até a data de comercialização. Caso as hastes florais tenham maior probabilidade de ficarem prontas depois da data comemorativa, o produtor pode ficar atento ao mercado e, fornecer essas hastes florais para uma floricultura ou até mesmo uma empresa de decoração. As informações geradas através dessa metodologia também podem servir de embasamento para a melhoria do aplicativo PhenoGlad mobile, para que o produtor possa acompanhar através do aplicativo a evolução da sua lavoura.

Conhecendo-se os inúmeros usos dos modelos agrícolas, o próximo passo é a constante melhoria desses modelos para que possam representar de maneira mais realística o dia-a-dia do produtor e, cada vez mais auxiliar na tomada de decisão do campo. Para o modelo PhenoGlad, acredita-se que as próximas melhorias necessárias sejam a introdução do modelo de crescimento, a possibilidade de simular a qualidade das hastes florais produzidas e, a inclusão do efeito da deficiência hídrica no crescimento e no desenvolvimento da cultura.

Por isso, acredita-se que os resultados apresentados nesta tese servirão de base para a melhoria do modelo PhenoGlad no que diz respeito à deficiência hídrica.

Os resultados aqui apresentados mostram claramente os efeitos negativos da deficiência hídrica no crescimento e no desenvolvimento da cultura do gladiolo. O atraso na data de florescimento da cultura resulta em maior impacto no planejamento da produção. O produtor pode utilizar o modelo PhenoGlad para estimar a melhor data de plantio dos cormos, no entanto se a deficiência hídrica ocorrer, as hastes florais podem ficar prontas cerca de uma semana depois da data desejada pelo produtor. Além de dificultar o planejamento da produção para datas específicas do mercado, a deficiência hídrica reduz a qualidade das hastes florais, fator extremamente importante para culturas ornamentais, em que o objetivo principal é a decoração.

Da mesma forma, o último artigo também mostrou que as plantas diminuem a taxa de emissão de folhas em função do déficit hídrico e, como consequência atrasam o florescimento. A resposta das plantas de gladiolo em função da fração de água transpirável no solo (FATS) parece variar em função do estágio de desenvolvimento da cultura em que o déficit ocorre. Quando as plantas estavam próximas da fase reprodutiva, a FATS crítica para transpiração foi maior, indicando que a planta é mais sensível nessa fase de desenvolvimento. Ao mesmo tempo, ao iniciar o fechamento estomático com maior conteúdo de água no solo, a planta preserva mais água no solo, mas reduz a qualidade das hastes florais produzidas. Diferentemente, quando o déficit hídrico ocorre durante a fase vegetativa, a planta emite folhas mais lentamente e, a expansão foliar é menor. No entanto, após o final do experimento, quando a planta é reidratada, parece que as plantas se recuperam, não havendo redução na qualidade das hastes florais produzidas.

A cultivar Rose Friendship, apresentou área foliar e número de folhas semelhantes nos dois regimes hídricos e, manteve a qualidade das hastes florais produzidas. Apesar de ter apresentado FATS crítica baixa para transpiração e crescimento foliar relativo, essa cultivar parece ser a cultivar mais tolerante ao déficit, pois mantém a qualidade das hastes florais, sendo uma alternativa para produtores que não desejam investir em irrigação. Para os produtores de gladiolo que não vêem problema em colher as hastes florais um pouco mais tarde, mas que não abrem mão da qualidade, é recomendável que, pelo menos próximo ao espigamento da cultura, seja realizado irrigação suplementar. No entanto, se o objetivo principal é ter as hastes florais em uma data específica de comercialização, o importante é que não ocorra deficiência hídrica durante a fase vegetativa da cultura.

Informações como essas tem aplicação prática e auxiliarão o produtor a tomar a melhor decisão e, a agregar mais renda à sua propriedade. Seja através da informação das regiões não recomendadas para cultivo ao longo do ano ou, conhecendo as regiões do estado que poderão produzir gladiólos caso a mudança climática ocorra. Seja tendo acesso a uma ferramenta que lhe permitirá saber antecipadamente quando as hastes florais ficarão prontas, ou até mesmo conhecendo a resposta das culturas à deficiência hídrica e as cultivares mais tolerantes a esse estresse.

8. CONCLUSÕES

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, já que haverá uma ampliação do período recomendado para plantio nas épocas do ano que atualmente sofrem danos por baixas temperaturas.

O modelo PhenoGlad mostrou boa performance nas diferentes datas de plantio, anos de cultivo e locais. Nas primeiras três previsões do RS, o RMSE variou de cerca de 7 a 4,5 dias. Em SC, o RMSE variou de 5,5 a 3,4 dias. Esses erros são aceitáveis considerando que se trata de uma previsão realizada cerca de 45 dias antes da colheita. Com esse método, os produtores podem conhecer de forma antecipada as chances de as hastes florais ficarem prontas antes ou depois da data desejada, o que pode auxiliar na tomada de decisão.

O déficit hídrico aumenta a duração da fase vegetativa do gladiolo e, consequentemente, a duração do ciclo total, dificultando o agendamento da produção. A massa seca total e a massa seca haste floral são reduzidas sob déficit hídrico, porém a partição da massa seca entre os órgãos da planta não é alterada. A qualidade das hastes florais produzidas é reduzida em condições de déficit hídrico, sendo essencial a irrigação suplementar para garantir um alto valor do produto comercializado.

A FATS crítica para transpiração no gladiolo varia de acordo com o estágio de desenvolvimento em que o déficit hídrico é aplicado, sendo maior quando ocorre próximo à fase reprodutiva e menor quando ocorre na fase vegetativa. Quando o déficit ocorre próximo à fase reprodutiva, as hastes florais produzidas têm uma qualidade inferior, enquanto que, se a deficiência hídrica ocorre durante a fase vegetativa, a qualidade das hastes florais pode ser recuperada após a reidratação. No entanto, o déficit hídrico altera a taxa de aparecimento das folhas, que ocorre mais lentamente, atrasando o ponto de colheita das hastes florais e dificultando o agendamento da produção. Para gladiolo, as cultivares mais tolerantes ao déficit hídrico são aquelas que mantêm a emissão de folhas, o crescimento foliar e a qualidade das hastes florais mesmo sob déficit hídrico, sendo que as cultivares Rose Friendship e Amsterdam apresentam as melhores características.

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