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Models to Predict Flowering Time in the Main Saffron Production Regions of Khorasan Province

[1]M.A. Behdani, [2]A. Koocheki, [2]M. Nassiri and [2]P. Rezvani
[1]Saffron Research Group, Faculty of Agriculture, The University of Birjand,
P.O. Box 97175/331, Birjand, Iran
[2]Center of Excellence for Special Crops,
Ferdowsi University of Mashhad, Mashhad, Iran

Abstract: The objective of this study was to develop a thermal model that can be used for prediction of saffron flowering time. For this purpose, existing data on saffron flower emergence time were collected in a wide range of temperature regimes over the saffron production regions of Khorasan province, Iran. Linear second-order polynomial and 5-parameter beta models were used and statistically compared for their ability in predicting saffron flowering time as a function of temperature. The results showed a significant delay in flowering date across the temperature gradient. While beta model had a better statistical performance but the simple linear model also showed a good predicting ability and therefore, can be used as a reliable model.

Key words: *Crocus sativus*, flower emergence, model, thermal regime

INTRODUCTION

Khorasan province is known as the major saffron production area of Iran. Although early autumn is the expected time for saffron flowering in the province, there is a considerable variation in flower emergence across the region. Matching this variation calls for quantitative understanding of flowering response of saffron to unexpected environmental variability.

Development is an irreversible process of change in the state of a plant, which generally progresses according to a more or less fixed and species-specific pattern (Atkinson and Porter, 1996). Many developmental stages are crop specific such as silking in maize, double ridge in wheat, or tuber formation in potatoes. While all these stages occur after a substantial vegetative growth, flowering in saffron is a unique process that starts before regular vegetative events such as leaf appearance and growth (Kafi *et al*., 2002). Therefore, known approaches for quantitative prediction of developmental stages in field crops e.g., Growth Degree Days (GDD) or photothermal units (PTU) cannot easily be applied to saffron.

Flower emergence in saffron is influenced by factors such as radiation, nutrients and water availability. However, previous studies have shown that it is principally controlled by temperature (Kafi *et al*., 2002) and therefore, temperature would be the main criteria for estimating the time of flower emergence in this plant.

Robertson (1968) was one of the first to develop a model relating development rate to temperature and photoperiod. He used a quadratic function to explain nonlinear effects of these variables on development rate of wheat while taking into account response to day and night temperatures separately. Such a nonlinear models have been frequently used for predicting development in different crops (Gao *et al*., 1992; Grimm *et al*., 1994). Summerfield *et al*. (1991) suggested a different approach based on the fact that despite any specific response to day or night temperatures in some plant species, over the wide range of conditions, mean daily temperature is the main driving force of a crop to flowering. Subsequently this method shown to be useful in predicting flowering times in various crops (Ellis *et al*., 1990; Summerfield *et al*., 1993) and could be reliable for saffron as well.

Flower initiation in saffron occurs during early spring to mid-summer, depending on the location (Koul and Farooq, 1984; Milyaeva and Azizbekova, 1987; Molina *et al*., 2005a). High temperature are required to release bud dormancy and for flower initiation, which is optimal between 23-27°C, however, flowers will appear in the early autumn at a markedly lower temperature (Molina *et al*., 2005a, b). Accurate estimation of this

Corresponding Author: Mohammad Ali Behdani, Faculty of Agriculture, The University of Birjand, P.O. Box 97175/331, Birjand, Iran Tel: +98-561-2254041 Fax: +98-561-2254050

time should be helpful for planning harvest practices, which is highly dependent on local labors. While there are a large body of literatures on quantitative models for predicting flowering time in many plant species, to the best of our knowledge such a study is not yet reported for saffron.

Therefore, this study aims to test different existing thermal models for estimating saffron flower emergence time over a wide range of temperature gradients.

MATERIALS AND METHODS

This study was conducted in 2004 and 2005. Existing data of saffron flowering time were collected during a wide range of temperature regimes over the saffron production regions of Khorasan province of Iran. Days To Flowering (DTF) was defined as the number of days from The first of October to flower emergence and these data was collected from saffron fields with different ages in four main saffron production areas of the province including Torbat, Gonabad, Birjand and Qaen. These areas were chosen across a temperature gradient and long term mean temperatures of September in studied areas were used as the predictor of DTF.

Linear Eq. 1 (Summerfield *et al*., 1991), second-order polynomial (Eq. 2) and 5-parameter Beta model Eq. 3 (Yin, 1996) were used and statistically compared for their ability in predating saffron flowering time as a function of temperature.

$$DR = B\,(T-T_b) \text{ if: } T<T_o$$
$$DR = C\,(T_c-T) \text{ if: } T>T_o \quad (1)$$

$$DR = A+BT-CT^2 \quad (2)$$

$$DR = \exp(\mu)\,(T-T_b)^{\alpha}\,(T_c-T)^{\beta} \quad (3)$$

Where:

- DR = Rate of development (day^{-1}, inverse of time from the first of October to flowering)
- T = Mean temperature of October
- T_b = Base temperature (°C)
- T_C = Ceiling temperature (°C)
- T_o = Optimum temperature (°C) and A, B, C, μ, α and β are model parameters

T_o is The zero of the first derivative of DR in Beat model so that:

$$T_o = \alpha\, T_C + \beta\, T_b/(\alpha+\beta) \quad (4)$$

Models were fitted using the nonlinear regression procedure of SigmaStat® for Windows ver.1.01, San Rafael, CA.

RESULTS AND DISCUSSION

Development Rate (DR) of saffron showed a unique response to mean September temperature, which was identical for three models. DR increased with temperature to a maximum at To and decreased to zero at Tc (Fig. 1). In the Polynomial and to some extent in Linear model DR response to temperature was symmetric around To, but with Beta model in temperatures above To, DR was sharply dropped to zero, which shows more realistic performance of Beta compared to other models.

All of the three models studied were able to reliably predict the development rate of saffron with r^2 of 0.79, 0.87 and 0.99 for Linear, Polynomial and Beta models, respectively. However, the best and more realistic estimate of cardinal temperatures (Tb, To and Tc) was obtained by Beta model (Table 1). Estimated base Temperature (Tb) was the same for Polynomial and Beta models, however, optimum and ceiling temperatures were different depending on the fitted model. Using these models Days To Flowering (DTF) at different

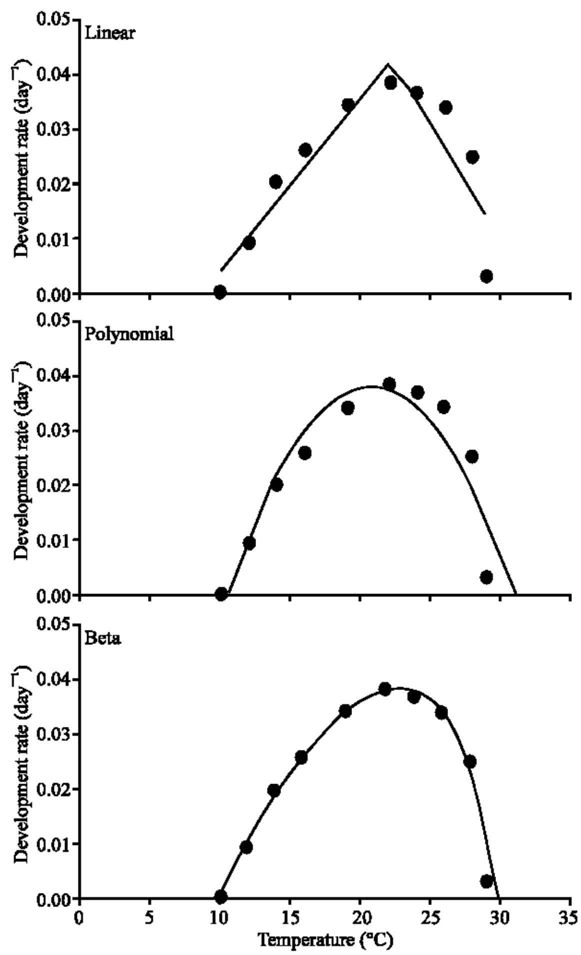

Fig. 1: Development rate of saffron as a function of mean September temperature

Table 1: Estimated parameters of linear, polynomial and beta models and the values of optimum temperature (T_o) and days to flowering from first of October (DTF) at T_o predicted using different models

	Model parameters										
Model	A	B	C	μ	α	β	T_b	T_c	T_o	DTF	R^2
Linear	-	0.76	0.812	-	-	-	8.92	33.4	22.1	19.7	0.79*
Polynomial	0.14	0.02	-0.004	-	-	-	10.20	31.2	21.8	20.5	0.87*
Beta	-	-	-	- 6.058	0.887	0.394	9.99	29.0	23.1	21.1	0.99*

*: Significant at $p<0.05$

temperatures could be predicted as the inverse of DR as shown in Table 1 for maximum DR. At optimum temperature, saffron flower emergence starts after 19 to 21 days from the beginning of October depending on the model used.

Flowering time in saffron has a narrow range and is sensitive to unfavorable environmental conditions (Kafi *et al*., 2002). Therefore, precise prediction of this developmental event is crucial for obtaining a good yield (Atkinson and Porter, 1996). Since flowering in saffron, like many other plant species, significantly responds to temperature it would be possible to quantify this relation using regression models (Ellis *et al*., 1990; Summerfield *et al*., 1993).

In this study, three different models were used and statistically tested for their performance. While all of three models showed a good predicting ability, 5-parameter Beta model had a better estimate for cardinal temperatures and flower emergence time of saffron which were well corresponded to the existing data in the region (Kafi *et al*., 2002). This model was also used for prediction of flowering time in rice with reasonable results (Gao *et al*., 1992; Yin, 1996).

CONCLUSION

Saffron production areas of Khorasan province of Iran are extended over a wide range of climate with considerable differences in environmental conditions, mainly temperature and flowering emergence of saffron varies over this temperature gradient. The results of this study showed that flowering time of saffron could be predicted from mean September temperature using simple linear model to more complicated Beta model with promising results.

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