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PhenoGlad: A model for simulating development in Gladiolus

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ABSTRACT

Crop simulation models are important tools to help farmers in planning management practices and flowering time of cut flowers, like Gladiolus (*Gladiolus* x *grandiflorus* Hort.). The objective of this study was to develop a robust Gladiolus phenology model, named PhenoGlad, for field applications. The model describes the timing of developmental stages, including harvest point, the vase life of Gladiolus spikes and the low (chilling) and high (heat) temperature effects on spike quality. The Gladiolus developmental model simulates on a daily basis the cumulative leaf number and the phenology using a non-linear temperature response function and genotype-specific coefficients considering three main phases: corms sprouting phase, vegetative phase, and reproductive phase. Data from nine field experiments conducted during five years (2011–2015) in three locations across the Rio Grande do Sul State and in one location in Santa Catarina State, Brazil, were used. These cultivar x planting dates x years x locations experiments provided a rich data set for parameterizing and evaluating the Gladiolus model. The PhenoGlad model accurately simulated the dynamics of leaf development, final leaf number and the timing of developmental stages among cultivars, planting dates, years and locations, with an overall RMSE of 0.5 leaves for leaf development and final leaf number, 6.5 days for the date of reproductive developmental stages, and 1.3 days for simulating the vase life of harvested spikes. PhenoGlad was also accurate in predicting the effects of chilling and high temperatures damage on florets.

1. Introduction

Gladiolus (*Gladiolus* x *grandiflorus* Hort.) is native of areas in the Mediterranean, and southern and central Africa, propagated by corms, and commercially grown as a cut flower, with a wide range of colours (Schwab et al., 2015). Crop phenology is the result of complex processes of development at different levels, from cell differentiation, organ initiation (morphogenesis) and extends to plant senescence (Hodges, 1991). Both genetic and environmental (biotic and abiotic) factors affect crop phenology (Jones and Kiniry, 1986; Bouman et al., 2004; Setiyono et al., 2007, 2010). The main abiotic factor that drives Gladiolus phenology in the field is air temperature (Shillo and Halevy, 1976a; Streck et al., 2012). Photoperiod may also affect development, but Gladiolus is considered a facultative short-day plant (Shillo and Halevy, 1976b).

Planting date has an important role in regulating growth and quality of field grown Gladiolus, and developmental parameters, like days to germination, sprouting percentage and days to the 6-leaf stage, because they are correlated with air temperature (Adil et al., 2013). Akpinar and Bulut (2011) conducted studies with different Gladiolus species planted in open field in three growing seasons in order to define the most suitable species for flower yield and quality. The authors concluded that climatic factors, such as temperature and light intensity are major factors that drive development and yield of Gladiolus.

Extreme temperatures (low and high) can cause damage to Gladiolus vegetative and reproductive parts (Shillo and Halevy, 1976a). Freezing temperatures during the vegetative phase cause leaf injury whereas during reproductive phase cause severe corolla

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damage. Leaves are more tolerant to high temperature (36–40 °C) (Shillo and Halevy, 1976a; International Flower Bulb Centre, 2011) than florets, which can be injured at temperatures above 25 °C (International Flower Bulb Centre, 2011).

Crop simulation models are simple representations of complex processes that drive growth and development during the growing season (Lentz, 1998). In process-based models, processes of the system (plant) are described using mathematical functions, which contain genetic and environmental parameters that affect biological processes (Prusinkiewick, 2004). Therefore, crop simulations models are suitable tools in studies of growth and development of crops in response to the environment (Penning de Vries et al., 1989). Furthermore, crop models provide quantitative information from which management decisions, such as irrigation, fertilization and pest control, can be taken at the field scale (Gary et al., 1998). With regard to temperature effects on crops, there are basically two approaches used in crop models: linear and nonlinear models. Linear models assume a linear relationship between temperature and rate of crop development (Streck et al., 2008). Nonlinear models use a non-linear relationship between temperature and rate of crop development (Landsberg, 1997). This approach was used in the Wang and Engel model for wheat (Wang and Engel, 1998; Streck et al., 2003a,b) to combine genetic and environmental factors and has been applied successfully to several other agricultural crops (Setiyono et al., 2007, 2010; Streck et al., 2007, 2008, 2009, 2011).

Most of crop modeling efforts have been devoted to grain crops, and only a few for ornamental crops (Gary et al., 1998). However, ornamental crop models have a large range of applications, including to assist growers in planning the timing of management practices and to predict flowering time, as growers usually sale their products in markets close to the consumers or for specific holidays and events such as wedding parties and conferences ceremonies. In addition, ornamental crops models should provide information about quality, a major price component of ornamental products (Lentz, 1998).

Models of ornamental species available in the literature include lily (*Lilium longiflorum* Thumb.) (Erwin and Heins, 1990), dahlia (*Dahlia pinnata* Cav.) (Brondum and Heins, 1993), pansy (*Viola* x *wittrockiana* Gams.) (Adams et al., 1997), chrysanthemum (*Dendranthema grandiflora* Tzvelev.) (Larsen and Pearson, 1999), *Campanula carpatica* Jacq. 'Blue Clips', 'Deep Blue Clips' and *Campanula* 'Birch Hybrid' (Niu et al., 2001), miniature rose (*Rosa* L. sp.) (Steininger et al., 2002), 'Freedom' poinsettia (*Euphorbia pulcherrima* Willd) (Liu and Heins, 2002), African violet (*Saintpaulia ionantha* Wendl.) (Streck, 2002), celosia (*Celosia argentea* L.) and impatiens (*Impatiens walleriana* Hook.) (Pramuk and Runkle, 2005), salvia (*Salvia splendens* F.) and marigold (*Tagetes patula* L.) (Moccaldi and Runkle, 2007), 18 bedding plants (Blanchard and Runkle, 2011), and *Brunonia australis* and *Calandrinia* sp. (Cave et al., 2013). The majority of the models developed for the above species were parameterized in greenhouses, not in open air field. No report on a model for Gladiolus was found in the literature.

The objective of this study was to develop a robust Gladiolus phenology model for field applications. In order to have practical application, the model has to predict the timing of developmental stages, including harvest point, the vase life of Gladiolus spikes, and low and high temperature effects on spike quality.

2. Material and methods

2.1. Controlled experiment

A controlled environment experiment was conducted at the Federal University of Pampa (UNIPAMPA), Itaqui, Rio Grande do Sul State (RS), Brazil, part in a growth chamber (PHYTOTRON) and part in a climatic chamber (Model Q315C) with temperature and relative humidity control. Five ambient temperature treatments in continuous dark conditions (7 °C, 16 °C, 25 °C, 30 °C, 35 °C) with 10 replications in a completely randomized experimental design were used. Each replication was a 1.7 l pot filled with soil from the surface layer of a soil classified as Ultisol (USDA, 1999). The ambient relative humidity was 80%.

The cultivar used in this experiment was Amsterdam (white florets). Commercial corms previously vernalized with perimeter between 14 and 16 cm were planted in the pots (one corm per pot) at a 10 cm depth. The pots were filled with the soil and placed in the chamber 24 h before the corms planting. Irrigation with tap water was carried out to maintain the soil close to field capacity.

After planting, each pot was observed daily for plant emergence. Emergence date was defined as the first day when the shoot was visible above the soil. The emergence date of each temperature treatment was defined as the date when 50% of individual plants had emerged. The rate of shoot emergence (day^{-1}) was calculated for each treatment as the inverse of the duration of the sprouting phase (from planting to plant emergence).

2.2. Field experiments

Field experiments were conducted in three locations (Santa Maria, Itaqui and Frederico Westphalen) across the Rio Grande do Sul State and in one location (Curitibanos) in Santa Catarina State, Brazil, located in the southeast of South America (Fig. 1), during five years (2011–2015). Experiments in Santa Maria were irrigated (drip irrigation) whereas experiments in Itaqui, Frederico Westphalen and Curitibanos were rainfed. The experiments in Santa Maria were conducted at the experimental station of the Departamento de Fitotecnia of the Federal University of Santa Maria (UFSM) (latitude: 29° 43′S, longitude: 53° 43′ W and altitude: 95 m), in Itaqui at the experimental station of UNIPAMPA (latitude 29°07′10″ S, longitude 56°32′32″ W and altitude: 50 m), in Frederico Westphalen at the experimental area of UFSM (Frederico Westphalen campus) (latitude: 27° 23′ 47.58″ S, longitude 53° 25′ 41.24″ W and altitude: 489 m), and in Curitibanos at the experimental station of the Federal University of Santa Catarina (UFSC) (latitude: 27° 16′ 24.45″ S, longitude 50° 30′ 10.94″ W and altitude: 992 m). In Santa Maria, an experiment was also conducted in a commercial farm during the Spring 2015, totaling nine field experiments with different cultivars, planting dates, and sites (Table 1).

The four locations (Fig. 1) are different in climate and soil conditions. The average annual temperature in Santa Maria is 19.4 °C, 20.2 °C in Itaqui, 20.4 °C in Frederico Westphalen and 16.5 °C in Curitibanos. The soil in Santa Maria is a transition between a Typic Hapludalf soil and a Rhodic Paleudalf soil, in Itaqui is a Ultisol, in Frederico Westphalen is a Rhodic Hapludox, and in Curitibanos is a Hapludcept (USDA, 1999).

A total of ten cultivars of Gladiolus were used in the experiment (Table 1). The ten Gladiolus cultivars were selected because they are widely grown by commercial farmers and representative of the wide range of colours and developmental cycles of Gladiolus cultivars used in Brazil. A wide range of planting dates was used in the experiments, including two years with monthly planting dates (Table 1). These cultivar x planting dates x years x locations experiments provide a rich data set for parameterizing and evaluating the Gladiolus model.

In all field trials, commercially vernalized corms were planted in beds with two rows, 40 cm among rows and 20 cm among plants within the rows. The planting depth was approximately 10 cm. The experimental design was a complete randomized block design with four replications. Each replication had 10 corms, totaling 40 corms per cultivar. In each experiment, 24 plants of each cultivar were tagged (six plants per replication), and used for measurements.